Diplomarbeit

zum Thema

# THE INFLUENCE OF SEASON ON SURVIVAL IN PERSONS AGED 105+ IN GERMANY

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# Abstract

**Background:**

Exceptional longevity is a phenomenon of the present time. Life expectancy in general increased during the $20^{th}$ century, and the number and proportion of people aged 105 and over (semi-supercentenarians) has risen dramatically in the last decades. Nevertheless, nearly nothing is known about the factors that influence mortality at these exceptional ages because it was not possible to gather data on a sufficient number of such individuals with reliable information on age. This diploma thesis aims to investigate determinants of survival in persons aged 105+ in Germany. Since previous research has indicated that seasonal determinants influence mortality, I focus on these seasonal factors. The first factor considers the effects of *month of birth* as an indicator for environmental influences in early life which in turn influence mortality in later life. The second factor, called *month of living,* refers to seasonal mortality as a result of biomedical reactions due to specific climatic conditions. In addition I look into the effects of *sex, region of residence* and the influence of *period*.

**Methods:**

Data for the empirical analysis came from the Max Planck Institute for Demographic Research, where a dataset has been gathered which includes nearly all Germans older than 105 years after 1989. The age information of each included person was carefully validated in several steps, and this dataset will eventually form part of the International Database on Longevity (IDL).

I applied event history techniques to examine the influence of certain covariates on the length of survival. In the first set of models I investigated the effects of seasonal covariates on survival. In addition I provide descriptive statistics and several survival graphs for *month of birth* and *month of living* as well as for the other covariates.

**Results:**

The findings indicate that mortality differences in semi-supercentenarians by *sex* and *region of residence* are very low and not statistically significant. Similar to the pattern in younger ages, mortality in semi-supercentenarians declined during the observation period from 1989 to 2005. Regarding the seasonal influences, it was found that the survival risk by *month of birth* is lowest for the September-born and highest for the February- and March-born. The differences between these months are statistically significant (at the 5 percent level) but it is still difficult to find a distinct seasonal pattern. Considering the seasonal pattern for *month of living*, the highest mortality was found in December and January and the lowest in July. The results indicate a seasonal pattern with a decreasing seasonal mortality in spring and increasing mortality in autumn.

**Conclusion:**

The results of the study indicate that the mortality pattern in German semi-supercentenarians is different from the pattern at younger ages. For the latter, survival is lower for men compared to women, and people living in East Germany still suffer higher mortality than their West German counterparts. In semi-supercentenarians the differences regarding these two factors are low. Along with the finding that survival differences by *month of birth* in semi-supercentenarians can probably be attributed to random variation, I conclude that mortality at these extreme ages is generally more affected by random factors. This pattern is probably caused by heterogeneity.

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# 1. Introduction and overview

The individuals studied in this diploma thesis are the very last survivors of their generation. They were born at the end of the 19th century and survived two World Wars and several economic crises. My aim with this thesis is to investigate the influence of season and other factors on the survival of people aged 105 and above. After the introduction I will provide an outline of exceptional longevity and the development of oldest old mortality in the past (Chapter 2, page 8). Subsequently, some forecasted future trends of longevity are presented. In the theoretical part of this thesis an overview of the prevailing theories regarding survival in the old and the factors that cause differences in life span is provided (page 15). This overview of the current state of knowledge describes the potential impact of genetic and environmental factors, as well as the observed mortality differences regarding sex. Special attention is given to the theories of seasonal mortality (page 28). Hypotheses regarding the included variables are presented at the end of Chapter 2 (page 40), concerning which of the variables will probably influence the chance of survival at these exceptional ages and how seasonal mortality will probably be distributed over the year. The dataset and the event history techniques used are introduced in the third chapter (page 45). The empirical analysis will follow in Chapter 4 (starting at page 51). First, the impact of validation status is examined; in a second step, further descriptive statistics and the event history models are provided. In the last part of that chapter (page 65), the impact of season on mortality is investigated in detail. The concluding section (Chapter 5, page 70) provides a review on the empirical results in the context of the hypotheses and the current theories.

# 2. Background and theory

The quest for longevity is as old as humankind. Countless generations of scholars have searched for the keys to longevity and for ways to extend human lifespan. Most of what is known about longevity today has been learned in recent years, but there is still relatively little knowledge about why some individuals live to middle age and others live to extreme ages (Carey 2004, p. 1). Such a fundamental question in aging research has been discussed in many scientific papers but until now only a few of the factors that influence exceptional longevity have been explained sufficiently. It is also still unknown whether human death rates after age 110 increase, reach a plateau, or start to decline (Vaupel et al. 1998). This lack of knowledge is mainly due to the problematic quality of today's oldest old mortality data, especially at ages above 105. This age group consists of the last survivors of a generation and right up to the present day it has not been possible to gather a sufficient number of such old individuals with reliable information on age. The International Database on Longevity is the first collaborative international effort to obtain such an exhaustive number of people aged 105 and above and will very probably help to shed some light on the mortality of the oldest old.

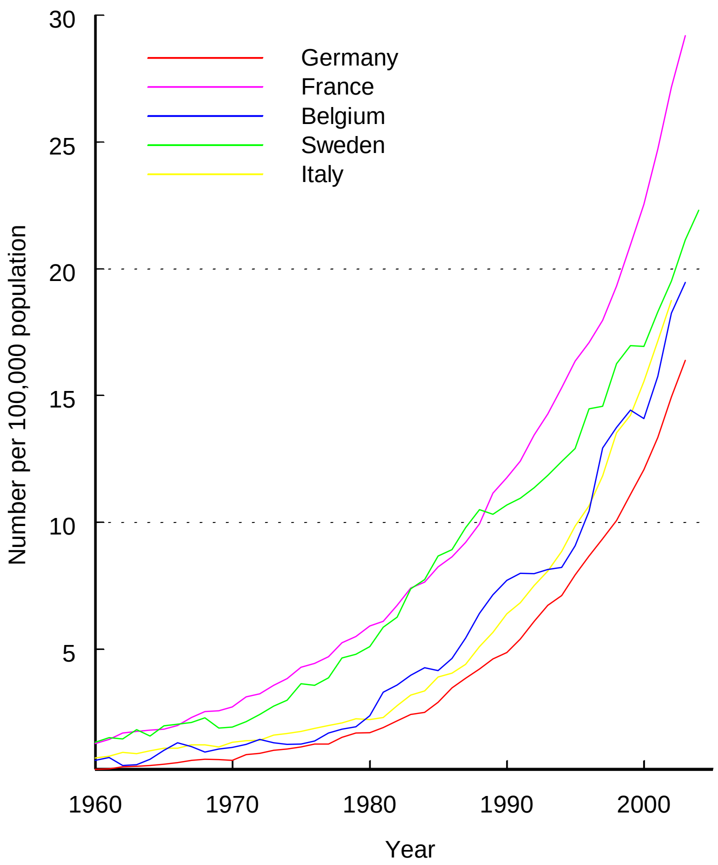
## 2.1 Longevity

### 2.1.1 Review of exceptional longevity

The spread of exceptional longevity is a phenomenon of the present time. With an increase in the average and maximum age, the number of the oldest old rose dramatically in the last decades. Aggregated data for twelve highly-developed low-mortality countries show that between 1950 and 1990 the number of people aged 90 to 99 rose by the factor 7.9, and the number of centenarians rose 22-fold (Kannisto 1994, p. 21-22).

As the number of the oldest old increases, the proportion of elderly in the total population increases too. The proportion of people aged 80 and above grew from 1.57 percent in 1960 to 3.79 percent in 1990 in West Germany, a similar increase could be found in eight further countries in Central and Northern Europe. Other European countries with reliable information on age reported slightly smaller increases. As the absolute number of centenarians grew at the fastest rate, the proportion in the total population also increased extremely. For 14 developed countries the proportion of centenarians increased from about 0.5 in 1960 to 4.5 per 100,000 in 1990 (Kannisto 1994, p. 24-27). The number of women aged 100 and over per 100,000 female population for different countries is shown in Figure 1.

**Figure 1: Number of women aged 100 and over per 100,000 female population**




**Source: Author's calculations from data in the Kannisto-Thatcher database on old age mortality, as well as the New Cronos database**

Figure 1 indicates that centenarians before 1960 were quite rare. As their numbers increased in recent decades, the age groups 105 and above - the semi-supercentenarians - and 110 and above - the supercentenarians - came into focus. Robine and Vaupel (2002) suggest that the prevalence of known supercentenarians in low-mortality countries is about 10 times higher than in the mid-1970s (Robine and Vaupel 2002, p. 2). The first validated living supercentenarian was observed in the mid 1960s, and in 1998 more than 25 supercentenarians were alive in the observed countries[1] (Robine and Vaupel 2002, p. 12).

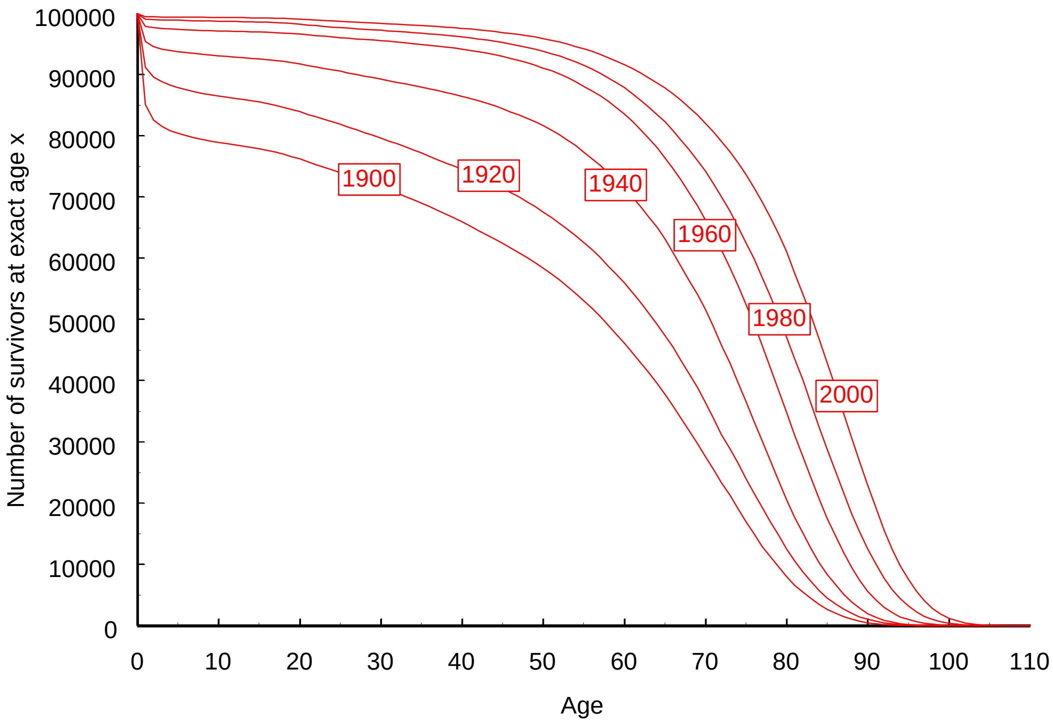
There are quite different opinions about the emergence of centenarians and supercentenarians at earlier times. There is agreement that all estimates of mortality and all information about extremely old persons from pre-industrialized times should be viewed with extreme caution. Ancient literature reported several cases of outstanding longevity. Some of the antediluvian patriarchs mentioned lived almost 1,000 years; the oldest, Methuselah lived to be 969 years old. In Genesis, the first book of the Hebrew bible, Noah and Abraham lived almost 300 years. Joseph, Jacob, Moses and many others were more than 110 years old (Jeune 1995, p. 13-14). Regarding this, Christensen and Vaupel (1996) suggested that early cases of people of an extremely old age were probably just a result of age exaggeration (Christensen and Vaupel 1996, p. 334). Jeune (1995) summarized that although different authors draw different conclusions about the possible emergence of centenarians, no finding suggests that supercentenarians were possible before the modern era (Jeune 1995, p. 15). Other authors concluded that although life expectancy at birth was very low in the 20s or 30s (Wilmoth 2000, p. 1113), statistical modeling suggests that the maximum length of life in high-mortality times was not significantly lower than today (Hynes 1995, p.90). Wilmoth (1995) tried to prove that assumption and drew up several models to calculate the prevalence of centenarians prior to 1700. He stated that statistical models are useful to determine the likelihood of centenarians during historical eras because reliable records of centenarians are not available (Wilmoth 1995, p. 152). Using these methods it was found that the emergence of centenarians probably occurred around 2500 B.C. when the world population exceeded the figure of 100 million. Wilmoth added that he could not reject Jeune's hypothesis that there were no true centenarians prior to 1800 because his results are very sensitive to changes in his assumption about the average of life expectancy at age 50. If life expectancy at age 50 was nearer to 12 than to 14 years throughout this period, Jeune's

[1] The following countries contributed complete lists of validated supercentenarians to the International Database on Longevity (IDL): Belgium, Denmark, England and Wales, Finland, France, Japan, The Netherlands, Norway, Sweden and the United States.

assumption is likely to be correct. In any case, Wilmoth supports Jeune's conclusion that there were no supercentenarians before the mortality decline of the past 200 years (Wilmoth 1995, p. 153).

The increase in life expectancy in the late 19th and early 20th century was mainly caused by dramatic reductions in infant and child mortality. As shown in Figure 2, the age pattern of human mortality in 1900 was characterized by high death rates at the youngest ages. Most child mortality had disappeared by 1940. This change from an era of acute infectious diseases in the whole population to an era of chronic degenerative diseases in the elderly is called the rectangularization of the human survival curve. In addition, the survival curve shifted to the right (Wilmoth 2000, p. 1115-1117). Both developments are shown in Figure 2 with exemplary data from Switzerland[2].

**Figure 2: Transition to death between 1900 and 2000**

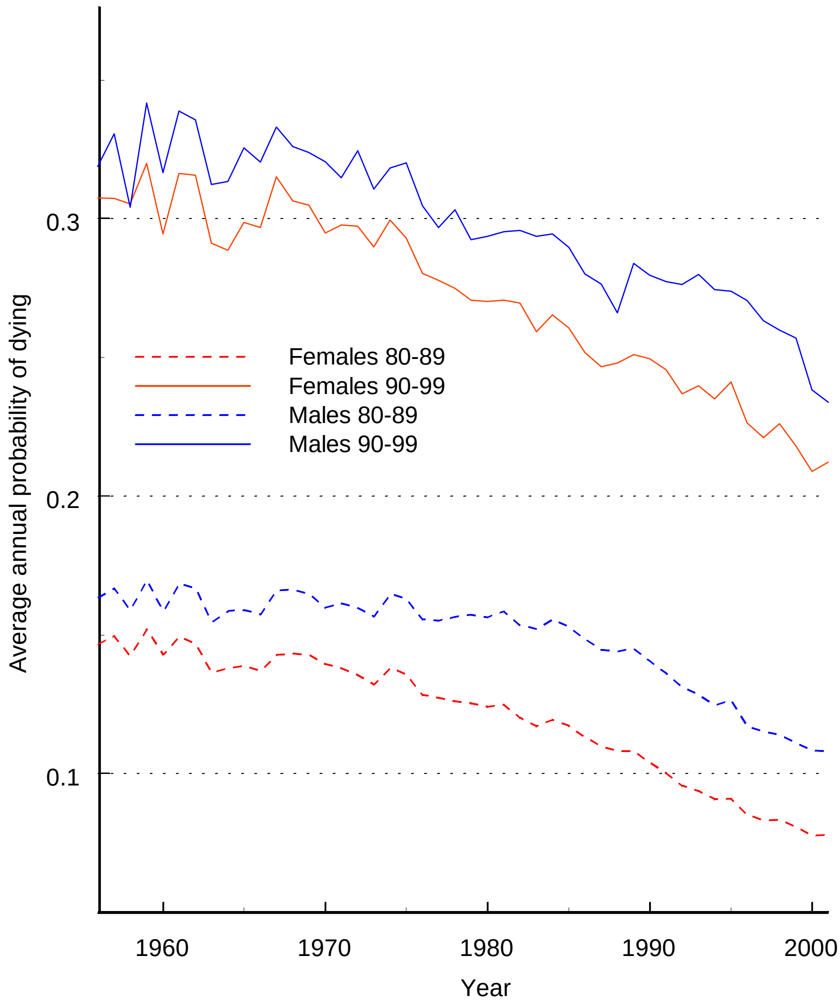



**Source: Author's calculations from Swiss data in the Human Mortality Database**

[2] Switzerland was chosen because age specific death rates were not influenced by the deaths of the two World Wars.

Today's rapid growth of the oldest old population is mainly caused by a systematic decline of mortality at older ages. Until the 1960s deaths rates at the higher ages had declined slowly, but since the 1970s the most rapid improvements of survival rates have occurred at ages above 60 (Wilmoth 2000, p. 1117). Figure 3 shows that the average annual probability of dying at ages above 80 has declined dramatically in Germany (East and West Germany combined). The developments are very similar for the two sexes. As Wilmoth already stated, the decline started at the beginning of the 70s, but accelerated over the years, especially in the 90s.

**Figure 3: Average annual probability of dying for persons aged 80-89 and 90-99 by sex in Germany (East and West Germany combined)**




**Source: Author's calculations from data in the Kannisto-Thatcher database on old age mortality**

It is assumed that those developments were primarily caused by advancements in the medical system, sanitation and nutrition. A recent hypothesis proposes that the reduction in lifetime exposure to infectious diseases and other sources of inflammation also contributes to the reduction of old age mortality (Finch 2004, p. 736). The improvements in old age mortality were accompanied by remarkable advancements in the health of the elderly. Vaupel (2005) points out that the health status of elderly persons in their 70s today is comparable to that of people in their 60s living 50 years ago. The physical and mental fitness of seniors today is better than ever and there is no indication that those developments will reach a limit in the near future (Vaupel 2005, p. 90).

### 2.1.2 Trends of longevity in the future

Until a few years ago, most researchers believed that life expectancy would not increase as fast as in the past and that it would reach a natural barrier. The first who mentioned this "limited lifespan paradigm" was Georges-Louis Leclerc, Comte de Buffon in the 18th century. Buffon proposed that a biological clock determines the lifespan of every individual (Christensen and Vaupel 1996, p. 335). An important proponent of this hypothesis is Fries. In the United States, life expectancy at birth has increased from 47 to 75 years, while life expectancy at advanced ages increased just slightly (Fries 2000, p. 1584). He mentioned that these developments in life expectancy during the last decades could be explained by a "compression of morbidity" hypothesis which he introduced in 1980 (Fries 1980, p. 130-135). This proposes that the increase in the average length of life is primarily caused by postponing the age of onset of morbidity. This will lead to a remarkable increase in the number of elderly above age 65 in the future, but life expectancy for the average old person will increase little (Fries 2000, p. 1584).

Several demographers and epidemiologists disagree with this hypothesis and suggest that empirical evidence shows that there is no natural limit to life span. From 1840 to the present day, the highest female life expectancy at birth has risen linearly, at a rate of about 2.5 years per decade. While in 1840 the highest value was recorded by Swedish women, who became 45 years old on average, the present record is held by Japanese women, who reach an age of almost 85 years. Despite these developments, many supporters of the "limited lifespan paradigm" tried to claim maxima for average life-expectancy that would not be surpassed. However, as shown in Table 1, these values were all exceeded, on average 5 years after publication, except for the most recently determined limits (Oeppen and Vaupel 2002a, p. 1029).

**Table 1: Estimates of maximum average longevity for females**

| Source | Limit | Year published | Year exceeded |
|---|---|---|---|
| Dublin | 64.8 | 1928 | 1921 |
| Dublin and Lotka | 69.9 | 1936 | 1946 |
| Bourgeois-Pichat | 78.2 | 1952 | 1974 |
| Coale | 84.2 | 1955 | 2000 |
| United Nations | 80.0 | 1979 | 1976 |
| Siegel | 79.4 | 1980 | 1976 |
| World Bank | 82.5 | 1985 | 1993 |
| United Nations | 82.5 | 1985 | 1993 |
| United Nations | 87.5 | 1989 | |
| World Bank | 90.0 | 1989 | |
| United Nations | 92.5 | 1998 | |
| Olhansky et al. | 88.0 | 2001 | |

**Source: Oeppen and Vaupel 2002b**

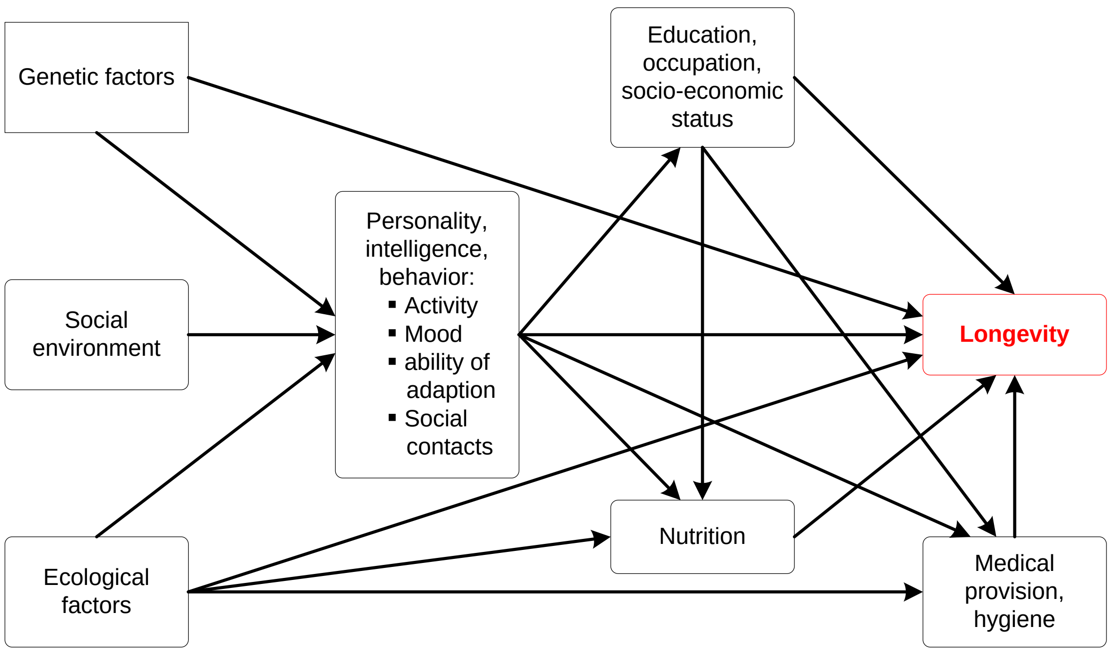
The findings indicate that a limit for life expectancy does not exist or is yet to be approached. Wilmoth (2000) stated that as long as death rates at older ages fall, life expectancy will continue to rise (Wilmoth 2000, p. 1121). However, due to past improvements in age-specific death rates, further developments at young ages would not have further remarkable influences on life expectancy. Death rates for these age groups are already near to zero. On this basis, any assumptions about future developments of mortality and life expectancy will have to conclude that there will be an increase in the number of elderly, whereas the conditions at younger ages will only change in a minor way (Dinkel 2002, p. 400-405).

