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„Mortality attributed to overweight and obesity among women and men in Germany“

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ASDR	Age-specific death rate
ASCDR	Age standardised crude death rate
BMI	Body mass index
BGS98	German Health Interview and Examination Survey (1998)
DALY	Disability adjusted life years
DEGS1	German Health Interview and Examination Survey (2008-2011)
DIW	German Institute for Economic Research
EU	European Union
GEDA	German Health Update
HR	Hazard ratio
OECD	Organisation for Economic Co-operation and Development
RKI	Robert Koch Institute
SOEP	Socio-economic panel
WHO	World Health Organisation
U.S.	United States of America

1 INTRODUCTION

The global prevalence of people living with obesity has tripled since 1975. Today, no country in the world is witnessing a decline in the prevalence of obesity (World Obesity Federation, 2023). The obesity epidemic reached Germany and developed over the last 30 years, rendering it the country with the highest obesity prevalence in the EU (Herold, 2021). The World Obesity Federation ranks the country in the highest obesity prevalence category (World Obesity Federation, 2023). Every second German is overweight and every fifth person is obese (Schienkiewitz et al., 2022).

Obesity is a risk factor for major diseases and death. Globally, obesity is the third highest ranking risk factor for disability adjusted life years (DALYs) after hypertension and smoking (Forouzanfar et al., 2015). The mortality risk due to obesity is compared to that of smoking in high-income countries (Adair & Lopez, 2020). At the age of 40, life expectancy is reduced by three years due to overweight and by seven years due to obesity (Peeters et al., 2003). 106,000 deaths were attributed to obesity in Germany in 2019. This ranks it fourth in the leading risk factors in Germany, after hypertension (high blood pressure), hyperglycaemia (high blood sugar) and smoking (Deggerich et al., 2023).

In Germany, overweight is more common among German men than women, whereas the prevalence of obesity is similar between the sexes (Schienkiewitz et al., 2022). Overweight and obesity increase with age. While overweight has remained stable at a high prevalence over the last 20 years in Germany, the prevalence of obesity has increased (RKI, 2015). The World Obesity Federation has projected the total prevalence of obesity to reach 36 % in Germany by 2035. This would be comprised of a prevalence of 42 % among men and 30 % among women (World Obesity Federation, 2023).

Smoking, alcohol consumption and overweight, including obesity, are three major public health challenges in Europe (OECD & European Union, 2022). While mortality associated with smoking and alcohol consumption has been explored to a great depth, mortality associated with overweight and obesity has not received as much attention. There is a distinct gender gap in mortality due to tobacco and alcohol consumption in most European countries. Men consume more and this contributes to the higher male mortality. However, women suffer more from the effects of overweight and obesity. 1 million additional years of life are lost to overweight and 1.89 million are lost to obesity in women in the U.S. 47,000 additional years of life are lost to overweight and 1.21 million are lost to obesity in men. At 18 years old, the life expectancy of normal weight and overweight men is similar whereas that of obese men is 2.7 years lower. In comparison, at 18 years old, overweight women live 1.1 years less and obese

women live 2.8 years less than women of normal weight (Muennig et al., 2006). Gender differences are genetic and socio-economic.

Mehta & Chang (2009) estimated weight attributable mortality for the U.S. using a nationally representative health survey. In the paper published in *Demography*, the authors find that 4 % of female and 3 % of male deaths in the U.S. can be attributed to obesity. This thesis implements a comparative approach for Germany using data from the nationally representative Socio-economic Panel (SOEP) data from the German Institute for Economic Research. Deaths according to weight status are modelled using survival curves. The effect of overweight and obesity on the risk of mortality are estimated by hazard ratios. These are translated into the overweight and obesity attributable mortality and excess deaths associated with the risk factors.

1.1 Definition

According to the WHO Regional Office for Europe (2022), overweight, including obesity, is defined as "*abnormal or excessive fat accumulation that presents a risk to health*". The WHO uses the concept of body mass index (BMI) as a standard health metric, taking into account a person's weight and height. A BMI over 25 kg/m^2 is considered overweight, and a BMI over 30 kg/m^2 is regarded as obese. Obesity is regarded as a chronic disease (Eknoyan, 2006). The WHO considers it to be a "*complex multifactorial disease*" (WHO Regional Office for Europe, 2022). While frequently being cited as a risk factor for other diseases and lower quality of life, obesity can also be a cause of death. Listed under endocrine, nutritional and metabolic diseases in the ICD-10, code E66 refers to the cause of death of obesity (WHO, 2016). Obesity can be categorised into two types: primary and secondary obesity. 95 % of patients have primary obesity, which is caused by genetic, behavioural and psychological factors. The term obesity refers to primary obesity in this thesis. Secondary obesity is rare and caused by endocrine disorders (Herold, 2021).

The body mass index (BMI), developed by Adolphe Quetelet in 1832, is the most frequently used tool to correlate the anthropometric assessment of body weight and height to health risks (Eknoyan, 2007). It is calculated as such,

$$BMI = \frac{w}{h^2}$$

where w is weight in kilograms and h is height in metres. Table 1 displays the category associated with each BMI range. An ideal BMI for most adults is in the range of 18.5 to 24.9 kg/m^2. A BMI below 18.5 kg/m^2 indicates underweight. A BMI of 25 to 29.9 kg/m^2 infers pre-obesity, while someone with a BMI of more than 30 kg/m^2 is said to be obese. Obesity is further grouped into obesity class I (30 <= BMI < 35 kg/m^2), obesity class II (35 <= BMI < 40 kg/m^2) and obesity class III (BMI >= 40 kg/m^2). Obesity class III is also referred to as morbid obesity. In this thesis, the term "non-overweight" is employed to refer to people with a BMI of less than 25 kg/m^2. This includes underweight individuals. Pre-obesity is also referred to as overweight. The term overweight is employed in this thesis. The obesity classes are grouped into one group with a BMI of at least 30 kg/m^2.

Table 1 Body mass index categorisation

BMI (kg/m^2)	**CATEGORY**
< 18.5	Underweight
18.5 – 24.9	Normal weight
25 – 29.9	Pre-obesity
30 – 34.9	Obesity
35 – 39.9	Obesity class II
>= 40	Obesity class III

Notes. Data source: WHO Regional office for Europe (2022)

75 % of excess body weight consists of adipose tissue (Herold 2021). A person with a high muscle mass may weigh more than average and therefore have a high BMI, which would falsely categorise them as overweight or obese. Nevertheless, BMI is used at the population level, rather than for an individual. When the BMI is aggregated for the population, it is more reliable. Alternative anthropometric tools are the waist circumference and waist-to-hip ratio. When confounders are controlled for, there is little difference between BMI and waist circumference in explaining health risks (Green, 2016). BMI is as good of a predictor of cardiovascular disease and type 2 diabetes as waist-to-hip ratio (Sperrin et al., 2016). BMI is a useful measure for large, representative samples and is more cost- and time-effective than waist circumference or other measurements in a large, representative sample (Green, 2016).