While there are different opinions about the future developments of life expectancy at birth, there is complete agreement that the increasing number of elderly will deeply affect nearly all of today's developed countries (Buiatti 2004, Dinkel 2002, Oeppen and Vaupel 2002a, Wilmoth 2000). In 2030 about 20 percent of all Europeans will be aged 65 years or more (Buiatti 2004, p. 1); for Germany the Federal Statistical Office expects a value of about 27 percent (Statistisches Bundesamt 2003). As our society ages, these developments will lead to problems with public expenditure for long-term care, health and pensions. In agreement with Vaupel (2004a), Dinkel notes that an increase in the average retirement age is most probably inevitable if the social security system is to stay solvent (Dinkel 2002, p.405). Vaupel stated that the people will even want to work longer because most of the elderly will be much healthier. However, a changing demography will affect nearly all policy decisions in the twenty-first century (Vaupel 2000, p. 198-199) and deeply change our society.

## 2.2 General theories about the determinants of survival of the oldest old

In recent years, the search for a single cause of ageing, such as a single gene or the decline of a key body system has been superseded by a new view (Weinert and Timiras 2003, p. 1706). Ageing is now seen as a complex process with causes and consequences in all areas of life, in which different factors affect the individual life span simultaneously. In recent decades, many studies have been conducted to uncover the complex correlations between the biological, psychological and social determinants involved. According to Franke (1985), the factors influencing longevity can be divided into two groups: genetic and exogenous (Franke 1985, p. 143).

**Figure 4: Correlates of longevity**




**Source: Franke 1985, p. 43**

The first group can be summarized as hereditary disposition. The second group, exogenous influence factors for longevity, can be roughly subdivided into social, psychological, ecological and biological factors. An overview of the assumed correlations is given in Figure 4. It should be noted that a wide range of predictive models for longevity are available. Franke's exemplary diagram is not exhaustive, but may serve as an illustration.

The group of psychological factors involves the achieved level of intelligence, the ability to adapt, life satisfaction, mood and behavior. Higher intelligence is usually associated with higher survival chances. A study of nearly 90,000 Scottish children found that even after controlling for socioeconomic variables, intelligence in childhood predicts differences in adult mortality and morbidity. A possible explanation is that intelligence enhances the ability to take care of one's health (Gottfredson and Deary 2004, p. 1-4). Subjective well-being and a more positive attitude towards life are linked with lower mortality, primarily because they are highly correlated with health status (Li 2005, p. 19).

Ecological factors mainly refer to environmental influences, while biological factors, which are closely connected to genetic factors, are medical parameters such as the general liability to diseases and the absence or existence of typical risk factors such as hypertension and diabetes.

The group of social factors refers to influences such as socio-economic status, marital status and sex (Franke 1985, p. 143-145). Higher socio-economic status is often connected with higher life expectancy, probably because of differences in working conditions and variations in access to medical care (Klein 1999, p. 449-452). It was also found that compared to single and widowed individuals, married people experience survival advantages, mainly due to a sharp decline in mortality of the married. Martikainen et al. suggest that the health-related behavior of unmarried people plays a major role in explaining the differences in accidental, violent and alcohol-related mortality in the 30-64 age group (Martikainen et al. 2005). The female survival advantage is described in section 2.2.2 on page 19.

### 2.2.1 Genetic factors

A research paper about the state of health of centenarians found that people above age 100 had remained functionally independent for most of their life and experienced only few hospitalizations. In a retrospective study in New England, 88 percent of centenarian women and 100 percent of centenarian men had still been independently functioning at an average age of 92 (Hitt et al. 1999, p. 652). That does not mean that the observed centenarians are completely healthy. A study among Danish centenarians discovered that only a minor proportion of subjects were cognitively intact and functioning well; about three quarters of the elderly experience cardiovascular diseases. Osteoarthritis, hypertension and dementia were present in more than 50 percent of the subjects. The fact that almost 75 percent of the Danish centenarians have survived at least one stroke, myocardial infection, malignant cancer, hip fracture or pneumonia supports the idea that the age of 100 is not reserved for people without impairments (Andersen-Ranberg, Schroll and Jeune 2001). Although no centenarian is completely healthy, they probably combine some unique features and behaviors that make them the last survivors of their generation. Some scientists assume that these features are special genes or a special combination of genes.

Most of the knowledge about the genetic influences on longevity has been gained in recent years. To identify the genetic determinants of survival, early studies tried to explore the familial component of longevity. They compared the life spans of parents and offspring and found a rather modest correlation. One of the most recent studies of the familial component in longevity was conducted in Iceland. This analysis of an extensive genealogy database confirms that age-specific death rates are significantly lower in the offspring of long-lived parents (Gudmundsson et al. 2000, p. 745-748). But that kind of family study faces a common problem. It is difficult to prove whether these effects are caused by genetic or by environmental influences within the observed families (Ljungquist et al. 1998, p. M441). Thus an observation of a significant familial correlation in longevity is a questionable proof for the existence of genetic influences.

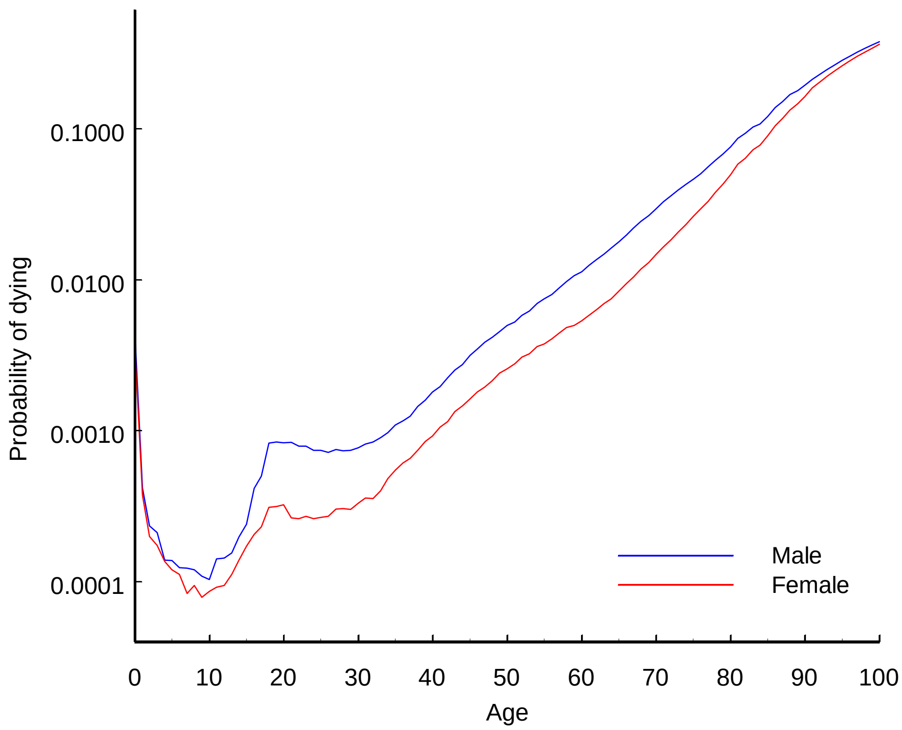
At present the best method to observe genetic heritability of life span is to investigate twins and adopted infants. The most well-known studies use Scandinavian register twin data and confirm the theory that genetic effects influence the individual life span for both sexes (Iachine et al. 1998). Ljungquist, who analyzed Swedish twin data, infers that up to 30 percent of the variance of life span is attributable to genetic factors (Ljungquist et al. 1998). Both Iachine and Ljungquist mentioned that the observed effects are stronger for monozygotic than for dizygotic twins. It is possible but unlikely that these differences are as a result of environmental and personal circumstances being more similar for identical twins than for their non-identical counterparts. As an alternative explanation Ljungquist mentioned the impact of bereavement on mortality, which is probably higher for a surviving monozygotic twin (Ljungquist et al. 1998, p. M445).

Other studies conclude that genetic factors have a different influence on survival at different ages. Sorensen noted that premature deaths between age 16 and 58 are mainly caused by genetic factors, especially when death is because of infection or vascular disease (Sorensen et al. 1988, in Ljungquist et al. 1998, in McGue et al. 1993 too). Perls stated another aspect. He suggests that the low impact of genes on mortality is valid for the ability to achieve an average age but the Scandinavian twin studies did not address the genetic influences on survival to the highest ages, such as ages beyond 100 (Perls, Kunkel and Puca 2002, p. 360-361, McGue et al. 1993, p. B241-B243). He assumes that centenarians have certain genetic characteristics which are exceptional in the population (Perls and Terry 2003b, p. 445). This view is also entertained by Vaupel, who speculates that specific genetic polymorphisms may have an increasing influence with age (Vaupel et al. 1998, p. 859). But most researchers point out that there was little success in identifying particular genes that are connected with slower ageing. A few studies found some special characteristics amongst centenarians which could probably reduce risk for some age-related diseases: for example a low prevalence of the apolipoprotein E type 4 allele which is a known risk factor for premature mortality as well as for coronary heart disease and Alzheimer’s disease in later life (Corder et al. 1993, Perls and Terry 2003a). An example for a genetic variation which is connected with accelerated ageing is the mutation that causes the Werner Syndrome. This rare disorder, whose most recognizable characteristic is premature aging, leads to many age-related diseases include cancer, heart disease, atherosclerosis and diabetes mellitus. Although the disorder is a result of a single gene mutation, multiple characteristics of ageing arise, such as thin skin, sparse hair-growth and loss of fat issue and pigment coating. The average age at death for patients with Werner Syndrome is 47, usually as a result of cancer or heart-disease (Heijmans, Westendorp and Slagboom 2000, p. 865-866). Other genetic factors found by Takata are the different frequencies of several human leukocyte antigens amongst centenarians as compared to an adult control group. These antigens are probably associated with a lower prevalence of autoimmune diseases (Christensen and Vaupel 1996, p. 334). A further twin study of the influence of genetic factors at later ages was conducted by McClearn et al. (1997). They described the genetic influence on cognitive abilities in twins of 80 or more years and found some evidence for specific genes responsible for cognitive functioning and, finally, for overall health condition at the oldest ages (McClearn et al. 1997). In summary it can be ascertained that the hereditary disposition has a strong influence on survival. Several studies suggest that about 25 percent of the variation of human life-spans can be attributed to genetic factors. But the dramatic improvement of survival rates and the rapid growth of the oldest old population within a few generations cannot be because of genetic changes or mutations. These rapid developments must be caused by non-genetic, environmental factors (Vaupel et al. 1998).

### 2.2.2 Sex

In humans being male or female is determined by genes. However, *sex* is not limited to the biological sex but also includes the influences from many different factors, including social, environmental and psychological ones, and these factors may change with societal changes.

**Figure 5: Annual probability of dying by sex in Germany**




**Source: Compiled by author from data in the Life Table 2001/2003 (Statistisches Bundesamt 2004)**

Nevertheless, ever since human mortality has been studied, female survival has been higher at almost all ages. The German survival pattern by sex is no exception. The age-specific probabilities of dying are persistently higher for men. The relative differences are highest at ages around 20 and converge slowly until age 100, which is the highest age included in the German Life Table. The described pattern is shown in Figure 5.

The German Federal Statistical Office does not publish the sex-specific mortality rates for people aged 100 and above because they are so vulnerable to age errors. Kannisto used the method of extinct generations to estimate the probabilities of dying for centenarians and found that even at these ages mortality is consistently higher for males than for females (Kannisto 1988, p. 395-396). The survival advantages at all ages lead to a remarkably higher life expectancy for women compared to men. Consequentially, the number of female elderly in a population is generally higher than the number of male ones. These ratios increase with age and differ from country to country, but the female preponderance among the oldest old is observed in all countries. The lowest values for centenarians were observed in Cuba, where the female:male excess is about 1.3:1 - in the Maori Population (1950-1990) the value is about 3.18. Noticeably higher values were found in Finland and Bulgaria, with seven to eight times more women than men among centenarians (Klinger 1990, p. 3-4). Kannisto computed a mean sex ratio for thirteen countries with good data: his result was 4.27. For semi-supercentenarians (aged 105+) the ratio is 5.65, for supercentenarians (aged 110+) 8.75. The ratios have increased between the 1970s and 1980s, thus Kannisto assumed an improvement in data quality in this period. He mentioned that age overstatement is more serious amongst men than women. Men are probably more proud of an exceptionally high age than women (Kannisto 1999, p. 237-239, 249).

Researchers proposed several different explanations for the observed sex differences in mortality. Biologically seen, the female advantage should not exceed 2 years (Luy 2002, p. 413), so most of the present sex-related differences in mortality exist because of behavioral and environmental factors. One of these risk factors is the higher male mortality because of traffic accidents, especially caused by drink-driving. Other studies mentioned differences in smoking behavior and other kinds of health behavior, the reduction of maternal mortality within the last decades, and long term effects of

World War I and II (Luy 2002). Further papers address the question of whether the difference in mortality risks after marital bereavement is a cause of lower male survival at the highest ages. At these ages the death of the partner is associated with long-lasting adverse mental and physical effects. Although few studies are convincing (Stroebe and Stroebe 1987, p. 279), there is evidence that widowhood is associated with an increased mortality for both sexes, but that the increase is greater for men (Bowling 1987, p. 117). A recent study of the influence of bereavement on the suicide risk of the surviving partner found a higher mortality risk for men too. One year after the loss of a partner, the risk of suicide is significantly increased for both sexes but very old widowed men have a suicide risk five times higher than women in the same situation. In the following years of widowhood it takes a longer time for men to recover from the death of the partner. In addition, the suicide mortality increases with age. Men aged 80+ experience higher suicide risks than men in the age groups 50-64 and 65-79. However, the authors mentioned that the loss of a partner alone cannot explain the increased suicide risks among men aged 80+. Other types of mental or physical disabilities are probably responsible for some of the differences in risk (Erlangsen et al. 2004, p. 381-382).

To sum up, sex is an important predictor for mortality. Men experience lower survival rates during their whole lifetime and, as a consequence, women outnumber men in all observed centenarian populations.

### 2.2.3 Environmental factors and behavior

In section 2.2.1 it was stated that the dramatic improvement of survival rates within a few generations must be caused by nongenetic, environmental factors. The most important environmental factors are presented in the following chapter. At first I will give an overview about the impact of social environment on mortality. In the second section of the chapter it is mentioned how caloric restriction and smoking behavior influence survival chances. In the last part I will provide some facts about mortality differences between East and West Germany.

#### 2.2.3.1 Social environment

The effect of social environment on health and survival is widely discussed and there is evidence that the quality and quantity of the social environment is a strong predictor for life expectancy (House, Landis and Umberson 1988). The first author who proposed that stable social relationships are beneficial for health was Emile Durkheim in 1897. His ground-breaking work about social conditions and suicide paved the way for later concepts of the influence of social relationships on survival (Durkheim 1999). Recent papers distinguish between several social constructs that influence physical health.

One of these concepts is “social support”, which has been discussed widely since the late 1970s (House, Landis and Umberson 1988, p. 541). It can be differentiated into three types: instrumental, informational and emotional support. While instrumental support refers to the supply with material sources, informational support refers to the provision of information in form of advice or guidance to help solve life’s problems. The third type of social support involves the expression of emotional feelings such as trust and empathy. These kinds of social support influence the individual’s ability to cope with stress (Cohen 2004, p. 676-677).

A further social construct that influences physical health is social integration: this is the participation in a broad range of social relationships. This construct is thought to include a behavioral component, for example active engagement, as well as a cognitive one, for example the identification with one’s social roles (Cohen 2004, p. 677).

In a study of Swedish men above age 50 it was found that individuals with high numbers of stressful life events and low emotional support suffer from a significantly higher mortality, while this was not the case for individuals with high numbers of stressful events but a high level of emotional support (Rosengren et al. 1993, p. 1104). A further analysis by Rosengren and others investigated the relationship between social support and coronary heart disease. They discovered that social support may be a factor protecting against new coronary life events. Although they stated that the findings must be interpreted with caution, they support the evidence that social relationships are an important influence on mortality (Rosengren, Wilhelmsen and Orth-Gomér 2004, p. 58-60).

The influence of social environment on the survival of centenarians has not yet been examined in detail. A basic description of the family conditions of Hungarian centenarians was published in 1990 (Klinger 1990). The study confirms the well-known fact that only few centenarians live together with their spouse. Because of their old age, most of the partners have died already and so widowhood is the most common family status among centenarians. But the authors mentioned that a relatively high proportion of the females never married and speculated that staying out of wedlock increases the chance of survival till the oldest age for women. They observed an opposite situation for males. The percentage of never-married men was only half the figure usual in their generation.

But living without a spouse does not necessarily mean that the centenarians live alone. For example, the average number of household members is 2.8 for females and 3.2 for males in Hungary. Both values are higher than the average Hungarian household size of 2.7. At least in post-communist Hungary, a high percentage of the oldest people seem to live together with their children or other family members (Klinger 1990, p. 8-9).

#### 2.2.3.2 Caloric restriction

One of the most potent and reproducible environmental variables that influences life span in nature is caloric restriction. In several experiments with animals from worms to rats, the maximum life span could be increased significantly by reducing the intake of calories by 30-70 percent (Weinert and Timiras 2003, p. 1713). In rodents, a diet containing all the essential nutrients and vitamins but with 40 percent fewer calories than normal increases both average life expectancy and maximum life span by 30 percent (Moody 2003, p. 372-373). In addition, metabolic, immune and collagen responses are significantly enhanced.

The mechanisms of dietary restriction on longevity are still unknown (Weinert and Timiras 2003, p. 1713). Some scientists assume that caloric restriction slows down the “basic biological clock”, for example the rate at which food is transformed into energy (Moody 2003, p. 373). Caloric restriction also leads to a slower progression of age-related changes of genes and, when examined in humans, to over-expression of high-density lipoprotein which removes cholesterol from the blood and carries it to the liver. This high-density lipoprotein is inversely related to several diseases including atherosclerosis. Considering all these issues together, dietary restriction seems to be a relevant factor to attain good health and increase life span. Because of the fact that most findings refer to animal experiments, most mechanisms in humans remain unresolved (Sharma 2004, p. 1207-1209). So Moody’s speculation that caloric restriction on a diet of 1,400 calories per day could lead to 30 extra years of life in humans (Moody 2003, p. 373) remains an assertion without proof.

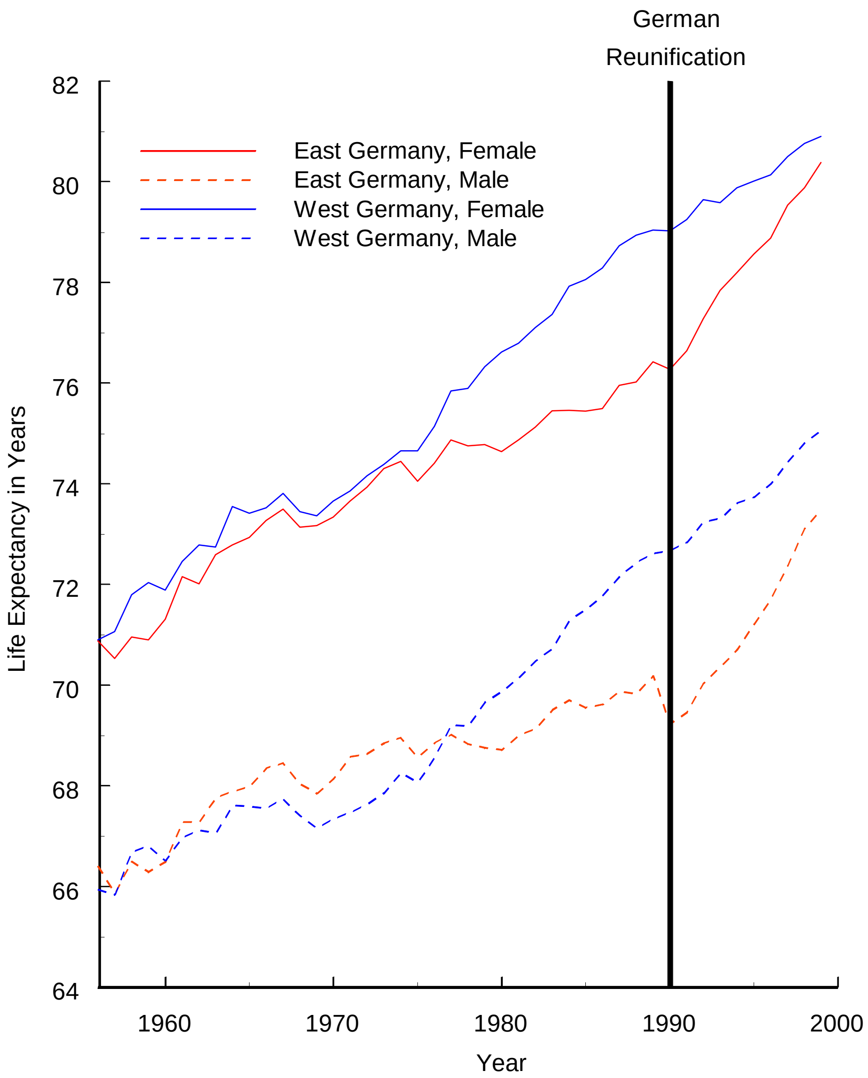
#### 2.2.3.3 Smoking

A well-documented mortality risk is long term cigarette smoking. It is a matter of common knowledge that smoking is clearly linked to higher mortality and the possible cause of many diseases. In a 40-year follow-up study, Doll et al. (1994) observed more than 30,000 British male doctors from 1951 to 1991 and found that overall mortality is twice as high in persistent cigarette smokers compared to lifelong non-smokers. This annual mortality per 1000 men declines with age and the ratio is about 1.3:1 at ages 85 years and over, probably because of reduced cigarette consumption in later life. The age by which half of the smokers have died is about 8 years less than for non-smokers (Doll et al. 1994, p. 905-906). Similar results have been estimated with the use of the Cancer Prevention Study II database, a prospective cohort study of 1.2 million adults in the United States. The authors determined that compared to smokers, non-smokers who have never smoked aged 35 years have a life expectancy which is about 8.9-10.5 years longer for men and 7.4-8.9 years longer for women (Taylor et al. 2002, p. 995). Both Doll and Taylor mentioned that smoking cessation before middle age helps to avoid most of the excess mortality attributable to smoking. This conclusion is also confirmed by Bratzler, Oehlert and Austelle (2002), who summarize the benefits of smoking cessation. Quitting smoking markedly reduces the risk of cardiovascular diseases within one to two years and the risk of smoking-related cancers within five to ten years after cessation. Even for those who quit between the ages of 70-74, the age-specific mortality rates compared to persistent smokers are significantly lower and decrease over the next 12.5 years (Bratzler, Oehlert and Austelle 2002, p. 187). A recent study of 157 centenarians living in Rome found that 83.8 percent of the centenarians have never smoked, while 13.5 percent are former smokers and only 2.7 percent active smokers. The average number of cigarettes smoked daily is quite low and the total average number of cigarettes ever consumed is well under the cut-off point where tumors are noticed in many studies. Nevertheless, centenarians who are active or former smokers suffer significantly higher mortality. While centenarians who never smoked live 27 months on average, centenarians who are active or former smokers live only 20.7 months. The authors concluded that smoking compromises remaining life expectancy even at the highest ages and that abstention from smoking is important at every age (Tafaro 2004, p. 425-430).

### 2.2.3.4 East and West Germany

The current life expectancy of East and West Germans is different. The disparate political, social and economic conditions in the two German states after World War II had a noticeable influence on demographic behaviors and also on health and mortality. Prior to 1945, both parts of Germany shared a cultural and political background (Gjonca, Brockmann and Maier 2000, p. 2) as well as an almost “identical demographic composition and behavior” (Dinkel 1999, p. 3).

**Figure 6: Life expectancy at birth from 1956 to 1999 in Germany**




**Source: Author’s calculations from data in Human Mortality Database**

After the end of the Second World War in 1945, life expectancy in both parts of Germany was relatively high (Heinemann, Dinkel and Görtler 1996, p. 15) but somewhat higher in West Germany (Federal Republic of Germany, FRG) than in East Germany (German Democratic Republic, GDR) (Dinkel 1999, p. 23). In the 1950s, mortality trends in East and West Germany converged. In the 1960s and in the beginning of the 1970s the life expectancy for East German men was temporarily even higher than that in West Germany. After 1975 the trends of mortality changed and diverged considerably. There was pronounced improvement in survival in the FRG, but life expectancy in the GDR lagged behind. The difference in life expectancy reached its maximum in 1990, the year of the German reunification (Dinkel 1999, p. 5).

After the collapse of the socialist regime, East Germany immediately changed to the Western political and socio-economic structures. This "shock scenario" for both mortality and fertility (Dinkel 1999, p. 3) led to a rapid decline in mortality in East Germany and a closing of the gap in East-West German life expectancy within a few years. At present, the decline of the East German mortality towards the levels in the West is still in progress. Today's differences in life expectancy are low for women but still substantial for men (Maier and Scholz 2004b, p. 1-2). The fast decline of East German mortality towards the levels in the West suggests that for mortality in later life, changes in current conditions are much more important than early life influences (Vaupel, Carey and Christensen 2003, p. 1679).

Dinkel (1999) investigated the possible determinants of the differences in life expectancy and discussed several possible explanations for higher mortality in East Germany before reunification. His first hypothesis refers to selective migration from East to West Germany before the construction of the wall in 1961. Mainly young adults and young families left the German Democratic Republic (GDR), a selection which probably had consequences on mortality in the long run (Dinkel 1999, p. 13). The second explanation is also associated with migration. Foreigners who migrated to West Germany in the past usually had a lower mortality than the native population (Dinkel 1999, p. 8). Official German mortality statistics do not distinguish between the native German and foreign population, therefore it is not possible to know whether this kind of migration had a positive effect on the West German mortality rates (Dinkel 1999, p. 13-14).

The negative effects of environmental pollution are addressed by the third hypothesis. While efforts to protect the environment were made early in West Germany, pollution control was almost unknown in the GDR. This could probably have caused long-term differences in mortality between the two German states (Dinkel 1999, p. 14). Another possible explanation mentioned by Dinkel refers to the health consequences of excessive uranium mining in East Germany immediately after the Second World War. More than 100,000 workers were involved in the mining for many years and the surrounding population were also directly exposed to a large amount of radiation; this probably increased the mortality in the southern areas of the GDR (Dinkel 1999, p. 14).

The fifth hypothesis is related to differences in life-style factors which lead to long-term differences in morbidity and mortality. Several studies show that the distribution of cardiovascular risk factors such as smoking, nutrition and cholesterol have been adverse for the East German population and thus could probably have led to higher mortality in the eastern part of Germany (Luy 2004, p. 103-104). Maybe the same is true for the different working conditions (Dinkel 1999, p. 15).

A further possible explanation addresses the lack of medical technology in East Germany. At the beginning of the cold war communist countries had lower mortality rates, but for various economic reasons they were unable to modernize their medical equipment in the same way the Western countries did. Most of the decline in mortality in the 20$^{th}$ century was due to medical improvements, thus differences in the medical support system could probably have resulted in mortality differences (Dinkel 1999, p. 15; Luy 2004, p. 104).

The last hypothesis refers to the psychological reactions to the stringent political system in the GDR. It is assumed that political suppression results in unfavorable conditions and, in particular, in a higher suicide mortality (Dinkel 1999, p. 15). This hypothesis is supported by the fact that suicide statistics were suppressed by GDR officials (Luy 2004, p. 103).

After discarding a number of rival explanations, Dinkel concluded that the lack of medical technology was primarily responsible for survival disadvantages in East Germany before reunification. In his opinion, none of the other arguments could provide a better explanation for both the higher mortality before 1990 and the immediate decrease after the fall of the Berlin Wall, when the health care system in

East Germany was rapidly brought up to the newest standards (Dinkel 1999, p. 15-19). Because of the facts that the elderly contributed most to the differences of mortality between East and West Germany (Luy 2004, p. 107-113) and that the elderly benefit most from advancements in the medical system, Dinkel's argument is very likely to be correct. Although Gjonca, Brockmann and Maier (2000) mention that it is also likely that there was not only one single influencing factor, they support the view that the differences in the medical systems play a major role in explaining the differences in mortality between the two German states (Gjonca, Brockmann and Maier 2000).

### 2.2.4 Seasonal patterns

In ancient Greece people already assumed that seasonal factors affect the living conditions of humans. In 400 B.C. Hippocrates of Cos was probably the first to recognize that "all diseases occur at all seasons, but some diseases are more apt to occur and to be aggravated at certain seasons" (Hippocrates ~ 400 B.C.a, Section III). In addition he stated: "In autumn, diseases are most acute, and most mortal, on the whole. The spring is most healthy, and least mortal" (Hippocrates ~ 400 B.C.a, Section III). In his opus "On Airs, Waters, and Places" Hippocrates extended the classical theory of the four elements - fire, earth, air and water and introduced the idea of four humours, which were liquids within the body: blood, phlegm, yellow bile and black bile. Every humour was connected to one element and to one of the four seasons of the year. In Hippocrates' view, diseases were always caused by an imbalance of the humours, and the characteristics, course and treatment of a disease were directly linked to the seasons (Hippocrates ~ 400 B.C.b).

Before the industrial revolution, seasons influenced the everyday life and behavior of people to a large extent. Seasonal variations determined the food and vitamin supply, the quality of accommodation, the daily work and the spare time activities; because of this, the seasons had an exceptional impact on mortality and fertility. Scientific interests at that time were of an extremely general nature (Kevan 1979) and aimed to gain knowledge about the connection between weather and health conditions. By the end of the 19th century, American scientists turned their attention to the advantages and disadvantages of various North American climates at different seasons of the year. Important scientific progress on that topic was made in the 1930s and 1940s, mainly as a result of the work of William F. Petersen, Clarence A. Mills and Ellsworth Huntington (Kevan 1979, p. 227).

Scientific interest increased, although the influence of seasons on everyday life declined with increasing technological progress. In today's developed societies most people can go about their everyday life without paying much attention to seasons.

Although seasonal variations are not at the center of attention anymore, they probably influence the lifespan of people in two different ways. The first kind of influence is related to the effects of different months of birth on later life expectancy. The second kind of influence reflects Hippocrates' findings and refers to the seasonal fluctuations in death and mortality during the different months of a year.

#### 2.2.4.1 Effect of *month of birth* on later survival

One of the first modern investigations into the effects of season of birth on subsequent mortality was conducted in the 1930s by Ellsworth Huntington (1938), a professor of economics at Yale University. In his book "Season of Birth" Huntington compared the seasonal birth distributions of several countries. He found that the basic annual rhythm of the number of births depends primarily upon the temperature and that the month of birth has a notable effect on the length of life (Huntington 1938, p. 11-15). In a sample of about 39,000 Americans from various climates, the difference in life expectancy between people born in the most favorable and the least favorable month of birth was about 3.8 years (Huntington 1938, p. 191). Individuals born in March live 50.8 years on average, whereas people born in August only reach the age of 47.0 years (Huntington 1938, p. 177). Since the average life expectancy of these Americans is about 49 years, the impact of the seasonal fluctuation on the length of life is quite remarkable (Huntington 1938, p. 191). Huntington infers from his results that the seasonal variation in the length of life is not only influenced by season of birth but also associated with the annual rhythm of the number of births (Huntington 1938, p. 173).

##### 2.2.4.1.1 Theories

Huntington's research suggests that environmental conditions during certain seasons influence fetuses and infants and thus mortality at later stages of life. A theory which proposed early life influences on later survival was developed by Barker in the 1990s. His fetal origins hypothesis states that conditions such as malnutrition during fetal life, infancy and early childhood shape the longevity potential of individuals and program the risk of later diseases. The first time Barker mentioned a connection between low weight in infancy and later disease was in 1989 (Barker et al. 1989). In a retrospective study of 5,654 men born between 1911 and 1930 in Hertfordshire, United Kingdom, he found that men with the lowest birth weights had the highest rates of ischaemic heart disease (Barker et al. 1989, p. 578-579). Later studies found that low birth weight and poor infant growth are also associated with hypertension, type 2 diabetes, stroke and increased blood pressure (Doblhammer 2004, p. 13-14). In addition, fetal undernutrition may be linked to later differences in metabolism and the hormone system. Barker proposed that an underfed baby will probably establish an alternative way of how to transform food into energy. This alternative way of handling food is probably not adequate in conditions of plenty after birth (Barker 2003, p. 733). But Barker points out that birth weight alone cannot adequately explain the associations to later diseases. Studies with information on child-growth and various socio-economic circumstances suggest that the course and treatment of a disease depend on a series of influences at different stages of development (Barker 2003, p. 734).

The main idea of the fetal origins hypothesis is that the critical period at the beginning of an individual's life has a remarkable effect on later survival. The month of birth can be viewed as an indicator for that critical period (Doblhammer 2004, p. 16) and is linked to several other hypotheses. Five of those hypotheses were summarized by Doblhammer (2004, p. 37-60).

The first hypothesis, called "seasonal distribution of deaths", assumes that the relation between *season of birth* and later mortality is caused by an age effect. Mortality risk in winter is usually higher than mortality in summer (see section 2.2.4.2). People born earlier in the year are older when they suffer the higher mortality risk of winter, thus, they may have a higher overall mortality (Doblhammer and Vaupel 2001, p. 2934). After controlling for the interaction between current month and age, Doblhammer found that the mortality of those born between April and June is still higher than the mortality of the January-born (Doblhammer 2004, p. 48). She concluded that the differences in survival ranked by month of birth are not caused by seasonal differences in mortality at different ages.

A second hypothesis is called the "procreational habits hypothesis", a term used in schizophrenia research. This hypothesis suggests that birth distribution is connected to socio-economic characteristics. In Finland some indications were found to support of the hypothesis. While a peak of births in late spring to early summer is observed for the general population, the birth distribution of patients with schizophrenia is significantly different. It is assumed that summer is the most favorable time to raise an infant in the cold climate of Finland, so the most favorable time to give birth to a child is late spring to early summer (Suvisaari, Haukka and Lönnqvist 2001, p. 756). The procreational habits hypothesis predicts that patients with schizophrenia who have a family history of the disease are more likely to be born in winter (Torrey et al. 1997, p. 21). Suvisaari, Haukka and Lönnqvist (2001) found an excess of births of patients with schizophrenia and also for their unaffected siblings during the winter months in Finland. This is likely to be caused by the fact that parents of patients of schizophrenia have done less family planning than parents of the general population. A further explanation could be an unobserved biological or environmental factor which is associated with schizophrenia (Suvisaari, Haukka and Lönnqvist 2001, p. 756). Although the procreational habits hypothesis had been rejected in the review of Torrey et al. (1997, p. 27-28), Suvisaari (2001) claimed that the sample sizes of earlier studies were too small to reliably detect this pattern (Suvisaari, Haukka and Lönnqvist 2001, p. 755-756).

Doblhammer and Vaupel (2001) tested the procreational habits hypothesis in relation to mortality with the help of Austrian data. They calculated the seasonal distribution of births by educational groups and found that the spring peak in births is stronger for people with high or medium education while the peak in births for people with low education is in autumn (Doblhammer and Vaupel 2001, p. 2937-2938). The differences in life expectancy were probably even more distinctive if these differences were taken into account, so Doblhammer (2004) concluded that the effect of *month of birth* on survival could not be explained by the procreational habits hypothesis (Doblhammer 2004, p. 49-50).

A third hypothesis which tries to explain the relationship between *month of birth* and life expectancy is the "deadline hypothesis" introduced in mortality research by Doblhammer (2004). This hypothesis refers to certain deadlines for school attendance. Those children who are born after a fixed date have to wait another year before they can enter school. According to the deadline hypothesis, such children are older than most of their classmates and because of that they are able to receive better marks. The hypothesis proposes that this advantage may continue for the whole life. Support for this hypothesis comes from Plug (2001), who provides evidence that the learning abilities of older classmates are better on average. This results not only in a better education but also in higher earnings later in life. In the Netherlands the cutoff date is October 1 and it was found that people born after that date in autumn are relatively good learners and high earners (Plug 2001). Doblhammer (2004) tried to replicate those results with Austrian data from the beginning of the 20$^{th}$ century. Although the cutoff date for school entrance was also October 1 and the autumn-born were thus the oldest among their classmates, the educational level of autumn-born persons was lower than that of persons born in spring (Doblhammer 2004, p. 53). These unexpected findings suggest that aspects other than a certain deadline for school attendance probably affect the differences in educational attainment, as well as survival by *month of birth*.

A fourth hypothesis refers to the effect of selective survival in the first year of life. The hypothesis assumes that infants born in autumn experience higher mortality during their first year of life. Due to this, the autumn-born infants who survive would be relatively more robust and their mortality at adult ages should thus be lower. In order to examine this hypothesis, Doblhammer analyzed the mortalities in the first year of life and after age 50. If selective survival causes the differences in life expectancy, a negative correlation between infant and adult mortality rates can be expected. With Danish data however, a significant positive correlation between mortality in the first year and that after age 50 was found. Doblhammer concluded that the selective survival hypothesis has to be rejected (Doblhammer 2004, p. 53-57). She proposes that debilitating influences during pregnancy or the first few infant months are the causal mechanisms which are likely to explain the mortality differences by *month of birth* (Doblhammer 2004, p. 59).

#### 2.2.4.1.2 Empirical evidence

Considering the mortality by *month of birth* in German semi-supercentenarians, Doblhammer, Scholz and Maier (2005) found that the birth distribution of German semi-supercentenarians was different from the birth distribution in the years 1881-1898 of the German Empire. The relative risks of survival from birth to age 105 and over ranked by *month of birth* were highly correlated with the observed pattern in Danish elderly. December-born individuals have a statistically significant higher chance of living until age 105; for the June-born the survival chance is statistically significantly below the expected value. The authors support Doblhammer's conclusion (2004) that the effects of *month of birth* are linked to factors in the earliest period in life or during pregnancy (Doblhammer, Scholz and Maier 2005, p. 5-6).

Further results from recent empirical studies found conflicting evidence for *month of birth* effects on later survival. A study of mortality in rural Gambia presented evidence that the season of birth is a strong predictor of later mortality. In a sample of 3,102 individuals born between 1949 and 1994, highly significant *month of birth* effects were found. Compared to people born during the harvest time from January to June, individuals born during the 'hungry season' from July to October suffer an increased risk of dying, mainly because of infectious diseases; people born in November and December have an intermediate risk. While the mortality risks for both groups were similar at an early age, they diverge dramatically from the age of 15 onwards. Given the fact that this seasonality has been observed for more than 40 years, the authors proposes a long-lasting effect of malnutrition on the development of the immune system as the most likely explanation (Moore et al. 1997, p. 434). Moore et al. (2004) tried to replicate their Gambian results with longitudinal data from Bangladesh. They included 172,228 births and 24,697 deaths between 1974 and 2000 from a Bangladeshi region called 'Matlab'. Though the methodology was similar and the sample was large, no seasonal pattern related to season of birth was found. The authors speculated that the Gambian findings are probably the result of a unique setting (Moore et al. 2004).

A third study was conducted in rural Senegal, a country close to Gambia. While the infant mortality differs significantly by month of birth, no differences for the age groups 1 to 14.5 years were found. Above age 20, the mortality risk was even slightly lower for individuals born in the hungry season. But this result should be viewed with caution because there were only very few deaths above age 14.5 (Simondon 2004).

Lawlor reviewed these studies and concluded that different results can probably be explained by a cohort effect, because the Gambian individuals were born in the 1950s and 1960s, whilst the individuals from Senegal were born between 1978 and 1984. An alternative explanation is that the results are random variation. This would mean that there is no connection between *season of birth* and mortality in adulthood in these countries (Lawlor 2004, p. 145).

Other studies support the notion that the *month of birth* is a strong predictor of mortality. Examining genealogical data from European aristocratic families, Gavrilov and Gavrilova (1999) found that women born in May and December live about three years longer than women born in August. They controlled for various variables and were surprised that *month of birth* has such a remarkable effect on later survival. It is assumed that the seasonal lack of vitamins in late winter and early spring at the two critical periods in child development (third month of pregnancy and first month after birth) cause the differences in life expectancy by *month of birth* (Gavrilov and Gavrilova 1999).

In the Ukraine, Vaiserman et al. (2002) investigated a strong seasonal pattern related to *month of birth*. They analyzed 104,324 deaths recorded in Kiev between 1990 and 2000. It was found that individuals born in from April to July suffered the highest mortality, and people born between October and December the lowest one. The observed pattern is similar for all major groups of causes of death and also for both sexes. The maximum difference of life expectancy related to month of birth was 2.6 years in men and 2.3 years in women. Vaiserman also supposed that seasonal climatic changes and thus differences in diet may explain the observed effects on life expectancy. Individuals born from April to July experience most of their fetal life in nutritionally unfavorable months characterized by acute vitamin deficiencies, whereas individuals born in winter mainly experience nutritionally favorable months. According to studies in rats, the life expectancy of young rats was increased by maternal protein restriction in the period of lactation but decreased by maternal protein restriction in pregnancy (Vaiserman and Voitenko 2003).

#### 2.2.4.1.3 Summary

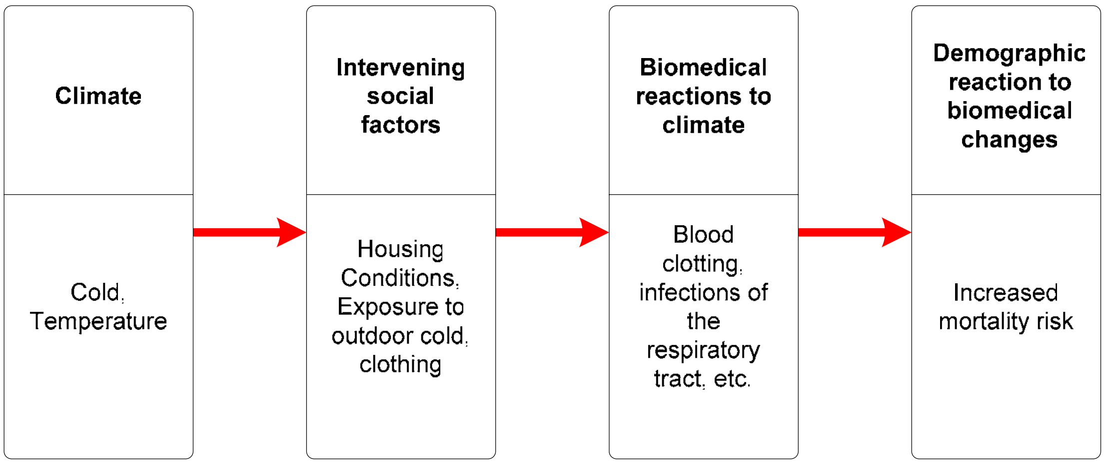
All things considered, it appears that season of birth is an indicator for mortality in later life but that the mechanisms of how such early environmental conditions determine lifespan are still open to debate. There is agreement that pregnancy and infancy are the most critical phases of human development but it is hotly debated whether environmental effects such as season affect the human body at these stages of development or whether the social conditions before and after the birth of a child cause the seasonal fluctuations in mortality by *month of birth*. However, as shown in the preceding studies and supported by various researchers there is some evidence that deprivation during pregnancy and early infancy cause differences in late-life survival. *Season of birth* may serve as an indicator for such debilitating effects.