1.2 Gender differences

Women have a higher BMI than men on average. Women are, on average, smaller than men. The average height of German men is 178 cm whereas the average height of German women is 166cm (German Federal Statistics Office, 2023b). Men's height provides them with an advantage when the BMI is calculated. The difference in BMI is partially caused by sex differences in the deposition of fat when gaining weight. Women gain more fat whereas men gain more lean tissue, leading to women typically having more body mass as fat. This fundamental difference appears to be due to the diverging reproductive cost of the two sexes. Women needed more fat in the past to be able to bear children and breastfeed them (Power & Schulkin, 2008). Adiposity occurs in women when at least 30 % of the body weight is fat, whereas in men when at least 20 % of the body weight is fat (Herold, 2021). Another explanation for the sex difference in BMI is craving patterns. Craving is the strong desire to eat. Women have higher levels of craving than men. Craving is positively associated with weight gain, including obesity (Hallam et al. 2016). Most recently, researchers have found that epigenetic differences in the pro-opiomelanocortin (POMC) gene can lead to obesity in women (Lechner et al., 2023). POMC is involved in satiation. Women who have more methyl groups attached to POMC have a 40% increased risk of becoming obese. The authors did not find an increased risk for men.

Socio-culturally, women are more likely to overestimate their weight whereas men are more likely to underestimate their weight (Brug et al., 2006). Self-attitudes of women towards their weight are worse than those of men (Stake & Lauer, 1987). Overweight is not associated with poorer relationships for men whereas it is for women (Fikkan & Rothblum, 2012). Excess weight may have more negative consequences for women than for men.

1.3 Research gap and objective

Compared to tobacco and alcohol consumption, overweight is a lesser researched risk factor in Germany. The aim of this thesis is to understand weight attributable mortality among men and women in Germany over the period of 2002-2020. As far as I am aware, no one has used the Cox proportional hazard regression with age as the time scale to uncover mortality associated with overweight and obesity in Germany. Further, attributable mortality and excess deaths have not been calculated for German women and men separately.

Genetics result in different forms of fat storage for men and women. Social expectations and pressure on appearance and weight are borne more by women than by men. Unhealthy behaviours such as smoking and alcohol consumption are more common among men than women, although the gap is shrinking. It is useful to examine whether this is also the case for the risk factors overweight and obesity and how this relates to mortality. This can uncover the excess deaths of men and women from overweight and obesity. Prevention and treatment can then be targeted appropriately. The research aim leads to the central research question:

How does mortality attributed to overweight and obesity vary for women and men in Germany?

Three sub-questions will assist in answering this. Firstly,

a. *What patterns and trends are visible in German overweight and obesity?*

Secondly,

b. *How many excess deaths occur due to overweight and obesity for German men and women?*

And finally,

c. *How does weight attributable mortality differ between Germany and the U.S. in Mehta & Chang's (2009) study?*

1.4 Relevance

1.4.1 Scientific relevance

As obesity is a top risk factor for premature mortality in Germany, the topic should be studied to calculate the gains in longevity in the absence of obesity. This should provide a foundation for new recommendations to decrease premature deaths. These can be tailored by gender in case there are significant differences. Obesity has been a major issue in the U.S. for longer than it has been in Germany, with the U.S. being the developed country that has led the epidemic. Mehta & Chang (2009) estimated weight attributable mortality in the U.S. between 1992 and 2004 using the Health and Retirement Survey. This methodology of this thesis loosely follows Mehta & Chang (2009) and the results will reveal whether their findings hold true for Germany.

1.4.2 Societal relevance

Poor health and elevated mortality risk resulting from overweight and obesity do not only affect the individual but also the population as a whole. Direct costs consist of the financial costs for insurance and medical care. Medical care costs around 30 % more for obese patients (Withrow & Alter, 2011). In 1998 obesity led to costs of the equivalent of 11 billion euros in Germany (Bergmann & Mensink, 1999, as cited in Bellach, 1998). Today, this figure has risen to 63 billion euros (Deggerich et al., 2023). Indirect costs include the loss of labour productivity and eventually death. Gender-specific differences are relevant here as the working population is still dominated by men (German Federal Statistics Office, 2022).

1.5 Structure

The following thesis is structured as such. Omran's (1971) Epidemiological Transition acts as the theoretical framework for this thesis. After the framework is outlined, the present situation of obesity in Germany is assessed. The literature review provides information on the causes and consequences of obesity. Based on the data available from Germany and the literature review, hypotheses are drawn up. The data source and summary characteristics are described. The choice of data variable construction is defended, and the method is outlined. The results are then explored in the discussion, where limitations are addressed. Ultimately, the conclusion responds to the research question and suggests starting points for the future.

2 THEORETICAL FRAMEWORK

2.1 History of the Obesity Epidemic

In the Stone Age, weight was seen as a sign of fertility and wellbeing (Eknoyan, 2006). This link arose at least partially because famine and chronic malnutrition were persistent throughout most of history. Natural selection favoured humans with strong energy storage mechanisms for food reserves (Eknoyan, 2006). Eventually, the second Agricultural Revolution led to increases in food availability. The food demand was only met in the early 20th century in Western Europe, including Germany. The two World Wars and their aftereffects re-introduced food shortages. Following the Marshall Plan and Currency Reform in 1948, the German economy recovered and food supply was restored (Kesternich et al., 2014).

Strong energy storage mechanisms are no longer necessary and actually make individuals susceptible to obesity. Only in the last decades of the 20th century did overweight and obesity become problematic. Since then, however, it has worsened to become an epidemic.

With the start of the Anthropocene came a shift in the global food system (Willett et al., 2019). In an attempt to improve crop yield and reduce hunger in a rapidly growing global population, the global food system enabled the production of ultra-processed food (Temple, 2022). The price of ultra-processed food and food with high sugar contents decreased rapidly due to an increase in its manufacturing. Marketing tools were and still are employed to attract consumers to buy the unhealthy food (Swinburn et al., 2011). The obesity epidemic started in 1976 – 1980 in the U.S. and spread to high-income Western countries in the 1980s.

2.2 Epidemiological Transition

The Demographic Transition, based on Thompson (1929) and Landry (1934), describes how populations transform from high birth and death rates to low rates (Notestein, 1944). This transformation is driven by development and technologies of the Industrial Revolution, including improved nutrition and medical care. The Epidemiological Transition outlines the transformation from infective diseases and malnutrition to chronic and degenerative diseases in our societies alongside the Demographic Transition (Omran, 1971). The first phase is the *Age of Pestilence and Famine* where mortality was high due to malnutrition, famine and infectious diseases. This represents pre-modern societies. In the second phase, *The Age of Receding Pandemics*, mortality declines as countries develop. Epidemics become less frequent, thereby accelerating the decline in mortality. In the third stage, the *Age of Degenerative and Man-Made Diseases*, mortality reaches a low, stable level. This is characterised by non-infectious diseases, particularly degenerative diseases, cardiovascular disease, cancer and substance abuse. Cardiovascular disease, substance abuse and some forms of cancer are caused by individual behaviour patterns. Omran developed three versions of the model: the Classical/Western model, the accelerated model and the contemporary/delayed model. Germany is considered an example of the Classical/Western model. It underwent the Epidemiological Transition from the mid 19th to the late 20th century. Life expectancy increased with the Epidemiological transition.

Further increases in life expectancy were not anticipated in 1971 when Omran developed the Epidemiological Transition Theory. A fourth stage was appended to this model by Olshansky & Ault in

1986. The *Age of Delayed Degenerative Diseases* occurs where mortality is postponed to older age (Olshansky & Ault, 1986). This became possible in the Classical/Western model due to drug development, increased diagnosis and treatment and behavioural change. These developments have increased life expectancy further and decreased the number of deaths from cardiovascular disease. Germany may be placed in this position as life expectancy continues to increase and the number of deaths from cardiovascular disease has declined since the 1970s. However, cardiovascular disease remains the leading cause of death (German Federal Statistics Office, 2021).

The third stage of the Epidemiological Transition can be compared to the fourth stage in Popkin's (1993) Nutrition Transition, named similarly as the age of *Degenerative diseases*. Diets are unhealthy; they consist of high levels of fat and sugar but low levels of fibre and polyunsaturated fatty acids due to the shift in the global food system since the Industrialisation. Physical activity is low as a consequence of the Industrialisation and modernisation. The poor diet paired with a sedentary lifestyle enable degenerative diseases. The fourth stage of the Epidemiological Transition proposed by Olshansky & Ault (1986) resembles the fifth and final stage of the Nutrition Transition. The phase of *behavioural change* consists of a change in diet and regular physical activity to prevent or delay degenerative diseases and improve health and wellbeing. While the Epidemiological Transition model acts as a framework for this thesis, it does not elaborate on gender or sub-national differences, such as socio-economic factors. These nuances are explored in data from the German census and health surveys as well as in the body of literature.

2.3 Prevalence of overweight and obesity in Germany

The German micro census provides information on health for 1 % of the population each year. BMI data is collected every four years and is available starting in 2005. Table 2 shows the proportion of German women and men per BMI group over time. The underweight and normal weight categories were merged to form the non-overweight group. The level of underweight has remained between 3 and 4 % among German women. The proportion of non-overweight women decreased until 2013 when it rose. The proportion of overweight women increased before decreasing in 2013. Obesity has gradually become more prevalent among women. Among German men, the prevalence of underweight has remained below 1 %. The proportion of non-overweight men has decreased over time. The proportion of overweight men increased until 2013 before decreasing. As with women, the prevalence of obesity has increased among men. Normal weight is more prevalent than overweight among women whereas this

pattern is reversed among men. While overweight may have been decreasing or stagnating in the most recent years, obesity is on the rise for both sexes.

Table 2. Prevalence of BMI groups for different years, women and men

BMI group	Non-overweight (%)	Overweight (%)	Obesity (%)	Non-overweight (%)	Overweight (%)	Obesity (%)
YEAR	**WOMEN**			**MEN**		
2005	58.6	28.6	12.8	42.3	43.4	14.3
2009	57.4	28.9	13.7	40.1	44.2	15.7
2013	56.7	29	14.3	38.7	44.2	17.1
2017	56.9	28.5	14.6	38	44	18.1
2021	57.5	27.7	14.8	37.7	43.7	18.7

Notes: Underweight and normal weight categories are merged by author to form non-overweight group. Data source: German micro census 2021, German Federal Statistical Office.

Health patterns can be explored to a greater depth in surveys. Three national health surveys were carried out in the Federal Republic of Germany between 1984 and 1986, between 1987 and 1989 and between 1990 and 1991. In 1992 the healthy survey East (OW91) was appended to provide information about the population from states belonging to the former German Democratic Republic. In 1992 17.4 % of West German men and 19.6 % of West German women were obese. In comparison, levels were higher in East Germany. 20.6 % East German men and 25.8 % of East German women were obese. Obesity levels were higher among East Germans than West Germans immediately after the reunification, yet this difference has become insignificant since (Lampert et al., 2019). 67% of men and 53% of women were found to be overweight in 1992. The German Health Interview and Examination Survey (BGS98) was carried out between 1997 and 1999. The prevalence of overweight remained identical to the health survey findings from 1992. 18.9 % of men and 22.5% of women were obese in BGS98 (Mensink et al., 2013). Between 1992 and 1998, a decrease in obesity was witnessed among men and East German women whereas an increase in obesity was detected among West German women. A second wave of the Health Interview and Examination Survey (DEGS1) was conducted between 2008 and 2011. According to DEGS1, still 67.1 % of German men and 53.1 % of German women are overweight. 23.3 % of men are obese and 23.9 % of women are obese (Mensink et al., 2013). Most recently, the prevalence of obesity has increased for both sexes but by more among men than women. It seems that men are catching up with the women. The results from the health survey reveal a higher prevalence of overweight and obesity among German men and women than the results from the micro census.

Another health survey, the German Health Update (GEDA), has been running since 2009. Results from the most recent wave (2019/2020) state that 53.5 % of German men and 46.6 % of German women are overweight. 19 % of both women and men are obese. 13.2 % have obesity class I, 4 % have obesity class II and 1.8 % have obesity class III. The prevalence of overweight remained similar since 2012 whereas the prevalence of obesity increased by more than 2 percentage points for both sexes in this time period (Schienkiewitz et al., 2022). Currently 2 % of the German adult population is considered underweight, with 1% of men and 3% of women being classified as such (Schienkiewitz et al., 2022). Overweight is more prevalent among men than women whereas there does not seem to be a gender difference for obesity. Overweight increases with age for both men and women. Obesity also increases with age until around age 65. At mid-age (30-65) obesity is almost twice as common as at younger age (18-29) for women and more than twice as common for men (Schienkiewitz et al., 2022).

The GEDA findings are lower than the those from DEGS1 but higher than the micro census. Differences may arise due to the different samples as well as methodological choices. The German Health Interview and Examination Survey included anthropometric examinations of participants. In contrast, the German micro census and German Health Update rely on self-reporting of height and weight. BMI is systematically underestimated in self-reports due to the overestimation of height and underestimation of weight (RKI 2015).

Obesity is more prevalent in the U.S. than in Germany. At the time of their study, Mehta & Chang (2009) cite that 30% of American men and women are obese; 40% are considered overweight. The most recent estimates from the National Health and Examination Survey until 2017/2018 show that 42.5% of Americans are obese and 30% are overweight (Fryar et al., 2020). While the proportion of overweight Americans has decreased over time, the proportion of obese Americans has increased. This implies that the U.S. individuals have gained more excess weight over time, as a proportion of the overweight population has become obese.