### 2.2.4.2 Effect of *season of living* on survival

#### 2.2.4.2.1 Theoretical approaches and empirical findings

Seasonality in death, as mentioned by Hippocrates (~ 400 B.C.a), is influenced by various climatic factors and environmental conditions. A causal model which describes the influences on seasonal mortality was developed by Rau (2004). He stated that climatic conditions affect the body and trigger biomedical reactions like blood clotting or infections. The correlation between climate and the body's biomedical reactions is modified by intervening social factors such as housing conditions, exposure to outdoor cold or heat, and other conditions at the individual level. The interaction between these three elements leads to demographic reactions (Rau 2004, p. 5-17). These reactions lead to changes in mortality risk as well as to influences on fertility and migration behavior. Figure 7 gives a graphical overview of this model of causality.

**Figure 7: Chain of causality for seasonality in mortality**

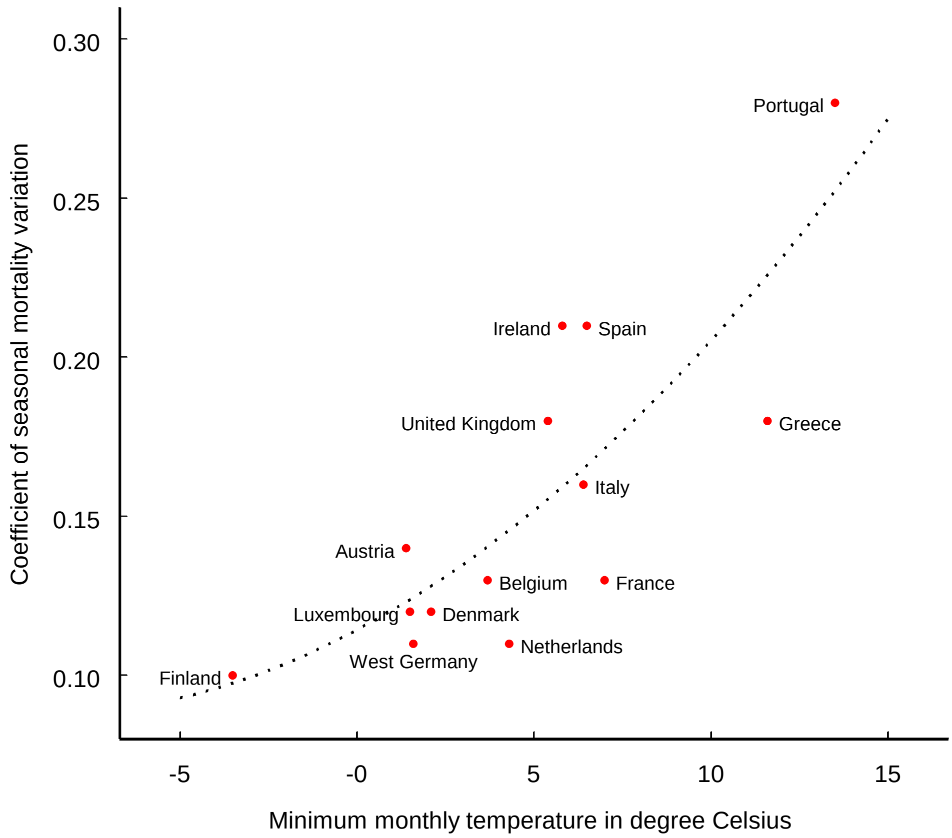



**Source: Rau 2004, p. 12**

The causal connections between the parts of the model are not fixed. According to Rau (2004), two different patterns of change in seasonal mortality were observed in the past. The first pattern is the decline in summer mortality in the 18$^{th}$ and 19$^{th}$ century (Rau 2004, p. 37). Kevan (1979, p. 230) showed that Canadian mortality rates in the early 1800s peaked between July and September. Landers (1993) observed a similar pattern in London and other parts of England between 1670 and 1779 (Landers 1993, p. 203-241). From the results of archaeological studies, it can be concluded that summer peaks of mortality were also present in Ancient Rome and Egypt (Rau 2004, p. 18-25). The most likely cause for high summer mortality in London and Canada is an increase of gastro-intestinal diseases (Kevan 1979, p. 230), whereas in Ancient Rome the main cause of death was malaria, a disease which spreads fast in high population density areas, especially in the Mediterranean climate (Rau 2004, p. 19). The decline in this phenomenon can be demonstrated from several populations. In the Canadian population, the degree of seasonality decreased dramatically by the early 1900s, when the summer peak of death rates was not observed anymore: August and September changed from being the months with the maximum mortality to those with the lowest mortality (Kevan 1979, p. 230). A similar change took place in London in the 17th century and in urban France between 1850 and 1915. The disappearance of high summer mortality within such short periods of time cannot be attributed to climatic changes (Rau 2004, p. 37-38): the development is likely to have been caused by remarkable improvements in living standards and medical practices, as well as improved hygiene and food preservation techniques. Due to this, intestinal diseases withered almost completely so that the prevalence of the winter respiratory diseases became more important (Kevan 1979, p. 230). At the beginning of the 20th century, March (1912) observed seasonal mortality in twelve European countries but found no summer peak of deaths anymore. Only mortality of infants was still highest in summer (March 1912, p. 507-508).

The second pattern, which has been observed since the middle of the 20th century, is the decrease of the annual amplitude of seasonal fluctuations. The decrease has been reported for several countries around the world but did not start simultaneously (Rau 2004, p. 38-39). For Denmark, Rau and Doblhammer (2003) analyzed the distribution of monthly mortality for different cohorts. It was found that the older cohorts experience higher amplitudes: for the oldest cohorts, born between 1878 and 1888, the risk of mortality was 34 percent higher in January than in August whereas for the youngest cohorts, born between 1908 and 1918, the amplitude declines to 17 percent (Rau and Doblhammer 2003, p. 204). It is believed that the decline of seasonal variations in recent years is mainly caused by the spread of central heating (Keatinge et al. 1989, p. 75). Other explanatory factors include aspects of individual behavior during the cold season, e.g. increased car ownership and adequate clothing outdoors (Rau 2004, p. 14-15). Adequate clothing is also assumed to be a reason for differences in seasonal mortality across 14 European countries as described by Healy (2003): higher mortality in winter is observed in all European countries but certain countries experience dramatically higher winter mortality. Using monthly mortality data from the United Nations Databank, Healy found that countries with the mildest winters experience the highest seasonal mortality fluctuations: his results are illustrated in Figure 8 (Healy 2003, p. 785-786). A similar pattern was already observed by McKee in 1989.

**Figure 8: Excess winter mortality in 14 European countries**




**Source: Compiled by author from data in Healy 2003, p. 786**

Healy (2003) stated that other climatic variables, such as average rainfall in winter and relative humidity, are not linked to differences in winter mortality differences between the 14 European countries. The highest excess in winter deaths was observed in Portugal, Greece, Spain, Ireland and the United Kingdom and the lowest values were found in northern European countries. The findings also indicate that there is a strong relationship between per capita gross domestic product (GDP) and winter excess mortality. Countries with a higher average GDP per person have lower seasonal fluctuations in mortality. It is also shown that housing standards are an important factor influencing winter excess mortality. Countries with high energy efficiency and insulation standards exhibit lower mortality in winter. Healy stated that the ability of a population to protect themselves from environmental stresses such as cold is a key factor explaining the differences in winter excess mortality across Europe. This includes housing standards as well as adequate clothing and the quality of the health care system (Healy 2003).

Compared to other European countries, Germany suffers rather low winter excess mortality with a winter rate about 11 percent above the average mortality figure (Healy 2003, p. 785). Similar results were found by Lerchl (1998), who observed the long-term trends of seasonal variations in mortality in Germany. The analysis was based on data from the Federal Bureau for Statistics for the period between 1946 and 1995. Lerchl found a relatively stable pattern of seasonal fluctuations with the lowest mortality rates during the late summer months August and September and the highest values in late winter between January and March. As observed in other European countries, the annual seasonal fluctuations decreased since the middle of the 20th century. This trend persisted until the early 1970s, after which no further decline of seasonal variations was found. Lerchl supports the hypothesis of Keatinge et al. (1989), who analyzed seasonal mortality in England and Wales and summarized that this decline of seasonality is most likely to have been caused by a spread of central heating within this period and is also connected to the improvements in the healthcare system over time (Lerchl 1998, p. 84-88, Keatinge et al. 1989, p. 75).

Another aspect of seasonal mortality was analyzed for the first time by Quetelet in 1838: his results show that winter excess mortality increases with age and is most visible at the highest ages (Rau 2004, p. 40-41). Feinstein (2002) found a similar pattern in the United States. He analyzed data from the U.S. National Center for Health Statistics for the years 1994 to 1998 and found gradually increasing seasonal variations with age for all causes of death except external causes (Feinstein 2002, p. 472). A study of French centenarians by Robine and Vaupel (2001) also showed that seasonal mortality variations are higher for centenarians than for the population as a whole (Robine and Vaupel 2001, p. 924-925.). It could probably be assumed that the increase of winter excess mortality with age is caused by a *sex* effect. If women experience higher seasonal fluctuations than their male counterparts, compositional changes in the population can cause an increase in seasonal variations with age. Rau and Doblhammer (2003) analyzed sex-specific differences in seasonal mortality. The results for different cohorts were somewhat conflicting, thus the authors conclude that seasonal variations increase for both sexes as they age but that the increase starts at later ages for women (Rau and Doblhammer 2003, p. 207-211). A further study conducted in 1981 by McDowall showed that men have slightly higher seasonal fluctuations above age 44, whereas the seasonal variations under the age of 44 are higher for women (McDowall 1981, p. 17). But these and many other studies suggest that sex differences in seasonal mortality are small and mostly insignificant. Thus it is most likely that compositional changes based on sex cannot be the cause of the increase in winter excess mortality with age.

Two popular misbeliefs in the general public about today's seasonal mortality are mentioned by Rau (2004). The first one refers to the influence of influenza on winter excess mortality (Rau 2004, p. 5). In contrast to common assumptions, Donaldson and Keatinge (2002) found that only 2.4 percent of all winter excess deaths were either directly or indirectly due to influenza. They concluded that health professionals and the media should move their focus from influenza to the prevention of cold stress as a cause of higher winter mortality (Donaldson and Keatinge 2002, p. 89-90). The second misbelief is related to suicide mortality, which is assumed to be responsible for higher mortality during the winter months. But in 1897 Durkheim (1999) had already mentioned that deaths from suicide peak between late spring and early summer. Moreover, it is stated that only about 1 to 2 percent of the overall death pattern can be attributed to suicide, thus it probably does not play a major role in seasonal mortality (Rau 2004, p. 5).

#### 2.2.4.2.2 Summary

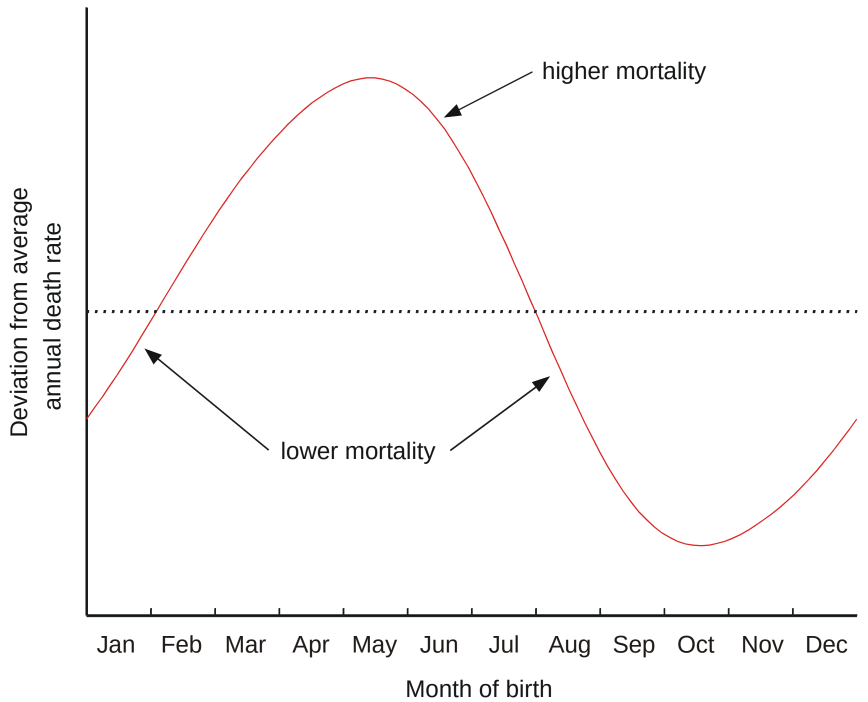
In general it can be stated that even in today's advanced societies seasonal fluctuations in mortality can be found in almost all countries. The European pattern is characterized by higher mortality in winter and lower mortality in summer but differs between the countries. While Mediterranean countries suffer higher seasonal fluctuations, countries with harder winters usually experience lower seasonal variations. It is assumed that the ability of a population to protect themselves from external cold is the central cause for differences in winter excess mortality between the different countries. Seasonal mortality is observed in Germany: as in other European countries, seasonal variations have decreased since the 70s, most probably because of the spread of central heating in that period. Based on the fact that seasonal variations in mortality are most pronounced in the oldest old, it is most likely that season also affects mortality in semi-supercentenarians.

## 2.3 Theoretical considerations

### 2.3.1 Hypotheses about the association between *month of birth* and survival

Previous research indicated that seasonal mortality by month of birth differs between climates and countries. Doblhammer and Vaupel (2001) showed for Austria, a country neighboring Germany, that individuals born in summer usually suffer higher mortality than people born in winter.

**Figure 9: Hypothesized deviation from average annual death rate by *month of birth***

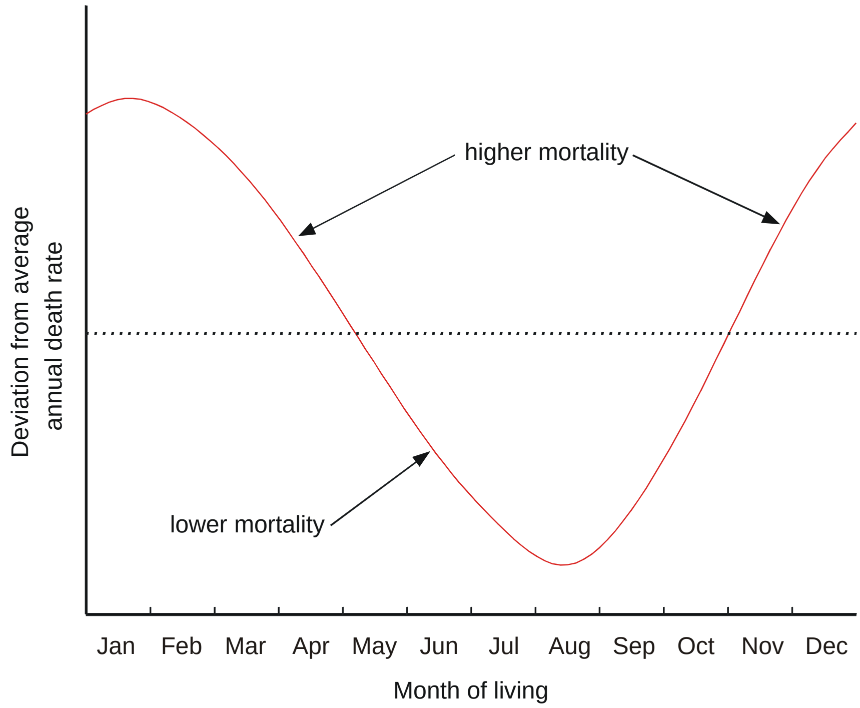


The difference in average lifespan is highest (0.6 years) between the May- and the October-born (Doblhammer and Vaupel 2001, p. 2935). It is assumed that the seasonal pattern is similar in Germany because Austria and Germany share climatic conditions as well as a similar cultural, social and economic background. The October-born individuals will probably live the longest, and May-born people will probably have the shortest life span among the population. The hypothesized seasonal pattern by *month of birth* is shown in Figure 9.

### 2.3.2 Hypotheses about the association between *month of living* and survival

As described in detail by Lerchl (1998) the German pattern in the seasonality of mortality is similar to the pattern of other European countries with higher mortality in winter and lower mortality during the summer months. Although the seasonal amplitude decreased in the observed period, Lerchl found no long-term phase shift between 1946 and 1995 (Lerchl 1998, p. 84-87).

**Figure 10: Hypothesized deviation from average death rate by *month of living***

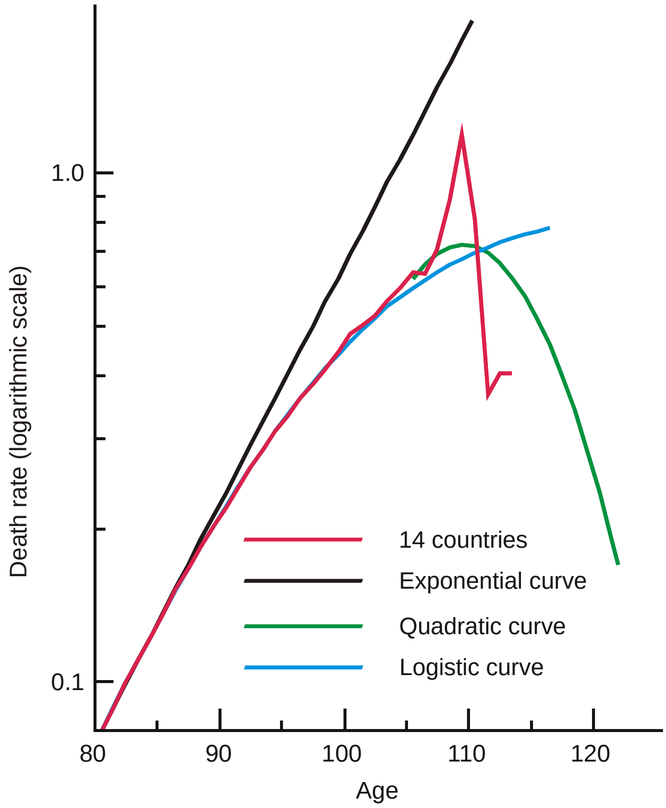



Therefore it is assumed that highest mortality rates will be found in January and February and lowest death rates in August. The hypothesized monthly distribution of deaths is shown in Figure 10.

### 2.3.3 Hypotheses about the influence of other factors on survival

Naturally, age is the most important determinant in mortality differentials. With the exception of infancy and perhaps exceptionally high ages, death rates rise when people grow older. In 1825 Benjamin Gompertz proposed that the mortality rates increase in a geometric progression. Since then his function has become popular as Gompertz's Law of Mortality. While the formula is a useful approximation for younger ages in a wide variety of species, it was found that human mortality does not rise exponentially at advanced ages (Vaupel 1998-2, p. 245). Vaupel et al. (1998) used aggregated data for 14 countries with reliable death information to show that the increase in the risk of death tends to decelerate at ages above 80. The authors compared the observed pattern with an exponential, logistic and quadratic curve that best fits to the used data (see Figure 11).

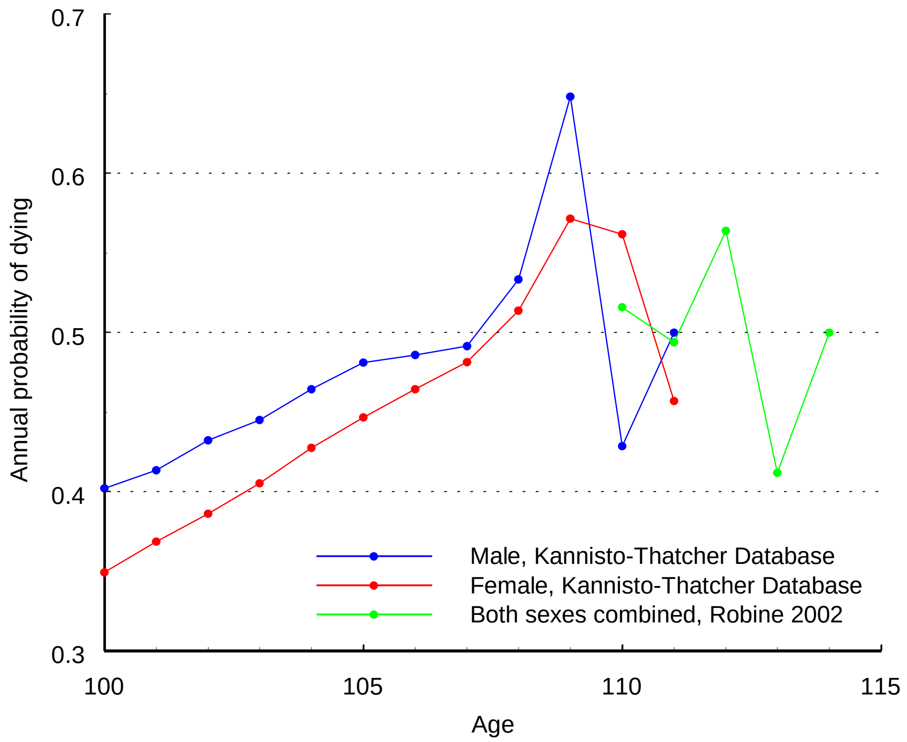
**Figure 11: Death rates from age 80 to 122 for females**




**Source: Vaupel et al. 1998, p. 857**

It was found that the pattern in these 14 countries is considerably different from the pattern proposed by Gompertz. After age 110, mortality levels off or even declines but due to problems with the accuracy of data, mortality rates above age 110 are still uncertain (Vaupel et al. 1998, p. 858). To calculate annual probabilities of dying above age 100, Thatcher, Kannisto and Vaupel (1998) pooled data from 13 countries – their results are shown in Figure 12 (Thatcher, Kannisto and Vaupel, p. 56). All 13 countries in the analysis were low-mortality countries; this means that they all had a life expectancy for both sexes combined between 75 and 79 years in 1994 (Thatcher, Kannisto and Vaupel 1998, p. 21). First results with data from the International Database on Longevity suggest that death rates stagnate between 110 and 114 (Robine and Vaupel 2002, p. 14).

**Figure 12: Annual probability of dying ($q_x$) after age 100**




**Source: Compiled by author from data in Robine 2002, p. 15, as well as own calculations from data in the Kannisto-Thatcher database on old age mortality[3]**

[3] Data from 13 countries (Austria, Denmark, England and Wales, Finland, France, Germany, Iceland, Italy, Japan, the Netherlands, Norway, Sweden and Switzerland) for the period 1980-2002 is used. The countries were the same as chosen by Thatcher, Kannisto and Vaupel 1998, p. 20-23.