2.4 Literature review

Only in the last half a century have researchers acknowledged overweight and obesity to be a disease (Eknoyan, 2006). In recent years some scientists have argued that overweight below the obesity threshold is not dangerous, and can actually have health benefits (Mehta & Chang, 2009). However, these findings are disputed (RKI, 2015). Differences in methodology, such as the treatment of age, the

inclusion of certain confounders and the period studied affect the results (Mehta & Chang, 2009). Causes and effects of overweight and obesity vary for individuals and are not yet fully understood, however, it is now undisputed that genetics, socioeconomic circumstances and behaviour play vital roles (WHO Regional Office for Europe, 2022).

2.4.1 Causes

The thrifty genotype hypothesis postulates that people with genes which predispose to adiposity used to have an advantage during periods of starvation and hunger. However, now that the food supply is always met in Western countries in the 21st century, people with these genes unnecessarily prepare their bodies with fat storage. Eventually this induces obesity (Smith & Ravussin, 2005). Young adults in Germany are most vulnerable to weight gain (Haftenberger et al., 2016). This is particularly problematic because it becomes more difficult to lose weight when it is accumulated at an earlier age (RKI, 2015).

Socioeconomic factors affect BMI. People with a lower socioeconomic position are more likely to be obese than people with a high socioeconomic position (Bann et al., 2017). International studies show the same pattern (Schienkiewitz et al., 2022). Hoebel et al (2019) analysed longitudinal data from the German national health examination surveys DEGS1 and BGS98. They found that the low and middle socioeconomic groups in Germany experienced a rise in obesity from 1990 until 2011 whereas obesity remained lowest and constant in the high socioeconomic group (Hoebel et al., 2019). Income had a significant effect for men whereas education had a significant effect for women. The GEDA 2019/2020 shows that the prevalence of obesity is always lowest in the high education groups and significantly lower than in the low education groups. At all ages, German men and women with the lowest level of education are more than 50 % more likely to be obese than the highest educated people. This pattern is not found among the overweight population. Comparing the results to the GEDA 2012 survey, there has been a widening in health inequalities in terms of BMI by education over time (Schienkiewitz et al., 2022).

Weight status is also influenced by behavioural factors. Calorie intake is too high among many overweight and obese individuals. The obesogenic environment, consisting of ultra-processed food and the food industry, contributes to the growth of overweight and obesity. The combined effect of smoking and obesity on health is particularly large. The all-cause mortality of obese smokers is 3.5 – 5 times higher than that of normal weighing non-smokers (Freedman et al., 2006). Lack of physical activity,

driven partially through the sedentary lifestyle of our modern world, adds to the overweight epidemic (WHO Regional Office for Europe, 2022). The COVID-19 pandemic and subsequent lockdowns led to increases in body weight and BMI (Bakaloudi et al., 2022). Weight loss due to calorie restriction and increased physical activity seems futile in most cases (Ochner et al., 2015). More than 80 % of Germans with obesity remain obese after 10 years (Haftenberger et al., 2016). The probability of reaching normal weight from obesity (BMI of 30-34.9) is 1 in 124 for women and 1 in 210 for men. In a 9-year longitudinal study in the UK 53 % regained their weight after 2 years and 78 % did so after 5 years (Fildes et al., 2015). These findings illuminate the difficulty of weight reduction in the obese population and underline that obesity is a chronic disease.

2.4.2 Consequences

Overweight and obesity are significant risk factors for many diseases. Based on a longitudinal study conducted over a period of almost 10 years in the UK, Reeves et al (2014) concluded that every 8th hospital admission may be attributed to overweight or obesity. This can be converted to an additional 420,000 hospital admissions and 2 million extra days in hospital per year (the Million Women Study Collaborators et al., 2014).

Cardiovascular disease (CVD) is the leading cause of adult deaths globally (Vos et al., 2020) and in Germany (German Federal Statistics Office, 2021). Almost 17 % of German cardiovascular deaths in 2019 could be traced back to obesity (Deggerich et al., 2023). The Global Burden of Disease collaborators estimate that more than 2/3 of deaths of individuals with high BMI are caused by CVD (The GBD 2015 Obesity Collaborators, 2017). The no-longer decreasing mortality rate caused by CVD at younger ages in some countries is strongly associated with higher obesity prevalence in younger cohorts (Adair & Lopez, 2020). The authors believe that overweight and obesity are the central reason for increasing cardiovascular deaths. Prolonged obesity worsens cardiac function (Abdelaal et al., 2017). Adipose tissue secretes cytokines known as adipokines, such as leptin. When these cell-signalling proteins are progressively expressed, they lead to low grade inflammatory state. This causes cardiovascular disease (Nakamura et al., 2014).

Obesity is the leading cause of type 2 diabetes (Herold, 2021). Globally, up to 83 % of cases of diabetes can be traced back to obesity (Flegal et al., 2015). Every third diabetes death in Germany is related to obesity (Deggerich et al., 2023). In the early 1970s Sims et al (1973) conducted an obesity experiment on

28 volunteers. The participants were of normal weight by BMI classification and did not have a family history of diabetes. They were overfed for six months. The researchers found that obesity was associated with an increase in blood insulin levels and a decrease in response to glucose – characteristics of diabetes. Type 2 diabetes and obesity are linked so strongly that a new term was created for the co-morbidity, namely diabesity (James et al., 2004).

Lipometabolic diseases can be induced by obesity. More than 60 % of hypertension (high blood pressure) may be attributed to obesity (Abdelaal et al., 2017; Hall et al., 2015). Hypertension increases the risk for type 2 diabetes and cardiovascular disease. Dyslipidaemia can lead to osteoarthritis and cardiovascular disease. Low density lipoprotein (LDL)-cholesterol is responsible for deposits in the blood vessels due to more cholesterol in the blood than is necessary for cells. High density lipoprotein (HDL)-cholesterol can prevent or reverse the build-up of deposits in the arteries. LDL levels should not be too high and HDL levels should not be too low (Richter, 2014). Metabolic syndrome refers to the combination of at least three of the following: abdominal obesity, hypertension, high fasting glucose (blood sugar), high levels of triglycerides and low levels of high-density lipoprotein cholesterol (Herold, 2021). One of these health conditions frequently leads to a multitude of conditions and diseases.

The rising global prevalence of obesity is frequently cited as the cause for the recent increase in obstructive sleep apnoea syndrome (OSAS) cases (Senaratna et al., 2017). Overweight subjects have a 2.6-fold higher association with OSAS than those of normal weight. This association is 10 fold higher for obese individuals (Tufik et al., 2010). OSAS lowers the oxygen concentration in the blood, thereby decreasing supply to the organs. This can lead to cardiovascular disease and premature mortality. 40 – 80 % of patients with hypertension and coronary heart disease have OSAS (Yeghiazarians et al., 2021).

Causal relationships between overweight and various types of cancer have been identified. Overweight increases the risk of colon, oesophagus, kidney and endometrial cancer and breast cancer in postmenopausal women (Bianchini et al., 2002). Sufficient evidence has been found since then to include prostate cancer (Herold, 2021). Overweight causes insulin resistance and hyperinsulinemia. This affects the secretion of hormones. Increases in plasma insulin, insulin-like growth factor I, free oestrogens and androgens, and decreases in insulin-like growth factor binding proteins and plasma sex-hormone binding globulin can lead to cancer (Bianchini et al., 2002). Up to 8 % of all-cancer incidence can be attributed to obesity (Flegal et al., 2015). Every 10^{th} cancer death of non-smokers is linked to obesity (Haslam & James, 2005). According to estimates by the International Agency for Research on Cancer 30 % of breast, colon, endometrium, kidney and oesophagus cancers are attributed to

overweight and physical inactivity (International Agency for Research on Cancer, 2002). The WHO estimated that 30 % of cancer deaths could be avoided by limiting the risk factors of smoking, alcohol use, overweight and physical inactivity (RKI, 2015).

Higher bodyweight negatively affects the joints. Increased weight adds pressure on the joints. Excess fat facilitates cartilage loss, leading to further joint pain (Herold, 2021). The knee and hip are two common causes of concern. Obesity increases the risk of osteoarthritis by 6.8 times from that of normal weight (Coggon et al., 2001). Swedish researchers have found that there is already a four-fold risk of knee osteoarthritis for men with BMI between 23 and 25 kg/m^2 compared to men with BMI below 23 kg/m^2 (Holmberg et al., 2005). The odds ratio is 1.6 for women in the same BMI interval. This means that even people in the higher end of the normal BMI category face a higher risk of illness.

Overweight and obesity increase the risk of infertility. This is the case for primary infertility (never having been pregnant) and secondary fertility (having been pregnant at least once). Polycystic ovary disease is the most common cause of infertility. It is more common among obese women (Cogswell et al., 2001). Maternal obesity also increases the risk of early pregnancy loss and birth defects (Power & Schulkin, 2008).

COVID-19 is a novel critical illness which is more severe and fatal for obese than non-obese patients (Singh et al., 2022). The authors ran numerous analyses; the multivariate analyses identified that a BMI greater than 30 kg/m^2 increased the odds ratios for severe COVID-19 by 2.09. The odds ratios were 2.36 for hospitalisation, 2.32 for intensive care requirement, 2.63 for invasive mechanical ventilator support and 1.49 for mortality. While age is associated with COVID-19 severity, obesity may disturb this trend. (Kass et al., 2020) found that younger COVID-19 hospital patients were more likely to be obese.

2.4.3 Survival and mortality

Obesity as well as the diseases caused by overweight and obesity can be fatal. A BMI greater than 35 kg/m^2 doubles the mortality risk of someone with a normal BMI (Herold, 2021). As mentioned earlier, the effect of overweight on health is disputed. Herold (2021) suggests that there is no increased risk of death for individuals with a BMI between 25 and 29.9 kg/m^2. The risk of death increases when the excess weight exceeds 20 % of the normal weight. Danish researchers found that the BMI associated with the lowest mortality has increased from 23.7 kg/m^2 in the period 1976 – 1978 to 27 kg/m^2 in the period 2003 – 2013 (Afzal et al 2016). This means that overweight individuals would have a lower risk of

death than normal weight individuals. Two reasons for this are the movement towards preventive health care and the development of blood pressure regulating medication in the last 50 years. Regular health check-ups are possible and encouraged. Individuals with high blood pressure caused by obesity can get medication which regulates their blood pressure. While replicating Afzal et al's (2016) findings for the U.S., Wang et al (2017) suggest that the increase in BMI associated with the lowest mortality is influenced by different durations in follow-up in each survey period. This comment gives rise to the importance of methodological choices. Mehta & Chang (2009) comment on divergent results of weight-attributable mortality studies in the U.S. The authors indicate that the diverse findings arise due to the use of different data sources and methodologies.

Based on 1.46 million adults in the U.S, Berrington de Gonzalez et al. (2010) found a J-shaped relationship between BMI and all-cause mortality. Mortality is high for underweight, lowest at normal BMI and then increases exponentially from overweight to obesity grade III. The authors calculate hazard ratios for BMI groups. Hazard ratios (HR) are commonly employed in survival analysis to assess the effect of different groups on the outcome. Similar to odds ratios, a HR greater than 1 suggests that the group has a higher hazard rate than a chosen reference group, and thus a lower chance of survival. A HR less than 1 suggests that the group has a lower hazard rate and is favourable. In most cases the normal weight group (BMI 18.5 – 25 kg/m^2) is chosen as the reference group as this is considered the ideal BMI by the WHO. The authors estimated that HR are 1.13 for overweight individuals, 1.44 for obese class I, 1.88 for obese class II and 2.51 for obese class III. These findings suggest that the risk of death increases with BMI. In their representative longitudinal study of weight-attributable mortality in the U.S., using data from the Health & Retirement study (1992 – 2004), Mehta & Chang (2009) determined HR above 1 only for obesity class II and class III. HR for overweight and obese class I men were below 1. Linking BMI data from the U.S. National Health and Nutrition Examination Survey (1988 – 1994) to the National Death Index until 2006, Borrell & Samuel (2014) noticed differences between women and men. All-cause mortality rates were lower among overweight and grade I obese men than among normal weight men. Mortality rates were higher in individuals with grade II and grade III obesity. Contrastingly, mortality rates for all excess weight groups, including overweight and grade I obese, were higher than for normal weight women.

Research into the effects of overweight and obesity on mortality started in the U.S. where the obesity epidemic started. In comparison, research on the relationship between BMI and mortality remains relatively sparse in Europe. Bellocco et al (2010) followed 14,585 men and 26,144 women from the

Swedish National March cohort (1997 – 2007) after they filled out a detailed questionnaire about health and anthropometric measures. The authors found that overweight women had a HR of 1.02 and obese women had HR of 1.35. The HR for men were higher. Overweight men had a HR of 1.12 and obese men had a HR of 1.62. The authors also investigated the effect of the measures waist-to-hip ratio (WHR) and waist circumference (WC) on mortality. They concluded that BMI was a better predictor of all-cause mortality in men whereas waist circumference was a better predictor in women. This could relate to the gender differences in the deposition of fat in weight gain. Women are more likely to gain weight around their lower body to prepare for childbearing. True adiposity can then be measured by the waist which is where adipose tissue primarily builds during excessive weight gain.

2.4.4 Attributable mortality and excess deaths

Based on a meta-analysis, Flegal et al. (2015) find that 5 to 15 % of all-cause mortality can be attributed to obesity. Peeters et al (2003) investigate the relationship between BMI and life expectancy using data from 40 years of follow-up from the famous Framingham Heart Study. In the first step, the authors model survival functions of different BMI groups. The authors find that the survival probability of non-overweight men and women is higher than that of overweight and obese individuals, apart from in the first 20 years of follow-up where overweight male smokers have a higher survival probability than non-overweight male smokers. These findings contradict Mehta & Chang (2009) in that overweight reduces survival compared to non-overweight. However, Peeters et al (2003) does not control for age. Non-overweight individuals tend to be younger and thus have a higher survival probability. Muennig et al. (2006) estimated deaths attributed to obesity from the 1990-1992 National Health Interview Survey in the U.S. This data was linked to the National Death Index until the end of 1995. The authors recorded 37,000 additional deaths for overweight women and 70,000 additional deaths for obese women, compared to non-overweight women. 15,000 additional deaths were recorded for overweight men and 42,000 additional deaths were recorded for obese men, compared to non-overweight men.