In the most recent publication based on data from the International Database on Longevity, Robine et al. stated that their results strongly support the hypothesis that mortality of supercentenarians is constant up to ages of about 114 (Robine et al. 2005). Hence, it is assumed that the annual probabilities of dying of German semi-supercentenarians are similar to the values calculated by Thatcher, Kannisto and Vaupel (1998) and Robine (2002, 2005) shown in Figure 12. That means that the probability of dying probably fluctuates around a mean value of 0.5.

Figure 12 also indicates differences between the two sexes at these ages. *Sex* is one of the most important factors in determining mortality differences (Rau 2004, p. 164) and women usually live longer and have higher survival rates at nearly all ages (see section 2.2.2). Thus it could be proposed that male German semi-centenarians suffer higher mortality than their female counterparts.

The differences in mortality between the eastern and western parts of Germany could probably lead to the fact that the mortality of West German semi-supercentenarians is still lower than that of their East German counterparts. However, people reaching age 105 and over are still rare and very special within the population. It is also reasonable to assume that these people are in frequent contact with the medical system due to their exceptional age.

It is likely that higher mortality in East Germany was mainly caused by the lack of medical technology (see section 2.2.3.4), and the recent modernization of the medical equipment to the highest possible standards could probably remove this disadvantage in survival. Therefore, it is hypothesized that there are no further differences between semi-supercentenarians living in East or West Germany.

The past developments in mortality presented in 2.1.1 show that annual mortality rates at the highest ages have declined steadily since the early 70s. This development accelerated through the 90s, and it is thus reasonable to assume that survival has improved in German semi-supercentenarians too.

# 3. Data and method

This section will present some basic information about the dataset "Germany 105+" that is used in the present study. In addition, it explains which conditions led to the exclusion of cases out of the dataset and which software packages were used. Finally, a short introduction is provided to the event history modeling techniques applied in this study.

## 3.1 Data

A dataset called "Germany 105+" forms the basis for this study's analysis (Maier and Scholz 2003, 2004a). The dataset was gathered by the Max Planck Institute for Demographic Research between 2003 and 2005. At a later date this dataset will form part of the International Database on Longevity[4], which will focus exclusively on validated cases, where the personal information of each included person has been confirmed in a multi-step process. These steps differ from country to country. In Germany the raw data was provided by the Office of the German President. All local registry offices in Germany are required to report to the President every single person reaching age 105 and above on the occasion of their birthday; this fact probably makes the database of the German President the single most complete data source on persons aged 105+ available in Germany. In total the provided dataset called "Germany 105+" contained the details of 1,487 individuals who had received a congratulatory letter from the German President at their 105th or later birthday in the period from 1989 to 2002.

[4] The International Database on Longevity (IDL) is an international collaborative effort to gather demographic data for oldest ages. It was established in Rostock and Montpellier and will contain lists of persons above age 110 whose age has been validated, sorted by country. It will include individuals from the participating countries who are still alive as well as people who have died. At present the database includes complete lists of validated supercentenarians from 10 countries and incomplete lists for three other ones. Further countries, including Austria, Germany, Italy and Switzerland, will add their data in the near future.

In the first step of the validation process, the local registry office at the place of residence was asked whether the reported person is deceased or still alive. Furthermore, the registry office was asked to confirm the validity of the information received from the German President and for additional information about the person's place of birth. In a second step, the registry office at the place of birth was requested to confirm the information concerning the person's date and place of birth. A person was considered as age-validated if both the registry office at the place of birth and the registry office at the place of residence verified the person's age, place of birth and name. Unfortunately, these validation methods were not applicable for all cases. Almost one quarter (N=366) of the included individuals were born in territories belonging to the *German Empire* before World War I which are outside the current Germany. For these cases, the second step of the validation process was modified. Instead of sending the information concerning the person's date and place of birth to the local registry office at the place of birth, the information was forwarded to the *Standesamt I* in Berlin. This office maintains records of births for all former regions of the *German Empire*; it is unfortunately assumed that these records are far from being complete. Therefore, the age validation for that group of individuals is much more complicated than for the rest and still in progress.

**Table 2: Number of excluded cases (N=110) from dataset 'Germany 105+'**

| | |
|---|---|
| Total number of cases in original dataset | 1,487 |
| | |
| Deleted cases | |
| Test cases of the President's office | 2 |
| Moved abroad, no information on date of death | 2 |
| Adress unknown, no information on date of death | 5 |
| Person unknown at registry office at place of residence | 2 |
| Died before 105th birthday | 74 |
| Born in 1880 | 1 |
| Born in 1881 | 2 |
| Born in 1882 | 4 |
| Born in 1883 | 16 |
| Born in 1898 | 2 |
| | |
| Number of cases in used dataset | 1,377 |
| Validated cases | 947 |
| Not yet validated cases | 430 |

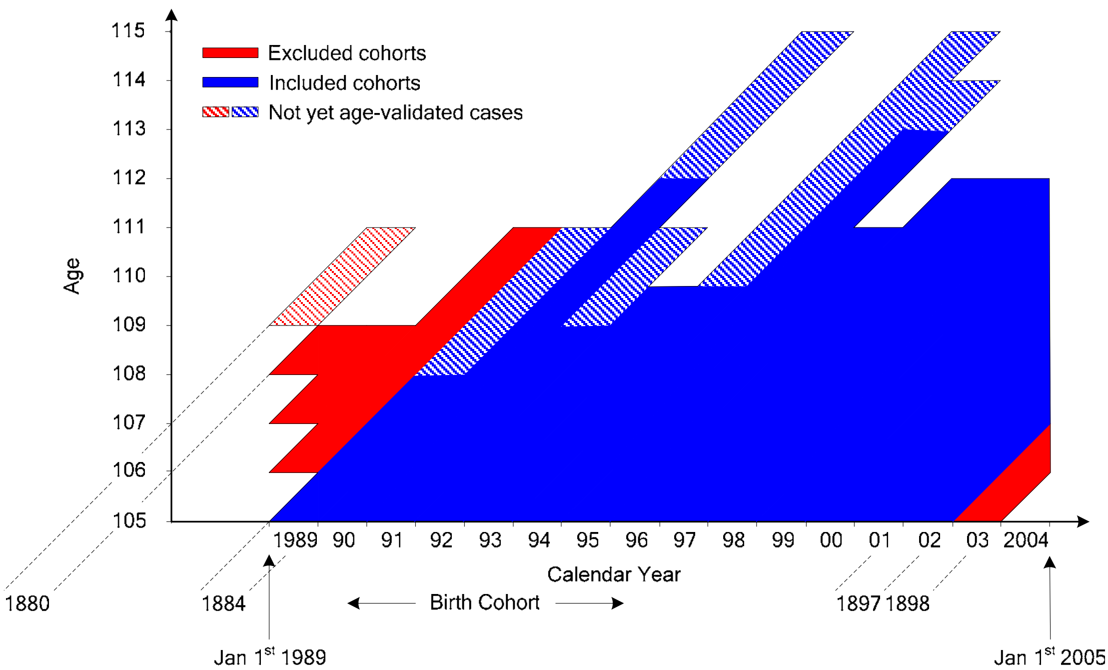
**Source: Compiled by author from data in 'Germany 105+'**

More than 180 individuals were still alive as the first step of the validation process was finished at the beginning of 2003. In February 2004 and again in February 2005 the registry offices at the place of residence were requested to update the information on the vital status of these individuals.

As a result of the validation process, several cases with inaccurate information entries were found and deleted. An overview of the excluded cases is shown in Table 2.

Two cases were used for testing purposes only. Another two individuals moved abroad and there was no appropriate way to receive reliable information on the person's age at death from a registry office at their current place of residence. Other cases were deleted because the registry office at the place of residence notified us that their current address was unknown or that they were not able to identify the person. The raw dataset from the Office of the German President also included numerous individuals who died before their 105th birthday. As this study only focuses on the mortality of people aged 105 and above, these cases were also removed from the analysis.

**Figure 13: Lexis Diagram of included cohorts in 'Germany 105+'**




**Source: Compiled by author from data in 'Germany 105+'**

The Lexis Diagram presented in Figure 13 shows that semi-supercentenarians born between 1880 and 1898 were included in the original dataset received from the office of the German President. For the purpose of the present study, the start of the observation period was defined as January 1st 1989. All individuals born in 1884 and later could celebrate their 105th birthday within this observation period. People born between 1880 and 1883 were older when they were included in the dataset. These cases could probably cause methodical problems, so they were also excluded from the further analysis. The same was done for two individuals born in 1898. They celebrated their 105th birthday in 2003. As the dataset from the office of the German President should only include all semi-supercentenarians reaching this age in or before December 31st 2002, both of these individuals were probably included erroneously.

After all the necessary adjustments have been made, the sample used in the present study consists of 1,377 semi-supercentenarians. 947 of them are regarded as age-validated, while 430 are considered as not yet age-validated.

This does not automatically mean that these 430 cases are invalid. Table 3 shows that one group of cases consists of persons born outside of today's German territories. All associated birth records are maintained at the *Standesamt I*. Due to the chaos of war in the 1940s, these records are far from being complete. In addition, they are only available in hard copy, which extended the processing time. So far 339 cases have been processed at the *Standesamt I*, of which 287 are regarded as not yet validated because no record of birth was found. Only 52 cases are still in process there.

**Table 3: Overview about not yet validated cases**

| | |
|---|---|
| **Total Number of not yet validated cases in dataset** | 430 |
| | |
| **Persons born outside today's German territories** | |
| No record at the *Standesamt I* | 287 |
| Still in process at the *Standesamt I* | 52 |
| | |
| **Persons born within today's German territories** | |
| Still in process - Special survey in Berlin | 15 |
| No record at the registry office at the place of birth | 53 |
| Registry office at the place of birth refused to cooperate | 21 |
| Registry office at the place of birth identified another person | 1 |
| Different birth name at registry office at the place of birth and the registry office at the place of death | 1 |

**Source: Compiled by author from data in 'Germany 105+'**

The second group of not yet validated cases consists of 91 people born within today's German territories. They can be divided into different subgroups. For most cases, no record was found at the civil registry office at their place of birth (one civil registry office identified another person born at this date). Since the civil registry office are not required by law to confirm the validity of the birth information, 21 civil registry offices refused to cooperate. A further 15 cases are still in process.

## 3.2 Methods of event history analysis (survival analysis)

I applied event history techniques because they are suitable for studying events that occur during the course of a life. Multiplicative intensity-regression models were estimated to observe the influence of certain covariates on the length of the person's survival. The process time is the age of the observed person and the baseline hazard (basic time factor "duration since 105$^{th}$ birthday") was modeled as a piecewise constant function. This means that the process time was divided into several segments. The hazard rates are constant for these time-segments, but they are allowed to vary across them. For additional information on the methods and techniques used see, for example, Blossfeld and Rohwer (1995).

I controlled for a set of time-constant and time-varying covariates that are categorical, too. The resulting model with the main effects is as follows:

**Equation 1:** $i(t)_{ijklmno} = a_{i(t)} b_j c_k d_l f_{n(t)} g_{o(t)}$

where $i(t)_{ijklmno}$ represents the mortality intensity, that is the probability that the observed person will die at a certain time *t*, given the information that are known about the person. The factor a represents the effect of the time factor (duration since 105$^{th}$ birthday in days), and $i(t)$ denotes the time segments in days in which the baseline hazard is divided and assumed to be constant (0-365, 366-730, 731-1095, 1096-1460, 1461-1825, 1826-2190). The factors *b* to *d* represent the effects of the time constant covariates '*sex*', '*region of residence*' and '*month of birth*', the factors *f* and *g* the time-varying ones '*month of living*' and '*period*'.

To estimate the models I used software called EvHa, developed by Jonathan McGill at the Max Planck Institute for Demographic Research in Rostock. The modeling, the construction of the variables, and the editing of the data were done with Intercooled

Stata 8.2 for Windows. Additionally, I verified the results from EvHa with the help of the event history module in Stata 8.2 and the extension for piecewise constant models provided by Jesper Sorensen (Stata Corporation 2003).

# 4. Results

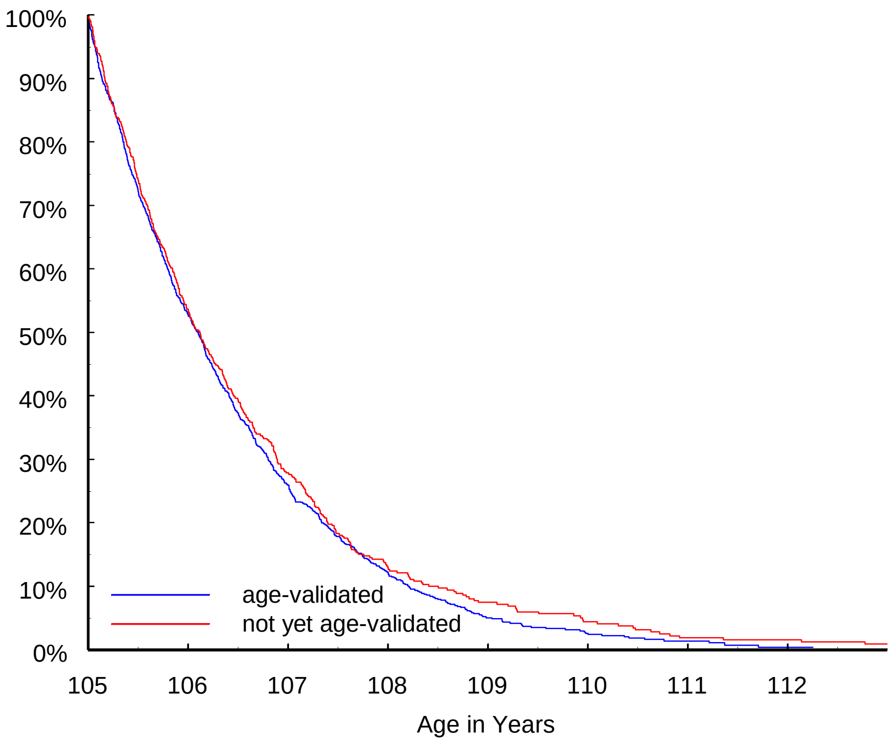
At the beginning of this section I will argue for the necessity to include only the validated cases in the further analysis. Afterwards I will provide the main characteristics of the sample and several survival graphs for the included covariates *sex*, *region of residence* and *period*, followed by the event history models. The section will close with an in-depth analysis of the seasonal components of mortality in semi-supercentenarians.

## 4.1 Descriptive statistics

### 4.1.1 Impact of validation status

As mentioned in section 3.1, the sample consists of 1,377 individuals, 947 of them are considered as age-validated, 430 are not yet validated. Here I address the issue of the possible impact of validation status on the results of the upcoming analysis.

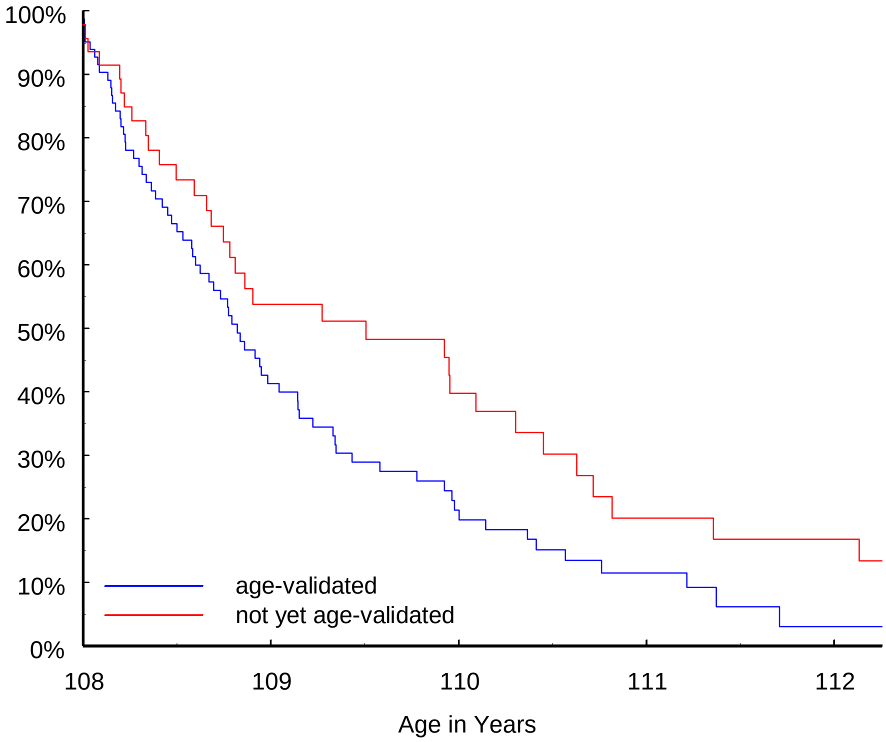
**Figure 14: Transition to death by validation status (Kaplan-Meier Survival Curve)**




**Source: Germany 105+ (own estimates)**

The survival curve in Figure 14 shows that the mortality trajectories of valid and non-validated cases are nearly identical up to age 108. Beyond this age the survival curves diverge visibly: non-validated cases seem to experience lower mortality at these ages than the persons aged 108 and above with validated information about their date of birth and date of death. This pattern beyond age 108 is shown in more detail in Figure 15.

**Figure 15: Transition to death by validation status for ages above 108 (Kaplan-Meier Survival Curve) (N=149)**



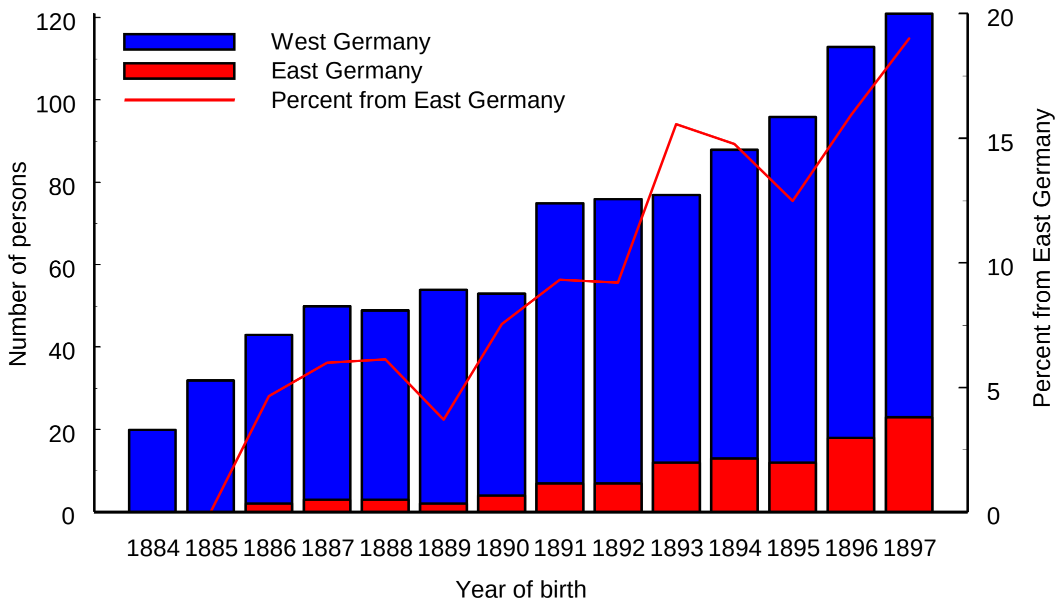

**Source: Germany 105+ (own estimates)**

It appears that there are systematic differences between non-validated and validated cases at ages above 108. I tested this with the help of a log-rank test for equality of survivor functions. In this case the P-value is equal to 0.0293 and the hypothesis about the equality of the survival distributions is rejected at the 5 percent level of significance. Because of that I will exclude all non-validated cases from further descriptive statistics and the event history modeling.

### 4.1.2 Characteristics of the sample

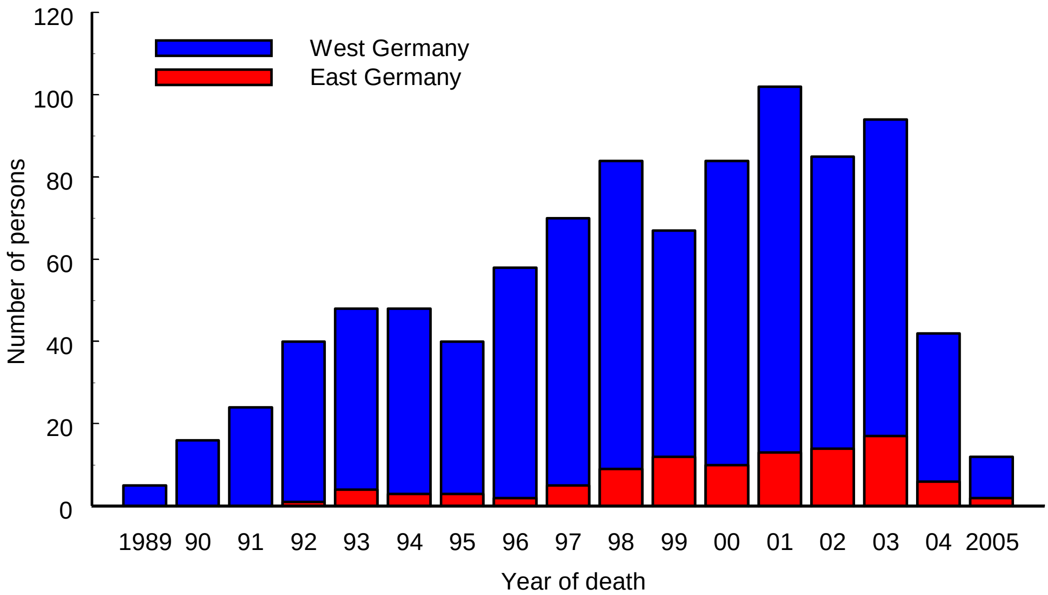
After the exclusion of non-validated individuals, 947 validated cases remain in the sample. All were born between 1884 and 1897. As shown in Figure 16, there was a steady increase from 20 persons born in 1884 to 121 persons born in 1897. This figure also shows that the number of individuals increased in both parts of Germany, but the proportion of individuals living in the eastern part of Germany rose steadily within the observation period. None of the individuals born in 1884 and 1885 came from East Germany, whereas later the proportion increased from about 5 percent in 1886 to 19 percent for people born in 1897. The reason for this could be that the persons born in 1884 and 1885 celebrated their 105$^{th}$ birthday in 1989 and 1990, and the East German registry offices were probably unable to report these persons during the transitional period around the German reunification.