2.5 Hypotheses

The results from the German health data and body of literature guide the following expectations. I expect that the prevalence of obesity of German women and men is higher than in the 1990s and that the prevalence of overweight remains equally as high as in the 1990s as the country remains in the third

stage of the Epidemiological Transition and appears to not make significant progress towards Olshansky & Ault's (1986) proposed fourth stage. The prevalence of overweight and obesity should increase with age until old age where it should decrease due to frailty. In line with the results of the German health surveys, I predict that more men will be overweight than women whereas marginally more women will be obese than men.

Based on the findings by Mehta & Chang (2009) and Borrell & Samuel (2014), I hypothesise that a significant number of deaths can be attributed to obesity. I expect that the obesity-attributable mortality is higher among women than among men given that obesity is more prevalent among German women than men and that women carry a larger burden of disease attributed to overweight and obesity (Muennig et al., 2006). I do not expect that any mortality is attributed to overweight for men. Some mortality may be attributed to overweight among women, again based on Muennig's (2006) findings. In concordance with the attributable mortality, I expect that obesity results in excess deaths in Germany, both for men and women. Though, more excess deaths occur among women than among men. I predict that overweight does not cause excess deaths among men and even that overweight may cause fewer deaths than non-overweight among men but more among women. Finally, I hypothesise that the number of deaths attributed to obesity in Germany is lower than the number of deaths attributed to obesity in the U.S. by Mehta & Chang (2009) due to the lower prevalence of obesity in Germany.

3 DATA

3.1 Data source

All data stems from the representative longitudinal German Socio-Economic Panel (SOEP). The study is conducted by the German Institute for Economic Research (DIW). Every year, around 30,000 individuals participate in the surveys by SOEP. Data has been collected in West Germany since 1984 and in East Germany since the reunification. Data collection is still ongoing; however, the version used for this thesis (SOEP core v.37) follows up until 2020 (DIW, 2022). Data use is free of charge for university students for research purposes given that the accompanying Professor applies for the data files in the name of the student. A data distribution contract is signed. The data is not shared and will be deleted after successful completion of the project.

Using data from the representative longitudinal study makes it possible to presume with a high level of confidence that the results hold for the German population in spite of heterogeneity. Thus, no adjustment or weighting of the sample is necessary. The use of longitudinal data is beneficial for this thesis as the mortality risk which accumulates over time with continued overweight or obesity can be tracked.

Numerous data sets are used for this thesis. Data is anonymised; no names are recorded. Linkage between the data sets is possible through a unique participant ID. The *ppathl* data set is the person-related meta-data set which is the "*building block of any analysis*" using SOEP data (SOEP Group, 2021). Basic demographic information is stored here, including sex, partner status, year of birth, year of death (if applicable). Data is available from 1984 to 2020. The *lifespell* data set complements this by capturing the last known date of contact with participants who did not die. The *pl* data set stores data from the individual questionnaire from 1984 until 2020. Not every question is asked in the interview every year for time and financial reasons. Individuals are allowed to participate from age 18 onwards. The *pequiv* data set provides the *age* of the interviewee, *level of education* (less than high school, high school and more than high school), *number of years of education*, *number of household members by age* and *net household income*. The measure *equivalised disposable income* was suggested by the OECD and adopted by the EU. It assumes that an increase in the number of household members decreases per capita expenditure, and that the cost of children is lower than that of adults (Hagenaars et al., 1994). It is calculated by dividing the net household income by the number of household members where the first adult has a weight of 1, any further adults and children over the age of 14 have a weight of 0.5 and children under 14 have a weight of 0.3. The *health* module records the participant's weight and height. The BMI is calculated using the appropriate formula and provided in the dataset. This data has been recorded bi-annually by SOEP since 2002. The *health* module of the individual questionnaire was updated in 2002 to apply the internationally accepted SF-12 indicators. The SF-12 health survey is a brief and reliable tool to measure overall health status (Andersen et al., 2007). General health, physical health and mental health are tested.

3.2 Descriptive characteristics

41339 individuals are included in this analysis of whom 21,226 (51%) are women and 20,113 (49%) are men. Their descriptive characteristics are displayed in Table 3. 434 women and 86 men are underweight. Due to the low number of cases, these are recorded in the group non-overweight alongside normal

weight individuals. Most women have a BMI between 18.5 and 25 kg/m^2 whereas most men have a BMI between 25 and 30 kg/m^2. The prevalence of obesity is equal between the sexes. The mean age at entry is 50 years for both men and women. The median age at entry is 47 years for women and 48 years for men. On average women spent 7 months more in the study with 8.4 years compared to 7.8 years for men. The median time spent in the study is 8.9 years for women and 8.4 years for men.

More women are single than men and being in any type of partnership is more prevalent among men. For both sexes, marriage/registered partnership is the most common form of partner status. Numerous studies have shown that married people have the highest wellbeing, whereas single, divorced and widowed people have a lower wellbeing. This effect is more pronounced for men (Waite, 1995). This is transformed onto a lower mortality risk. Married people are more likely to adopt healthy behaviours and seek preventive care and medical appointments.

Women tend to have a lower level of education and income than men. More women than men have less than or no more than a high school degree whereas more men than women have more than a high school degree. Having a high school degree is the most common level of education for both men and women. More than half of the individuals have a high school degree. The mean equivalised disposable income is more than €3,000 less for women than men with an annual income of €21,538 and €24,581 respectively. The gender difference is halved for median equivalised disposable income with a median annual income of €17,533 for women and a median annual income of €18,820 for men. This aligns with analyses from other socio-economic panel data from Germany estimate that the median household income in Germany after taxes was €17,201 in 1991 and €19,692 in 2010 (*Einkommensverteilung*, 2020). In comparison, analyses from EU-SILC (European Statistics on Income and Living Conditions) data for the same year estimate that the median household income was €19,186 for men and €18,448 for women. The mean household income was €21,937 for men and €21,018 for women (*Einkommensverteilung (Nettoäquivalenzeinkommen) in Deutschland*, 2022). The median equivalised disposable income is lower than the EU-SILC estimate of 2010. However, data is collected from 2002 onwards in this thesis. As most individuals joined in that year and the income data is extracted from the first interview, the income data is skewed to 2002. Income was lower in Germany in 2002 than in 2010.