**Figure 16: Distribution by year of birth for age-validated semi-supercentenarians (N=947)**




**Source: Germany 105+ (own estimates)**

**Figure 17: Distribution by year of death for age-validated semi-supercentenarians who died (N=919)**




**Source: Germany 105+ (own estimates)**

As may be expected, a similar pattern is observed for the distribution by year of death given in Figure 17. The included individuals died in the period between 1989 and 2005. The number of deaths increased from 5 persons in 1989 to 94 individuals in 2003. Again, the proportion of people who died in the eastern part of Germany increased within the observation period. As the observation period ended at the beginning of 2005, and no new semi-supercentenarians were included in 2004 and 2005, only few deaths were recorded within these years.

While the majority of the included semi-supercentenarians died, 28 persons (2.96 percent) were still alive at the end of the observation period in April 2005. These cases are considered as right censored. An overview about the number of censored cases and additional information on the main characteristics of the time-constant covariates is provided in Table 4.

**Table 4: Main characteristics of the used data sample; Time constant covariates**

| Characteristic | Total | Censored | | Deceased | |
|---|---|---|---|---|---|
| Persons older than 105 | 1,377 | 44 | 3.20% | 1,277 | 92.74% |
| *Valid Case* | | | | | |
| Yes | 947 | 28 | 2.96% | 919 | 97.04% |
| No | 430 | 16 | 3.72% | 414 | 96.28% |
| **Characteristics of 947 valid cases** | | | | | |
| *Region of residence* | | | | | |
| West Germany | 841 | 23 | 2.73% | 818 | 97.27% |
| East Germany | 106 | 5 | 4.72% | 101 | 95.28% |
| *Sex* | | | | | |
| men | 107 | 2 | 1.87% | 105 | 98.13% |
| women | 840 | 26 | 3.10% | 814 | 96.90% |
| *Month of birth* | | | | | |
| January | 78 | 2 | 2.56% | 76 | 97.44% |
| February | 86 | 1 | 1.16% | 85 | 98.84% |
| March | 81 | 3 | 3.70% | 78 | 96.30% |
| April | 74 | 1 | 1.35% | 73 | 98.65% |
| May | 71 | 5 | 7.04% | 66 | 92.96% |
| June | 58 | 0 | 0.00% | 58 | 100.00% |
| July | 68 | 1 | 1.47% | 67 | 98.53% |
| August | 87 | 3 | 3.45% | 84 | 96.55% |
| September | 94 | 2 | 2.13% | 92 | 97.87% |
| October | 85 | 8 | 9.41% | 77 | 90.59% |
| November | 70 | 2 | 2.86% | 68 | 97.14% |
| December | 95 | 0 | 0.00% | 95 | 100.00% |

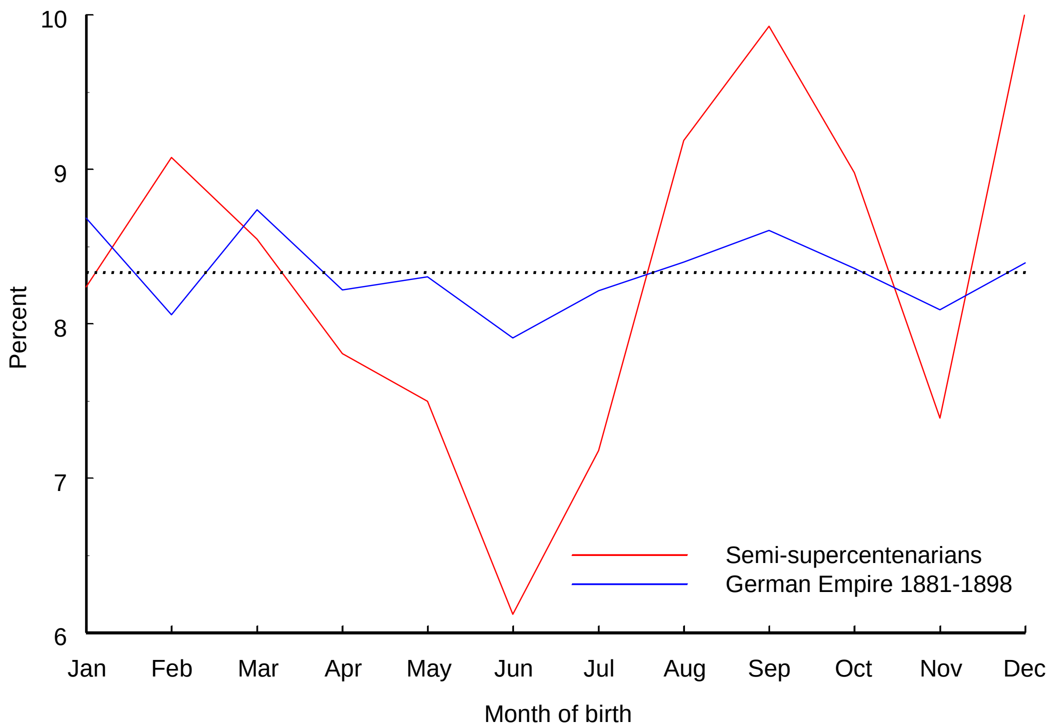
**Source: Compiled by author from data in 'Germany 105+'**

Most of the included semi-supercentenarians (N=947) lived in the Western part of Germany (N=841), only 106 persons in East Germany. The proportion of people living in East as compared to West Germany rose until the end of the observation period (see Figure 16). This probably explains why more East German than West German semi-supercentenarians were alive and hence censored at the end of the observation period (see Table 4).

As usual in studies about the highest ages, many more women are included in the sample. Here, about 89 percent (N=840) of all included people are female and only 11 percent (N=107) of them are male.

The distribution by *month of birth* for semi-supercentenarians varies from a minimum value of 56 people born in June to a peak value of 89 people born in December. On average, 85 persons were born in each month of the winter period between September and February, whereas the number of persons born in the summer period between March and August averages only 73 persons per month. Figure 18 shows that this seasonal distribution is different from the distribution for the general population at the time of their births.

**Figure 18: Distribution by month of birth for age-validated semi-supercentenarians (N=947) and of all births 1881-1898 in the German Empire**




**Source: Compiled by author from data in Doblhammer, Scholz and Maier 2005, p. 12, as well as own calculations from data in 'Germany 105+'**

For most months, the seasonal fluctuations by *month of birth* for the semi-supercentenarians follow the same pattern as for all births but are much more pronounced; only in the months from January to March are the variations reversed. Doblhammer, Scholz and Maier (2005) found that this seasonal pattern in the survival risks is highly correlated with previous findings in Danish data. The results also show that the deviation from the expected value is statistically significant for June- and December-born individuals (see section 2.2.4.1.2) (Doblhammer, Scholz and Maier 2005, p. 6).

Table 5 shows the survival time in person-days by *validation status* and for the two time-varying covariates *month of living* and *period*. All in all, the included semi-supercentenarians spent 717,667 days alive within the observation period; again, about two-thirds of the time (481,124 person days) was spent by validated individuals.

**Table 5: Main characteristics of the used data sample; Time varying covariates**

| Characteristic | Total | Censored | | Deceased | |
|---|---|---|---|---|---|
| Person days (all cases) | 717,667 | 47,230 | 6.58% | 670,437 | 93.42% |
| *Valid case* | | | | | |
| Yes | 481,124 | 31,309 | 6.51% | 449,815 | 93.49% |
| No | 236,543 | 15,921 | 6.73% | 220,622 | 93.27% |
| Characteristics of 481,124 valid person days | | | | | |
| *Month of living* | | | | | |
| January | 41,296 | 2,878 | 6.97% | 38,418 | 93.03% |
| February | 37,564 | 2,671 | 7.11% | 34,893 | 92.89% |
| March | 41,135 | 2,908 | 7.07% | 38,227 | 92.93% |
| April | 39,513 | 2,736 | 6.92% | 36,777 | 93.08% |
| May | 40,342 | 2,327 | 5.77% | 38,015 | 94.23% |
| June | 38,512 | 2,280 | 5.92% | 36,232 | 94.08% |
| July | 39,875 | 2,378 | 5.96% | 37,497 | 94.04% |
| August | 40,338 | 2,440 | 6.05% | 37,898 | 93.95% |
| September | 39,392 | 2,414 | 6.13% | 36,978 | 93.87% |
| October | 41,565 | 2,677 | 6.44% | 38,888 | 93.56% |
| November | 40,109 | 2,748 | 6.85% | 37,361 | 93.15% |
| December | 41,483 | 2,852 | 6.88% | 38,631 | 93.12% |
| *Period* | | | | | |
| 1989 to 1998 | 222,793 | 0 | 0.00% | 222,793 | 100.00% |
| 1999 to 2005 | 258,331 | 31,309 | 12.12% | 227,022 | 87.88% |

**Source: Compiled by author from data in 'Germany 105+'**

After examining the covariate *month of living*, it becomes apparent that most of the differences regarding the spent person days alive by *month of living* are caused by the varying number of days per month: the number of spent person-days peaks in January, October and December and troughs in February, April and June. The proportion of individuals being censored as compared to being dead at the end of the observation period increases steadily from about 5.7 percent in May to nearly 7.1 percent in February. The peak in this period is certainly a consequence of the end of the observation period in early 2005.

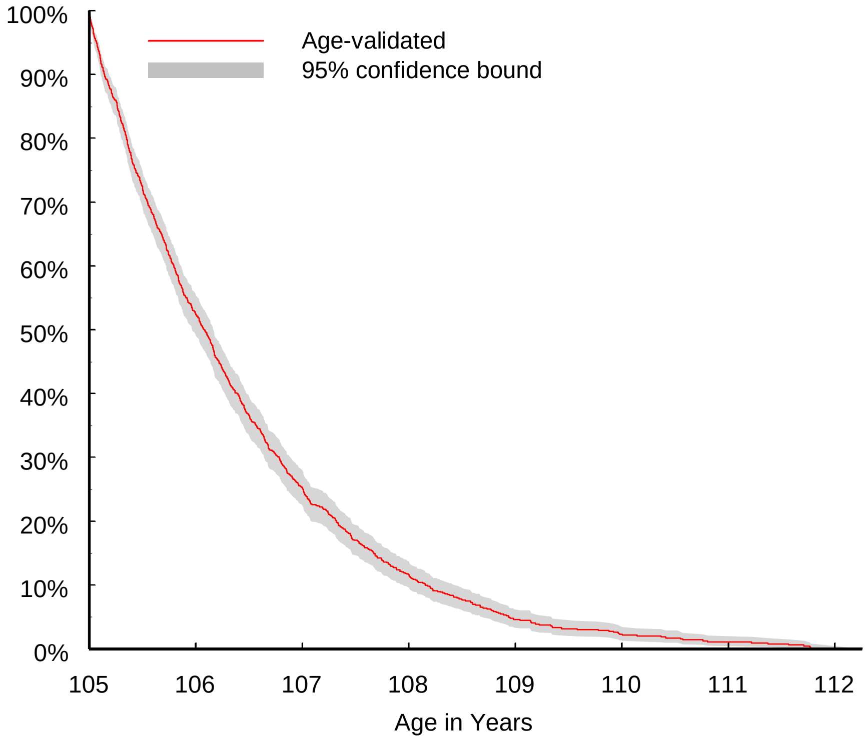
The chance of being censored as compared to being dead at the end of the observation period was highest just before the end of the observation period in early 2005. The vast majority of living semi-supercentenarians were censored in February 2005, some more in March and April. So the proportion of censored individuals was highest in these months and decreased the more the observed point in time is away from the end of the observation period.

The *period* variable in Table 5 distinguishes between the period before and after January 1st 1999. As a result of the rapid growth in the number of the semi-supercentenarians with time, more person days were spent in the second part of the observation period (258,331 person days), even though the first period (222,793 persons days) includes more calendar years. As expected, the proportion of censored cases is much higher in the second period.

### 4.1.3 Age, the dependent variable

As already mentioned, this study concerns the transition to death for an oldest old population of semi-supercentenarians. The observation period starts at the person's 105th birthday and ends at the day of death.

**Figure 19: Transition to death for validated semi-supercentenarians (Kaplan-Meier Survival Curve) (N=947). The grey shaded area denotes the 95 percent confidence interval.**




**Source: Germany 105+ (own estimates)**

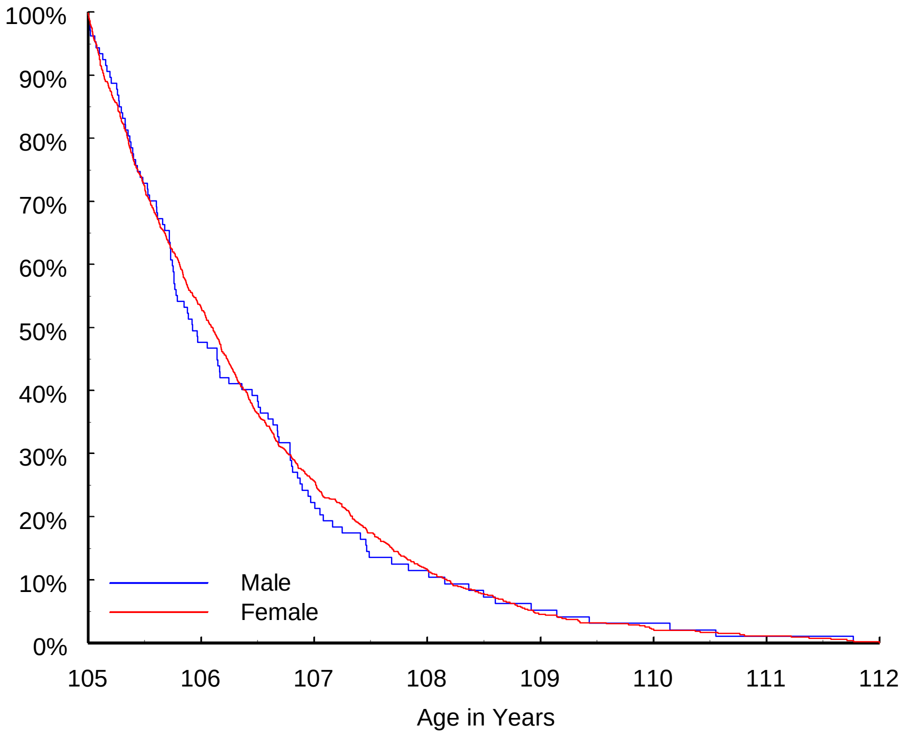
Persons who are still alive are censored at the day of arrival of a last letter from the "Meldestelle" (registry office at their place of living) in which the survival of the person is confirmed. The vast majority of those letters arrived in February 2005, some more in early March and the latest in May 2005. The Kaplan-Meier survival curve and the associated two-sided confidence bound at a confidence level of 0.95 for all validated persons are shown in Figure 19. About 47 percent of all semi-supercentenarians included in the sample died at age 105, only 2.5 percent reached the age of 110. The oldest validated person in the sample died at age 112.

### 4.1.4 The explanatory variables

#### 4.1.4.1 Sex

Figure 20 delineates the survival pattern by *sex*. It suggests that there are no systematic differences in the mortality rates between men and women at these extreme ages.

**Figure 20: Transition to death by *sex* (Kaplan-Meier Survival Curve)**



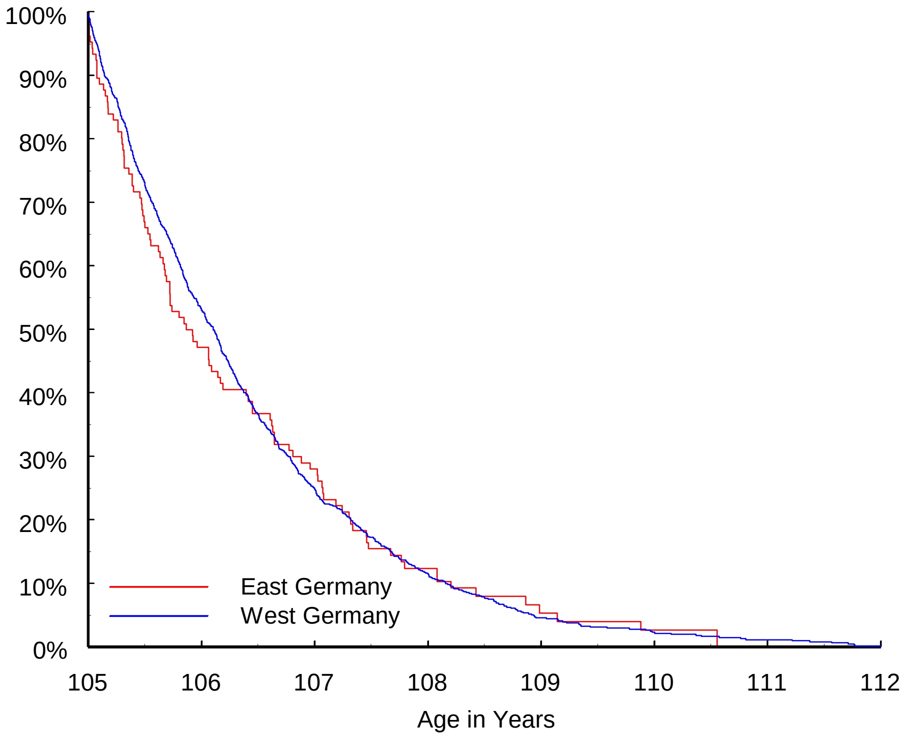

**Source: Germany 105+ (own estimates)**

In contrast to the male survival pattern, the Kaplan-Meier Survival curve for women is smooth and steady. Without much doubt, these fluctuations in the male survival curve are caused by the low number of male semi-supercentenarians included.

#### 4.1.4.2 Region of residence

The variable '*region of residence*' shows whether the person lived in the eastern or western part of Germany at his or her 105th birthday. We presume that people at these ages do not migrate between the two parts of Germany, though the place of residence and place of death was sometimes different. The associated Figure 21 shows the two survival curves. At first sight we cannot recognize systematic differences between East and West.

**Figure 21: Transition to death by *region of residence* (Kaplan-Meier Survival Curve)**

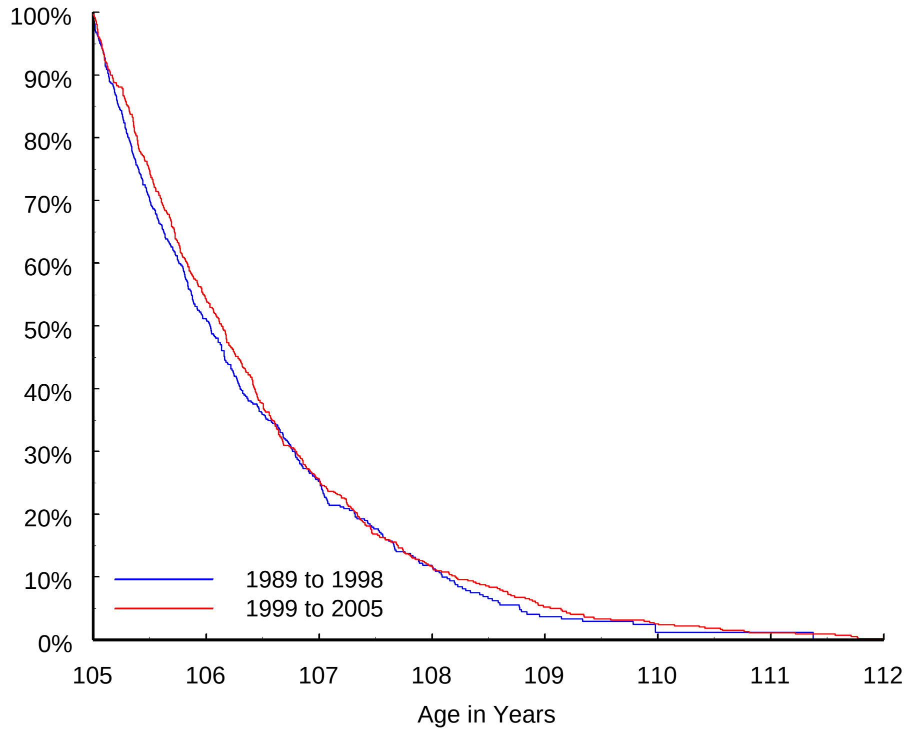



**Source: Germany 105+ (own estimates)**

#### 4.1.4.3 Period

Considering the influence of the time-varying covariate *period*, Figure 22 shows that semi-supercentenarians living before 1999 experience a rather higher mortality than individuals living after January 1$^{st}$ 1999. While the curve progression for both periods is virtually identical in the first few months after their 105th birthday, the curves diverge slightly after that. The differences are not significant: the associated two-sided confidence bounds at a confidence level of 0.95 overlap at all ages.

**Figure 22: Transition to death by *period* (Kaplan-Meier Survival Curve)**




**Source: Germany 105+ (own estimates)**

## 4.2 Event History Models

### 4.2.1 The influence of the covariates on the survival of semi-supercentenarians

The results of the four event history models are presented in Table 6. The first model shows the effect of the baseline factor age: this means the absolute risk of dying for the ages 105 to 110 - no further covariates were included. At age 105 the absolute risk is at its lowest (1.76 deaths per 1,000 person days) and it increases until age 108, where mortality risk peaks (2.46 deaths per 1,000 person days). The absolute risk of dying at age 109 and 110 is lower again (1.85, respectively 1.96 deaths per 1,000 person days).

**Table 6: Absolute and relative mortality risks associated with covariates for age-validated semi-supercentenarians (N=947)**

| | Model 1[3] | Model 2[3] | Model 3[3] | Model 4[3] |
|---|---|---|---|---|
| *Age*[1] | | | | |
| 105 | 1.76 | 1.75 | 1.62 | 1.81 |
| 106 | 1.99 | 1.99 | 1.86 | 2.08 |
| 107 | 2.13 | 2.13 | 2.03 | 2.28 |
| 108 | 2.46 | 2.47 | 2.38 | 2.66 |
| 109 | 1.85 | 1.86 | 1.86 | 2.08 |
| 110 | 1.96 | 2.00 | 2.02 | 2.27 |
| *Sex*[2] | | | | |
| female | | 1 | 1 | 1 |
| male | | 1.03 | 1.03 | 1.03 |
| *Month of birth*[2] | | | | |
| January | | | 1 | 1 |
| February | | | 0.92 | 0.92 |
| March | | | 0.93 | 0.94 |
| April | | | 1.13 | 1.15 |
| May | | | 0.96 | 0.97 |
| June | | | 1.10 | 1.12 |
| July | | | 1.04 | 1.05 |
| August | | | 1.14 | 1.14 |
| September | | | 1.37 * | 1.36 * |
| October | | | 0.94 | 0.93 |
| November | | | 1.06 | 1.04 |
| December | | | 1.22 | 1.21 |
| *Month of living*[2] | | | | |
| January | | | | 1 |
| February | | | | 1.00 |
| March | | | | 1.00 |
| April | | | | 0.85 |
| May | | | | 0.87 |
| June | | | | 0.99 |
| July | | | | 0.61 ** |
| August | | | | 0.90 |
| September | | | | 0.75 |
| October | | | | 0.82 |
| November | | | | 0.94 |
| December | | | | 0.99 |
| *Region of residence*[2] | | | | |
| West | | 1 | 1 | 1 |
| East | | 1.05 | 1.04 | 1.04 |
| *Period*[2] | | | | |
| 1989 to 1998 | | 1 | 1 | 1 |
| 1999 to 2005 | | 0.94 | 0.95 | 0.95 |
| *model fit* | | | | |
| log likelihood | -1456 | -1454 | -1449 | -1441 |

[1] absolute risks per 1,000 days
[2] relative risks as compared to a reference category
[3] associations of risk factors with mortality after controlling for the other factors in the model

** : $0.001 \le p < 0.01$
* : $0.01 \le p < 0.05$

**Source: Author's calculations from data in 'Germany105+'**

The second model shows the effects of the baseline factor age and of all covariates that are not associated with season. So, the model includes *age*, the time-constant factors *sex* and *region of residence*, as well as the time-varying factor *period*. The results regarding the variable *sex* show that men suffer a 1.9 percent higher mortality than women. The finding is in line with my hypothesis, but the effect is low and not statistically significant (at the 5 percent level).

Considering the covariate *region of residence* it was found that semi-supercentenarians living in the eastern part of Germany experience a 5 percent higher mortality than people living in West Germany. This difference between the two parts of Germany is also very low and not statistically significant.

The last included variable in Model 2 shows that the risk of dying decreased with historical time even in semi-supercentenarians. Compared to the mortality before 1999, people living in the second period suffer a 6 percent lower risk of dying. Although this finding is also not significant, the effect is stronger than for the previously included covariates *sex* and *region of residence*.

The third model shows the same effects as the second one, but additionally the time-constant covariate *month of birth* is introduced. January is defined as reference category. The lowest mortality risk is found for semi-supercentenarians born in February, the highest risk for September-born individuals. At ages above 105, their mortality risk is 37 percent higher than for January-born. This difference is statistically significant at the 5 percent level.

The fourth model shows the effect of all covariates. In addition to the included variables in Model 3, the time-varying variable *month of living* is added. It was found that mortality is lowest in July and highest between December and March. Again, January is chosen as the reference category. As compared to that, mortality risk is about 39 percent lower in July. The trough in July is the only month which is statistically significantly different from the reference month January (at the 5 percent level). Surprisingly, a further mortality peak is found in June, when survival is only about 1 percent lower than in January.

### 4.2.2 Interaction between *region of residence* and *period*

The results of the event history models in Table 6 indicate that mortality was similar in East and West German semi-supercentenarians. The following section will examine whether this is true for the entire observation period. For that reason I split the observation period into three periods. The first period is from 1989 to 1994, the second period ranges from 1995 to 2000 and the last period includes all years between 2001 and the beginning of 2005. As shown in Table 7, the highest number of person days are included in period three (217,909 person days), followed by period two (169,911 person days). In the first period the semi-supercentenarians spent only 93,304 person days, and the number for the East German individuals is especially low (3,601 person days, corresponding to 7 percent of the total of all subjects living in East Germany).

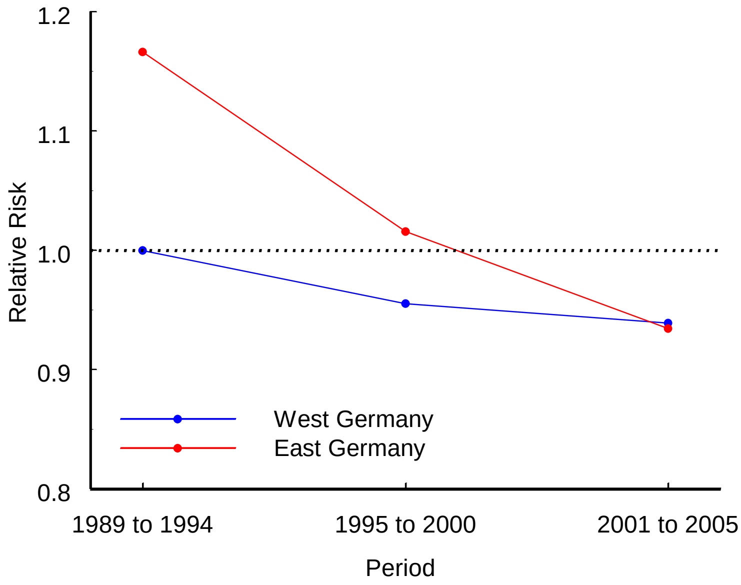
**Table 7: Cross tabulation of person days between *region of residence* and *period* for age-validated cases (N=947)**

| | | 1989 to 1994 | 1995 to 2000 | 2001 to 2005 | Total |
|---|---|---|---|---|---|
| *Region of residence* | | | | | |
| West Germany | N | 89,703 | 155,261 | 184,748 | 429,712 |
| | % | 20.9 | 36.1 | 43.0 | 100 |
| East Germany | N | 3,601 | 14,650 | 33,161 | 51,412 |
| | % | 7.0 | 28.5 | 64.5 | 100 |
| Total | N | 93,304 | 169,911 | 217,909 | 481,124 |

**Source: Author's calculations from data in 'Germany105+'**

The interaction model in Figure 23 shows that semi-supercentenarians living in the eastern part of Germany suffer higher mortality than their West German counterparts in the first two periods. While the risk of dying was about 17 percent higher before 1995, the difference is only about 6 percent in the second period. In the years 2001 and later, the mortality is even lower for people living in East Germany, though the results are not significantly different from each other (at the 5 percent level).

**Figure 23: Interaction effect between *region of residence* and *period***



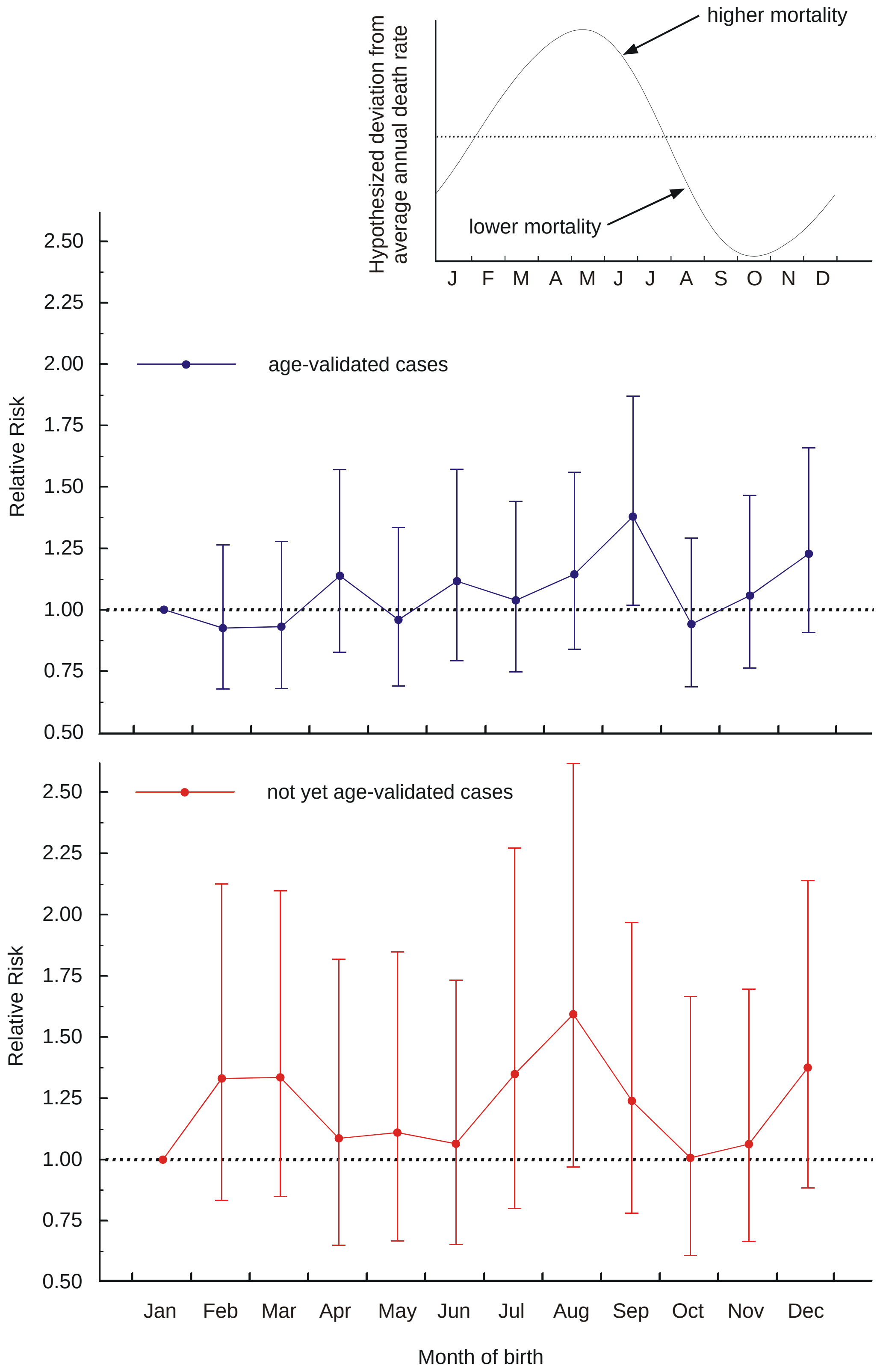

**Source: Author's calculations from data in 'Germany105+'**

The results suggest that the mortalities in the two parts of Germany were not as similar as the first event history models indicate. At the beginning of the observation period, mortality risk was higher in East Germany, and later mortality in West Germany was slightly higher compared to that in the East. However, the mortality risk decreased with historical time in both East and West Germany.

### 4.2.3 The effect of season

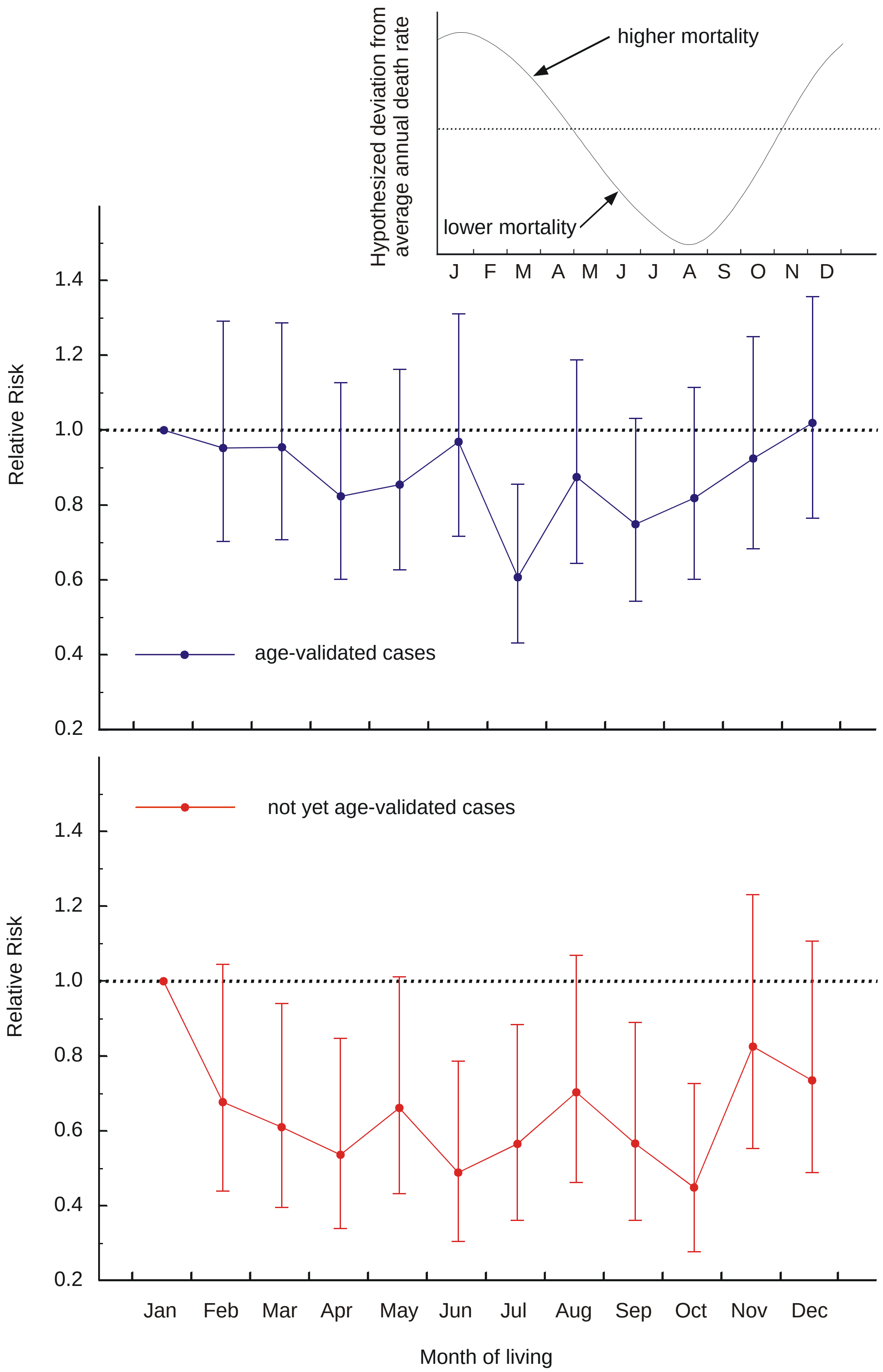
As the effects of the seasonal covariates *month of birth* and *month of living* were not that obvious, I will now analyze both patterns separately. Considering the effects of *month of birth*, the event history modeling showed that mortality was highest for the September-born and lowest for the February-born validated semi-supercentenarians. A detailed overview of the relative risks of validated semi-supercentenarians, as well as the associated confidence intervals (at the 5 percent level of significance) is given in Figure 24. The related pattern for the non-validated cases is also shown in that Figure. In my discussion of hypotheses, it was stated that individuals born in October would live longest and people born in May would probably have the shortest life span. However, this is not supported by the German semi-supercentenarians data. It is also difficult to discover an alternative pattern, thus it seems that survival is not influenced by month of birth at these ages. For non-validated cases the pattern is even more fluctuating and also indicates a random variation.

**Figure 24: Hypothesized deviation from annual death rate by *month of birth* and relative risk of mortality by *month of birth* for age-validated cases (N=947) and not yet age-validated cases (N=430)**




**Source: Author's calculations from data in 'Germany105+'**

**Figure 25: Hypothesized deviation from annual death rate by *month of living* and relative risk of mortality by *month of living* for age-validated cases (N=947) and not yet age-validated cases (N=430).**




**Source: Author's calculations from data in 'Germany 105+'**

For those who are included in the study the mortality pattern by *month of living* is presented in Figure 25. Considering all the validated cases, the event history modeling showed that the highest mortality is to be found in June and the lowest in July. Referring to the hypothesis, it was assumed that the individuals experience the highest death risks in winter, especially in January and February and the lowest mortality in late summer, in particular August. Apart from the deviation among the June-born, the pattern emerging from the data used supports this hypothesis: there is a clear seasonal death pattern with a mortality peak in the cold months and a trough in the summer, although these deviations are not significant due to the small number of cases. An event history model[5] with an aggregated variable *season of living* (the six months from October to March are coded as *cold season* and April to September as *warm season*) shows that the mortality risks associated with these two periods differ statistically significant from each other (at the 1 percent level). The relative risk of dying during the *warm season* is more than 16 percent lower than the mortality risk during the *cold season*.

### 4.2.4 Summary of the empirical findings

The results of the study indicate that the mortality pattern in semi-supercentenarians is different from the pattern in younger ages. Considering the analyzed determinants of mortality, it was found that *sex* differences in mortality are very low at these ages.

Regarding the four event history models, nearly the same was true for mortality differences by *region of residence*. However, an interaction model between *period* and *region of residence* showed that mortality in East Germany was probably higher at the beginning of the nineties but approached the West German level in the period between 1995 and 1999. Recent developments even indicate that the death risk in East German semi-supercentenarians is probably slightly lower now.

For both parts of Germany combined, the effect of the included *period* factor suggests that mortality, even at these exceptional ages, declined during the observation period. From 1999 to 2005 the death risk was about 5 percent lower than in the period between 1989 and 1998.

---

[5] Controlled for the covariates *sex*, *region of residence*, *period* and *month of birth*

Regarding the analyzed seasonal determinants it was found that *month of birth*, an indicator for environmental influences in early life, does not systematically influence the mortality at these highest ages. In analyzing the seasonal distribution by *month of birth*, I found that September-born have the lowest chance of surviving after age 105, while February-born have the highest chance.

Referring to the second seasonal variable *month of living*, it was shown that mortality is higher during the cold season and is lower during the warm season. The highest death risks were found for the period between December and March and the lowest for July. Except for June, where mortality is higher than expected, all monthly relative mortality risks follow the deviations from the average death risk predicted by the hypotheses in section 2.3.2.

# 5. Discussion and conclusion

The semi-supercentenarians in this study represent the last survivors of their generation. They were born at the end of the 19th century and celebrated their 105th birthday after the reunification of the two German states. They are a selected group of individuals who lived through many decades with sometimes unfavorable environmental conditions. My examination of these individuals indicates that some factors that determine survival at these exceptional ages are probably different from the factors at younger ages. In this section I will provide a review of my results in the context of their associated theories and hypotheses, as well as further research directions.

## 5.1 Review of the empirical findings in the context of the prevailing theories

The hypothesis regarding survival differences by *month of birth* stated that the mortality would be similar to the pattern found in Austria, with the lowest survival in May and the highest in October. Generally speaking, autumn-born individuals should live longer than those born in spring. It is assumed that unfavorable conditions and debilitating influences at the time of pregnancy or early infancy would probably cause these differences in late-life mortality. The pattern found among those included in the study is different from the hypothesized one. Survival after age 105 was lowest for semi-supercentenarians born in September and highest for individuals born in February. Both values are significantly different from each other at the five percent level. Thus, there is no support for the hypothesis that the spring-born live longer on average than the autumn-born. In Doblhammer’s findings in German semi-supercentenarians, mortality until age 105 was highest for June-born and lowest for December-born. This pattern is also different from the mortality after age 105 observed in this study. All these things considered, it is possible that the survival differences by *month of birth* in semi-supercentenarians can be attributed to random variation. People aged 105 and over are a highly selected group of individuals and the results from this study could reflect the fact that those who suffered unfavorable conditions and debilitating factors at the time around their birth and, thus, higher mortality throughout their life, did not reach such an exceptional age.

Regarding the second seasonal influence, previous studies suggested a peak in mortality in winter. This European pattern of mortality is less visible in Germany compared to other European countries, but most pronounced in the oldest ages. Considering that, it was hypothesized that death in semi-supercentenarians is more likely during the cold winter months as compared to the warmer summer months. Aside from the unexpected mortality peak in June, my hypothesis is confirmed by the data on German semi-supercentenarians. Among those who are included in the study, survival is lowest between December and January and highest in July. The results indicate a distinct seasonal pattern with a decreasing seasonal mortality in spring and increasing risk of dying in autumn. The differences between a warm season and a cold season are statistically significant (at the 1 percent level). The chance of dying is about 16 percent lower in the warm season (April – September) as compared to the cold season (October – March). This finding is in line with the results of Rau, who found that winter deaths in Denmark exceed summer deaths by about 17 percent (Rau 2004, p. 219).

Contrary to my expectations and the prevailing theories, it was found that the mortality pattern in semi-supercentenarians is very similar in men and in women. The results show that female survival is slightly higher, but this dissimilarity is far from statistically significant (P-value around 0.77).

The recent German Life Table shows that male excess in the annual probability of dying decreases with age. It might be that behavioral and environmental factors which cause higher mortality for males at younger ages disappear by age 105. It is also possible that the similar mortality pattern is caused by a selection effect due to heterogeneity. The number of female semi-supercentenarians in the dataset is about eight times higher than that of their male counterparts. That means that selection in males was much higher and it is quite possible that only the most robust male individuals lived until age 105. This would probably lead to lower overall male mortality at ages above 105 and thus to lower mortality differences by sex.

The development of life expectancy in East and West Germany was different during the observation period of this study. At the beginning of the 1990s, mortality was higher in the East but started to decline towards the levels in the West. There is agreement that this continuing development is likely to be caused by improvements in the medical system after German reunification. Due to this pattern in the whole

German population, it was hypothesized that mortality in semi-supercentenarians would be similar for both *regions of residence*.

At first sight, the event history models support that hypothesis. The models conducted show that the relative risks of survival are about the same in East and West and only slightly lower in East German semi-supercentenarians. However, an interaction between *period* and *region of residence* indicates that the patterns are probably not as similar as it first appears. At the beginning of the observation period, East German semi-supercentenarians suffered higher mortality. This excess mortality decreased with time and approached the levels of the West in the period between 1995 and 2000. Later, survival even became slightly better in the East when compared to the West. These results are intriguing, although they are not statistically significant.