Table 3. Descriptive characteristics, SOEP participants 2002 – 2020

VARIABLE	WOMEN		MEN	
N	21,226		20,113	
BMI group				
Non-overweight	10,982	(51.7 %)	6,917	(34.4 %)
Overweight	6,493	(30.6 %)	9,421	(46.8 %)
Obese	3,751	(17.7 %)	3,775	(18.8 %)
Age at entry				
Mean	50.0		50.2	
Median	47.0		48.0	
Time in study (years)				
Mean	8.4		7.8	
Median	8.9		8.4	
Partner status				
Single	5,431	(25.6 %)	3,195	(15.9 %)
Partner	1,940	(9.1 %)	2,273	(11.3 %)
Married/registered partnership	13,855	(65.3 %)	14,645	(72.8 %)
Education				
Less than high school	3,803	(17.9 %)	2,319	(11.5 %)
High school	12,371	(58.3 %)	11,575	(57.5 %)
More than high school	5,052	(23.8 %)	6,219	(31.0 %)
Equivalised disposable income (€)				
Mean	21,538.44		24,581.54	
Median	17,533.19		18,819.62	
Frequency of physical activity				
Never	9,143	(43.1 %)	8,051	(40.0 %)
Rarely	2,937	(13.8 %)	3,400	(16.9 %)
Once a month	1,029	(4.9 %)	1,305	(6.5 %)
Once a week	7,099	(33.4 %)	6,315	(31.4 %)
Daily	1,018	(4.8 %)	1,042	(5.2 %)
Smoker status				
Non-smoker	15,999	(75.4 %)	13,517	(67.2 %)
Smoker	5,227	(24.6 %)	6,596	(32.8 %)
Level of general health				
Low	3,977	(18.7 %)	3,080	(15.3 %)
Medium	15,299	(72.1 %)	14,883	(74.0 %)
High	1,950	(9.2 %)	2,150	(10.7 %)
Satisfaction with health				
Very low	1,069	(5.0 %)	889	(4.4 %)
Low	2,121	(10.0 %)	1,784	(8.9 %)
Medium	5,017	(23.6 %)	4,342	(21.6 %)
High	8,240	(38.9 %)	8,512	(42.3 %)
Very high	4,779	(22.5 %)	4,586	(22.8 %)
Deaths	1,389	(6.5 %)	1,738	(8.6 %)

Notes: Own groupings. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

Most people never engage in physical activity. 1/3 of women and almost 1/3 of men exercise once a week, which is considered the healthiest option. Daily exercise may be a form of overexercising. More women never exercise than men, however more men than women exercise rarely or once a month. More women than men exercise once a week and marginally more men than women exercise daily. ¼ of women smoke whereas 1/3 of men smoke. Almost ¾ of women and men have a medium level of general health. Most women and men rate the satisfaction with their own health as high, followed by medium for women and very high for men. 5% of women and less than 5% of men rate their health satisfaction as very low. 1,389 female deaths and 1,738 male deaths are recorded. This translates to 7 % of the female sample and 9 % of the male sample.

3.3 Censoring

To investigate mortality, survival time is measured from birth to death for an individual. In this thesis a minimum age of 30 is required as it is assumed that BMI no longer fluctuates greatly as it could in earlier years of life when the metabolism is faster. Nevertheless, this thesis considers entry of survey as the starting point, as opposed to birth. As the health module began in 2002, the 01/01/2002 is chosen as the starting point of data collection. The end point is the 31/12/2020 up to which data is collected by this version of SOEP. The study time, namely the calendar time period in which an individual is in the study, is not identical to the participant time which is the period of time which the participant spends in the study, measured from each participant's perspective. The study period consisted of a total of 19 years (2002-2020). The time-to-event variable, t is age in the study and is measured from the time origin *age at survey entry* to the endpoint *age at death* or *age at end of survey*.

Right censoring occurs when a participant exits the study, or the study ends before the event has occurred. In this thesis, right censoring occurred as some participants dropped out of the study or were lost to follow-up, e.g., migration. Other participants were still alive at the end of the study period. They were classified as censored on the last date. All censored cases were assigned a status of 0. Deaths were assigned a status of 1. Censoring is assumed to be non-informative. This suggests that people drop out of the survey randomly and not for a specific reason which would distinguish them from people who do not drop out. A SOEP-wide mortality follow-up was conducted in 2008/9 to find out whether participants who were lost to follow-up died. Left-censored cases are those which occurred at some point before the study started. Participants who died before 2002 did not have the chance to record their BMI as this variable was only collected in the *health* module from 2002 onwards. The study is

restricted to participants who entered in the year 2002 or later. Retaining people who entered the survey before 2002 and lived beyond 2002 could cause bias as it is unknown whether those who died before 2002 had a different BMI distribution to those who survived. Since the data originates from a panel data set where participant recruiting is ongoing, the start point could be anywhere between 2002 and 2020. Late entry is not problematic because the time-to-event is age, not study time. Of the total 41,339 individuals, 43% were recruited in the start year 2002. More than 75% of individuals were recruited within the first 10 years.

3.4 Data variable construction

Due to the wide coverage and panel structure of SOEP, not every individual participates in all surveys every year. This leads to a large number of missing values. Cases with any missing values were excluded (n = 116,446). Due to the lack of annual data collection of variables, an analysis with time-constant covariates is conducted. This means that only one value per variable is required for each individual. The variable *level of education* does not require any construction based on the assumption that education is completed by age 30, the minimum age for inclusion in this analysis. For all other variables, the first recorded value is selected. Where possible day, month and year data columns are merged to form date variables. When there is no day or month available, the midyear date *30/06/xxxx* is adopted.

BMI groups are formed based on the international classification, described in Table 1. Obesity classes are merged into one (BMI > 30 kg/m^2) due to the low number of cases of obesity class III (n = 555). Underweight individuals are merged with the normal weight individuals to form a non-overweight group (BMI < 25 kg/m^2) due to the small number of underweight cases (n = 520). The low number of underweight cases is expected as the percentage of underweight Germans stands at 3% for women and 1% for men (Schienkiewitz, 2022). In a separate attempt underweight individuals are excluded entirely from analysis. Results resemble those which include underweight. BMI is also tested as an interval variable. A higher BMI is associated with a 2% increase in mortality for men and a 3% increase in mortality for women ($p < 0.001$). After excluding underweight individuals, the HR remain the same. However, categorical BMI groups are chosen for this thesis in order to assess differences between non-overweight, overweight and obesity. *Age* is kept as an interval variable as it is used as the time scale.

Partner status is collected as a categorical variable by SOEP with six answer options: *single; partner; probably partner; married/registered partnership; probably married/registered partnership; unclear*.