One may speculate that the findings regarding the low differences between East and West, as well as between men and women, are caused by errors in the dataset. As in any study, low data quality could indeed have biased the results, but a multiplicity of descriptive statistics did not indicate any kind of systematic error. The dataset from the German President is probably the most complete data source on such old people in Germany. It is possible that some people aged 105 years or older are not included in the dataset, but there is no reason to assume that these persons are excluded systematically.

All in all, it can be stated that the determinants of survival in the semi-supercentenarians are not the same as at younger ages. While the effects of some factors agree with the effects predicted by the hypotheses, other effects are contrary to my expectations. The findings suggest that the effects of risk factors on mortality change at the oldest ages. The importance of life-long risk factors such as *sex* and *month of birth* decline with age, whereas current conditions such as *month of living* remain as a relevant determinant of survival. There are three possible explanations for this.

The first one is as Leonard Hayflick stated: “There is one and only one cause of death at older ages. And that is old age. And nothing can be done about old age.” (Vaupel 1998, p. 242) Hayflick’s statement represents the classic view on mortality at the oldest ages, first proposed by Aristotle in 350 B.C. (Vaupel 2004b, p. 48-49) However, there was evidence in this study that mortality in semi-supercentenarians declined with historical time; this development is similar to the pattern in the whole

German population. Laboratory experiments also suggest that mortality, even at advanced ages, is highly plastic (Vaupel, Carey and Christensen 2003). Therefore, this explanation is probably not true.

The second explanation is that mortality at these exceptional ages is simply more affected by random variation. On the one hand this random variation in life span could be caused by molecular aging processes. Finch and Kirkwood propose that chance variations in cell numbers, in cell fates during differentiation and in physiological patterns that unfold during adult life could explain differences in life span. These molecular processes are difficult to observe but the authors found support for their theory in worms and other animals. They argue that life span is determined by three major groups of factors, namely genetic, environmental and chance factors (Finch and Kirkwood 2000).

On the other hand, this random variation could probably be caused by heterogeneity. It was already demonstrated in 1979 that the variation in mortality is much higher in youth or middle age and tends to decline and even reverse at older ages (Vaupel, Manton and Stallard 1979). At younger ages the population consists of subpopulations with different risk of dying, mainly due to the factors mentioned in the theory section. Since the subgroups with the highest mortality risk tend to die first most risk factors seem to lose their explanatory power with age.

The third and final possible explanation is that other genetic or environmental determinants of survival are predominant at the highest ages but have yet to be discovered. In all likelihood, the truth lies somewhere in between, making further research necessary.

## 5.2 Further research directions

The results suggest that a sample containing 1377 cases, with 947 validated cases, is too small to achieve statistically significant results for monthly data, both for month of birth and month of death. However, it is very likely that the dataset from the German President covers the entire population at these ages, so at least for Germany it is not possible to increase the survey size. For this reason, it is reasonable to replicate the results of the study with similar data from other countries. As stated in the data section, data quality is an enormous problem when analyzing the oldest old. Using data from other countries that contribute to the International Database on Longevity would provide a way to avoid the data quality problem, and help to shed further light on the influence of season on survival at these exceptional ages.

It is worth considering contacting the semi-supercentenarians directly to collect more data about this unique group of people. Information about their social environment, their personality and their health status may help to better understand the patterns of survival after the age of 105.

# 6. References

Anderson-Ranberg, K., M. Schroll and B. Jeune (2001). Healthy centenarians do not exist, but autonomous do: A population-based study of morbidity among Danish centenarians. *Journal of the American Geriatrics Society* 49 (7): 900-908.

Barker, D. J. P. (2003). The developmental origins of adult disease. *European Journal of Epidemiology* 18 (8): 733-736.

Barker, D. J. P., C. Osmond, P. D. Winter, B. Margetts and S. J. Simmonds (1989). Weight in infancy and death from ischaemic heart disease. *Lancet* 334 (8663): 577-580.

Blossfeld, H.-P. and G. Rohwer (1995). Techniques of event history modeling: New approaches to causal analysis. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Bowling, A. (1987). Mortality after bereavement: A review of the literature on survival periods and factors affecting survival. *Social Science & Medicine* 24 (2): 117-124.

Bratzler, D. W., W. H. Oehlert and A. Austelle (2002). Smoking in the elderly: it s never too late to quit. *Journal / Oklahoma State Medical Association* 95 (3): 185-191.

Buiatti, E. (2004). Can we afford a further increase in life expectancy? *Aging Clinical and Experimental Research* 16 (1): 1-2.

Carey, J. R. (2004). Human longevity: How old can we grow? *UC Davis Magazine* 21 (3).

Christensen, K. and J. W. Vaupel (1996). Determinants of longevity: genetic, environmental and medical factors. *Journal of Internal Medicine* 240 (6): 333-341.

Cohen, S. (2004). Social relationships and health. *American Psychologist* 59 (8): 676-684.

Corder, E. H., A. M. Saunders, W. J. Strittmatter, D. E. Schmechel, P. C. Gaskell, G. W. Small, A. D. Roses, J. L. Haines and M. A. Pericak-Vance (1993). Gene dose of apolipoprotein E type 4 allele and the risk of Alzheimer's Disease in late onset families. *Science* 261 (5123): 921-923.

Dinkel, R. H. (1999). East and West German mortality before and after Reunification. *Unpublished manuscript*, University of Rostock.

Dinkel, R. H. (2002). Die langfristige Entwicklung der Sterblichkeit in Deutschland. *Zeitschrift für Gerontologie und Geriatrie* 35 (5): 400-405.

Doblhammer, G. (2004). The late life legacy of very early life. Springer-Verlag.

Doblhammer, G., H. Maier and R. D. Scholz (2005). Month of birth influences survival up to age 105+: first results from the age validation study of German semi-supercentenarians. *MPIDR Working Paper* 004: 1-14.

Doblhammer, G. and J. W. Vaupel (2001). Lifespan depends on month of birth. *PNAS* 98 (5): 2934-2939.

Doll, R., R. Peto, K. Wheatley, R. Gray and I. Sutherland (1994). Mortality in relation to smoking: 40 years' observations on male British doctors. *British Medical Journal* 309 (6959): 901-911.

Donaldson, G. C. and W. R. Keatinge (2002). Excess winter mortality: influenza or cold stress? Observational study. *British Medical Journal* 324 (7329): 89-90.

Durkheim, E. (1999). Der Selbstmord. Frankfurt a.M.: Suhrkamp Verlag.

Erlangsen, A., B. Jeune, U. Bille-Brahe and J. W. Vaupel (2004). Loss of partner and suicide risks among oldest old: a population-based register study. *Age and Ageing* 33 (4): 378-383.

Feinstein, C. A. (2002). Seasonality of deaths in the U.S. by age and cause. *Demographic Research* 6 (17): 469-486.

Finch, C. E. and E. M. Crimmins (2004). Inflammatory exposure and historical changes in human life-spans . *Science* 305 (5691): 1736-1739.

Finch, C. E. and T. B. L. Kirkwood (2000). Chance, development, and aging. New York: Oxford University Press.

Franke, H. (1985). Auf den Spuren der Langlebigkeit. Stuttgart, New York: F.K. Schattauer Verlag.

Fries, J. F. (1980). Aging, Natural Death, and the Compression of Morbidity. *The New England Journal of Medicine* 303 (3): 130-135.

Fries, J. F. (2000). Compression of Morbidity in the Elderly. *Vaccine* 18 (16): 1584-1589.

Gavrilov, L. A. and N. S. Gavrilova (1999). Season of birth and human longevity. *Journal of Anti-Aging Medicine* 2 (4).

Germany 105+ (2005/5/31). Rostock: Max Planck Institute for Demographic Research.

Gjonca, A., H. Brockmann and H. Maier (2000). Old-Age mortality in Germany prior to and after Reunification. *Demographic Research* 3 (1).

Gottfredson, L. S. and I. J. Deary (2004). Intelligence predicts health and longevity, but why? *Current Directions in Psychological Science* 13 (1): 1-4.

Gudmundsson, H., D. F. Gudbjartsson, A. Kong, H. Gudbjartsson, M. Frigge, J. R. Gulcher and K. Stefánsson (2000). Inheritance of human longevity in Iceland. *European Journal of Human Genetics* 8: 743-749.

Healy, J. D. (2003). Excess winter mortality in Europe: a cross country analysis identifying key risk factors. *Journal of Epidemiology and Community Health* 57 (10): 784-789.

Heijmans, B. T., R. G. J. Westendorp and P. E. Slagboom (2000). Common gene variations, mortality and extreme longevity in humans. *Experimental Gerontology* 908 (6-7 SI): 865-877.

Heinemann, L., R. H. Dinkel and E. Görtler (1996). Life expectancy in Germany: Possible reasons for the increasing gap between East and West Germany. *Reviews on Environmental Health* 11 (1-2): 15-26.

Hippocrates (1996). Aphorisms. Adelaide: The University of Adelaide Library.

Hippocrates (2004). On airs, waters, and places. Whitefish: Kessinger Publishing.

Hitt, R., Y. Young-Xu, M. Silver and T. Perls (1999). Centenarians: the older you get, the healthier you have been. *Lancet* 354: 652.

House, J. S., K. R. Landis and D. Umberson (1988). Social relationships and health. *Science* 241 (4865): 540-545.

Human Mortality Database (2005/5/14). University of California (Berkeley) and Max Planck Institute for Demographic Research (Rostock). Available at: www.mortality.org

Huntington, E. (1938). Season of birth. New York: John Wiley & Sons, Inc.

Hynes, J. (1995). The oldest old in pre-industrial Britain: Centenarians before 1800 - fact or fiction? In: Jeune, B. and J. W. Vaupel (Eds.), Exceptional longevity: From prehistory to the present, pp. 75-92. Odense: Odense University Press.

Iachine, I. A., N. V. Holm, J. Harris, A. Z. Begun, M. K. Iachina, M. Laitinen, J. Kaprio and A. I. Yashin (1998). How heritable is individual susceptibility to death? The results of an analysis of survival data on Danish, Swedish and Finnish twins. *Twin research* 1: 196-205.

International Database on Longevity (2005). Rostock: Max Planck Institute for Demographic Research. Available at: *www.supercentenarians.org*

Jeune, B. (1995). In search of the first centenarians. In: Jeune, B. and J. W. Vaupel (Eds.), Exceptional longevity: From prehistory to the present, pp. 11-24. Odense: Odense University Press.

Kannisto-Thatcher Database on Old Age Mortality (2005/5/14). Rostock: Max Planck Institute for Demographic Research. Available at: *www.demogr.mpg.de/databases /ktdb/*

Kannisto, V. (1988). On the survival of centenarians and the span of life. *Population Studies* 42 (3): 389-406.

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

Kannisto, V. (1999). Assessing the information on age at death of old persons. In: Jeune, B. and J. W. Vaupel (Eds.), Validation of Exceptional Longevity, pp. 235-249. Odense: Odense University Press.

Keatinge, W. R., S. R. K. Coleshaw and J. Holmes (1989). Changes in seasonal mortalities with improvment in home heating in England and Wales from 1974 to 1984. *International Journal of Biometeoroly* 33: 71-76.

Kevan, S. M. (1979). Season of life - season of death. *Social Science & Medicine* 13 (4): 227-232.

Klein, T. (1999). Soziale Determinanten der aktiven Lebenserwartung. *Zeitschrift fuer Soziologie* 28 (6): 448-464.

Klinger, A. (1990). Results of demographic study of the oldest people. In: Beregi, E. (Ed.), Centenarinas in Hungary : A Sociomedical and Demographic Study, pp. 1-21. Basel: Karger.

Landers, J. (1993). Death and the metropolis. Studies in the demographic history of London 1670-1830. Cambridge: Cambridge University Press.

Lawlor, D. A. (2004). Commentary: The art and science of epidemiology: governed by the seasons? *International Journal of Epidemiology* 33 (1): 144-146.

Lerchl, A. (1998). Changes in the seasonality of mortality in Germany from 1946 to 1995: the role of temperature. *International Journal of Biometeoroly* 42 (2): 84-88.

Li, Q. (2005). Subjective well-being and mortality in Chinese oldest old. *MPIDR Working Paper*: 1-33.

Ljungquist, B., S. Berg, J. Lanke, G. E. McClearn and N. L. Pedersen (1998). The effect of genetic factors for longevity: a comparison of identical and fraternal twins in the swedish twin registry. *Journal of Gerontology: Medical Sciences* 53a (6): M441-M446.

Luy, M. (2002). Die geschlechtsspezifischen Sterblichkeitsunterschiede - Zeit für eine Zwischenbilanz. *Zeitschrift für Gerontologie und Geriatrie* 35 (5): 412-429.

Luy, M. (2004). Mortality differences between Western and Eastern Germany before and after reunification. *Genus* 60 (3/4): 99-141.

Maier, H. and R. D. Scholz (2003). Aktuelle Sterblichkeitsentwicklungen und extreme Langlebigkeit. In: Max-Planck-Gesellschaft (Ed.), Jahrbuch 2003, pp. 229-235. München: Saur.

Maier, H. and R. D. Scholz (2004a). Immer mehr Menschen können 105. Geburtstag feiern. *Demografische Forschung Aus Erster Hand* 1 (1): 4.

Maier, H. and R. D. Scholz (2004b). Wiedervereinigung zeigt: für ein langes Leben ist es nie zu spät; Ostdeutsche holen in der Lebenserwartung auf. *Demografische Forschung Aus Erster Hand* 1 (3): 1-2.

March, L. (1912). Some researches concerning the factors of mortality. *Journal of the Royal Statistical Society* 75 (5): 505-538.

Martikainen, P., T. Martelin, E. Nihtila, K. Majamaa and S. Koskinen (2005). Differences in mortality by marital status in Finland from 1976 to 2000: Analyses of changes in marital-status distributions, socio-demographic and household composition, and cause of death. *Population Studies* 59 (1): 99-115.

McClearn, G. E., B. Johansson, S. Berg, N. L. Pedersen, F. Ahern, S. A. Petrill and R. Plomin ( 1997). Substantial genetic influences on cognitive abilities in twins 80 or more years old. *Science* 276 (5318): 1560-1563.

McDowall, M. (1981). Long term trends in seasonal mortality. *Population Trends* 26: 16-19.

McGue, M., J. W. Vaupel, N. V. Holm and B. Harvald (1993). Longevity is moderately heritable in a sample of Danish twins born 1870-1880. *Journal of Gerontology: Medical Sciences* 48 (6): B237-B244.

McKee, C. M. (1989). Deaths in winter: Can Britain learn from Europe? *European Journal of Epidemiology* 5 (2): 178-182.

Moody, H. R. (1998). Aging, concepts and controversies. Thousand Oaks, California: Pine Forge Press.

Moore, S. E., T. J. Cole, E. M. E. Poskitt, B. J. Sonko, R. G. Whitehead, I. A. McGregor and A. M. Prentice (1997). Season of birth predicts mortality in rural Gambia. *Nature* 388 (6641): 434.

Moore, S. E., A. J. C. Fulford, P. K. Streatfield, L. A. Persson and A. M. Prentice (2004). Comparative analysis of patterns of survival by season of birth in rural Bangladeshi and Gambian populations. *International Journal of Epidemiology* 33 (1): 137-143.

New Cronos Database (2005/4/20). Luxembourg: Eurostat. Available at: *www.europa.eu.int/comm/eurostat/newcronos/reference/display.do?screen=welcomeref&open=/&product=EU_MAIN_TREE&depth=1&language=en*

Oeppen, J. and J. W. Vaupel (2002a). Broken limits to life expectancy. *Science* 296 (5570): 1029-1031.

Oeppen, J. and J. W. Vaupel (2002b). Broken limits to life expectancy: Supplementary material. Available at: *http://www.sciencemag.org/cgi/content/full/296/5570/1029/DC1*

Perls, T., L. M. Kunkel and A. A. Puca (2002). The genetics of exceptional human longevity. *Journal of the American Geriatrics Society* 50 (2): 359-368.

Perls, T. and D. Terry (2003 ). Understanding the determinants of exceptional longevity. *Annals of Internal Medicine* 139 (5): 445-449.

Perls, T. and D. Terry (2003 ). Genetics of exceptional longevity. *Experimental Gerontology* 38 (7): 725-730.

Plug, E. J. S. (2001). Season of birth, schooling and earnings. 22 (5): 641-660.

Rau, R. (2004) Seasonality in human mortality: A demographic approach. University of Rostock.

Rau, R. and G. Doblhammer (2003). Seasonal mortality in Denmark: the role of sex and age. *Demographic Research* 9 (9): 197-222.

Robine, J. M., J. Gampe, A. Cournil and J. W. Vaupel (2005). IDL, the International Database on Longevity. *International Longevity Symposium*.

Robine, J. M. and J. W. Vaupel (2001). Supercentenarians: slower ageing individuals or senile elderly? *Experimental Gerontology* 36: 915-930.

Robine, J. M. and J. W. Vaupel (2002). Emergence of supercentenarians in low mortality countries. *North American acturial journal* 6 (3): 54-63.

Rosengren, A., K. Orth-Gomér, H. Wedel and L. Wilhelmsen (1993). Stressful life events, social support, and mortality in men born in 1933. *British Medical Journal* 307 (6912): 1102-1105.

Rosengren, A., L. Wilhelmsen and K. Orth-Gomér (2004). Coronary disease in relation to social support and social class in Swedish men. *European Heart Journal* 25 (1): 56-63.

Sharma, R. (2004). Dietary restriction and its multifaceted effects. *Current Science* 87 (9): 1203-1210.

Simondon, K. B., E. Elguero, A. Marra, A. Diallo, P. Aaby and F. Simondon (2004). Season of birth is not associated with risk of early adult death in rural Senegal. *International Journal of Epidemiology* 33 (1): 130-136.

Sorensen, T. I. A., G. G. Nielsen, P. K. Andersen and T. W. Teasdale (1988). Genetic and environmental influences on premature death in adult adoptees. *The New England Journal of Medicine* 318: 727-732.

Statistisches Bundesamt. Bevölkerungsentwicklung Deutschlands von 2002 bis 2050 (2003). Wiesbaden: Statistisches Bundesamt Deutschland. Available at: *www.destatis.de /presse/deutsch/pk/2003/bev_2050b.htm*

Statistisches Bundesamt. Sterbetafel 2001/2003 für Deutschland (2004). Wiesbaden: Statistisches Bundesamt Deutschland. Available at: *www.destatis.de/download /d/bevoe/sterbet03.xls*

Stroebe, M. S. and W. Stroebe (1987). Who suffers more? Sex differences in health risks of the widowed. *Psychological Bulletin* 93 (2): 279-299.

Suvisaare, J. M., J. K. Haukka and J. K. Lönnqvist (2001). Season of birth among patients with Schizophrenia and their siblings: Evidence for the Procreational Habits Hypothesis. *American Journal of Psychiatry* 158 (5): 754-757.

Tafaro, L., P. Cicconetti, G. Tedeschi, A. Baratta, R. Ursino, E. Ettorre and V. Marigliano (2004). Smoking and longevity: An incompatible binomial? *Archives of Gerontology and Geriatrics* 38 (Supplement 9): 425-430.

Taylor, D. H., V. Hasselblad, S. J. Henley, M. J. Thun and F. A. Sloan (2002). Benefits of smoking cessation for longevity. *American Journal of Public Health* 92 (6): 990-996.

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

Torrey, E. F., J. Miller, R. Rawlings and R. H. Yolken (1997). Seasonality of births in schizophrenia and bipolar disorder: a review of the literature. 28 (1): 1-38.

Vaiserman, A. M., A. C. Collinson, N. M. Koshel, I. I. Belaja and V. P. Voitenko (2002). Seasonal programming of adult longevity in Ukraine. *International Journal of Biometeoroly* 47 (1): 49-52.

Vaiserman, A. M. and V. P. Voitenko (2003). Early programming of adult longevity. *Journal of Anti-Aging Medicine* 6 (1): 11-20.

Vaupel, J. W. (1998). Demographic analysis of aging and longevity. *The American Economic Review* 88 (2): 242-247.

Vaupel, J. W. (2004a). Deutschlands größte Herausforderung: Wider die demographische Ignoranz: Unsere Lebensläufe und die unserer Kinder werden sich ändern, weil das Leben länger dauern wird. *Frankfurter Allgemeine Zeitung* 84: 41.

Vaupel, J. W. (2004b). The Biodemography of Aging. In: Waite, L. J. (Ed.), Aging, health and public policy. Demographic and economic perspectives, New York: Population Council.

Vaupel, J. W. (2005). 130 Jahre scheinen möglich. *Focus* 17: 90-91.

Vaupel, J. W., J. R. Carey and K. Christensen (2003). It's never too late. *Science* 301 (5640): 1679-1681.

Vaupel, J. W., J. R. Carey, K. Christensen, T. E. Johnson, A. I. Yashin, N. V. Holm, I. A. Iachine, V. Kannisto, A. A. Khazaeli, P. Liedo, V. D. Longo, Y. Zeng, K. G. Manton and J. W. Curtsinger (1998). Biodemographic trajectories of longevity. *Science, New Series* 280 (5365): 855-860.

Vaupel, J. W., K. G. Manton and E. Stallard (1979). The impact of heterogeneity in individual frailty on the dynamics of mortality. *Demography* 16 (3): 439-454.

Weinert, B. T. and P. S. Timiras (2003). Theories of aging. *Journal of Applied Physiology* 95 (4): 1706-1716.

Wilmoth, J. R. (1995). The earliest centenarians: A statistical analysis. In: Jeune, B. and J. W. Vaupel (Eds.), Exceptional longevity: From prehistory to the present, pp. 125-169. Odense: Odense University Press.

Wilmoth, J. R. (2000). Demography of longevity: Past, present and future trends. *Experimental Gerontology* 35 (9-10): 1111-1129.

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# Eidesstattliche Versicherung

Ich versichere eidesstattlich durch eigenhändige Unterschrift, dass ich die Arbeit selbständig und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Alle Stellen, die wörtlich oder sinngemäß aus Veröffentlichungen entnommen sind, habe ich als solche kenntlich gemacht. Ich weiß, dass bei Abgabe einer falschen Versicherung die Prüfung als nicht bestanden zu gelten hat.

Rostock, den 30.06.2005 Sven Drefahl