Three individuals who had an unclear partner status were removed from the analysis. Due to the low number of cases of people who are *probably married/registered partner* and *probably have a partner* for both men and women (n < 40), these were incorporated into the groups *married/registered partner* and *partner* respectively. The difference between the two scenarios is that in the former case, the partner status is not verified by the other partner. However, both partners do not necessarily take part in SOEP. It is reasonable to believe that when one person says they have a partner, this is true. Unfortunately, the dataset does not provide details on separation, divorce or widowhood. In place of partner status, Mehta & Chang (2009) include the variable marital status in their analysis. The four answer categories are *married; never married; divorced/separated;* and *widowed*. The authors also include the variable race/ethnicity. The National Institutes of Health Act of 1993 requires that minority groups are represented in study samples in the U.S (Sheikh et al., 2004). While there are migrant-specific questionnaires in SOEP, the core sample does not ask for race/ethnicity. A different factor that may be relevant in the context of the country, is location before German reunification. Before 1989, mortality was higher in East Germany than in West Germany but recently East Germany has caught up (Grigoriev et al., 2021). Disparities remain in male cohorts born between 1950 and 1970. As SOEP began before the reunification in 1990, a location variable is included to account for participants' location of residence in the year 1989. Three categories: *East Germany; West Germany*; and *abroad* are provided. The variable location is statistically insignificant and therefore not included in analysis. This is supported by Bergmann & Mensink (1999, as cited in Bellach, 1998) who suggest that weight differences within Germany are no longer caused by the East-West divide but by socio-economic factors.

Education with respect to high school is as an ordinal variable with 3 categories: *less than high school; high school;* and *more than high school*. This allowed for more distinctions than the interval variable *years of education*. Further, years of education is an American system which is not as straightforward in Germany as a person can graduate high school after 10 years and have a technical degree after 12.5 years whereas another person can finish high school in 13 years and not have pursued a post-secondary degree yet. Mehta & Chang (2009) also use categories based on highest achieved degree, although in a slightly different format. Four answer categories are *no high school diploma; high school diploma; some college;* and *college degree*. Equivalised disposable income is tested in numerous forms: income in 10,000 Euros, logarithmic income, quartiles, terciles, using a deviation from the median, and the poverty mark. The marginal effect of 1 Euro is negligible. Measuring income in 10,000 Euro amplifies the effect of income to make it visible in the coefficient. It is then used as an interval variable which shows a negative association with mortality. In their 2009 study, Mehta & Chang use the logarithm of income.

Logarithmic income is used to give a more normal distribution. However, as there are people who have an income of 0 in the present study, this led to errors. Using ordinal classifications proved to be the best option. The low income rate (German: *Niedrigeinkommensquote*) states that anyone who earns less than 70% of the median income has a low income and that anyone who earns more than 150% of the median income has a high income. This results in an ordinal variable with three groups. All are again insignificant for women. Another template that is used is income poverty (German: *Einkommensarmut*). Anyone who earns less than 60% of the median income has a low income and anyone that earns more than double of the median income has a high income. With this classification, women with median income have a significantly higher hazard rate than women with a high income. As expected, income is more important for men than for women. Quartiles were tested by splitting income into groups. In the case of four groups, the two highest had the same HR for men. Further, the effect of income is insignificant for women due to clustering around the mean. Therefore, terciles were deemed a good fit.

The variable physical activity is kept in the provided format with the five ordinal categories: *daily; once a week; once a month; rarely;* and *never*. In comparison, Mehta & Chang (2009) use a dummy variable specifying vigorous physical activity, which is measured as three or more times per week. Concerning smoking behaviour, Mehta & Chang (2009) arrange five categories: *never smoker; former smoker; smoking less than one pack per day; smoking one to two packs per day;* and *smoking more than two packs per day*. In this thesis, smoking is kept as a dummy variable. The individual survey by SOEP has more detailed questions on smoking behaviour, such as how many cigarettes a person smokes per day or whether non-smokers are former smokers. However, the respondents did not participate in the health module, meaning there is no BMI data available for them.

Further behavioural factors that influence mortality which Mehta & Chang (2009) did not include in their study are nutrition and alcohol consumption. Nutrition is investigated in SOEP by one question: "*Do you follow a health-conscious diet?*" biannually from 2004 until 2014. Four answer options are *yes, very strictly; yes, strictly*; *somewhat* and *no*. 30,468 cases (14,333 men and 16,135 women) and 2,749 (1,522 male and 1,227 female) deaths were recorded for the variable. The data is used as a sensitivity analysis and commented on in the discussion. Alcohol consumption is another behavioural risk factor for mortality. Data on alcohol consumption is limited in the dataset. An attempt is made to include the answers to the following question: "*How often do you drink the following drink: Beer, wine and champagne, spirits and mixers?*", which was asked in 2006, 2008 and 2010. The four possible answer categories are *regularly; from time to time; rarely* and *never*. To interpret the results it would be

essential to know much alcohol is consumed on these occasions. Further, the answer categories are vague and subjective. Drinking once a day could be considered regularly for one individual whereas drinking once a week could be considered regularly for another one. Nevertheless, wine and beer consumption are included in the model as a sensitivity analysis and briefly mentioned in the discussion. Too few cases were recorded to include mixer and liquor consumption. Regular liquor consumption was very rare among women and men: n = 30 and n = 128 respectively. 20 cases of regular mixer consumption were recorded for men and 19 cases of regular liquor consumption were recorded for women. Including responses on alcohol consumption limited the number of cases to 9,026 men of whom 1,047 experience death and 9,752 women of whom 797 experience death.

The ordinal variable *satisfaction with health* is rated on a scale from 0 – 10. This is grouped into 5 categories ranging from *very low, low, medium, high* to *very high*. Health measures from the SF-12 were rounded and categorised into three categories: *low, medium* and *high*. These depended on the minimum and maximum attainable values per indicator. The variables general health and physical functioning yielded similar results. General health is chosen as the measure used in analysis because it is a holistic measure that is most commonly used. Mental health had no statistically significant effect and is therefore excluded.

4 METHODOLOGY

Demographic methods to study mortality include age-standardised death rates and survival analysis. Survival models are used to model time-to-event phenomena. As the aim of this thesis is to investigate weight attributable mortality, the event is death. Kaplan-Meier curves are drawn to visualise the survival function of the studied population by sex and BMI group. Secondly, a Cox proportional hazard model is implemented as a regression model. Here, the effect of BMI and covariates on mortality is estimated. HR compare the probability of an event occurring between groups.

4.1 Age-standardised death rates

Death rates are analysed for BMI groups for women and men. Equation 1 denotes the crude death rate (CDR), which is the sum of age-specific death rates (ASDR).

$$CDR = \sum_{i=1}^{\infty} \frac{D_i}{N_i} \frac{N_i}{N} \quad (1)$$

Where $\frac{D_i}{N_i}$ refers to the number of deaths divided by the number of people in each age group and $\frac{N_i}{N}$ refers to the proportion of people of each age group. This can be summarised as

$$CDR = \sum_{i=1}^{\infty} M_i \; C_i$$

Where M_i is the age-specific death rate of the population and C_i is the proportionate age distribution of that population (Preston et al., 2001).

Age-standardised crude death rates (ASCDR) are calculated to account for the differing age compositions of male and female BMI groups. The age distribution of the German standard population 2011 is chosen for this as it is the most recent national standard population provided by the German Federal Health Monitoring System based on the German census of 2011 (Information System of the Federal Health Monitoring, 2011). More recently in 2013 the European wide standard population was updated by WHO, yet this includes all European countries, making it less suitable for this country-specific analysis. The total population, rather than that of women and men separately, is used to be able to compare the difference between the sexes. The age-standardised crude death rate is given by the formula:

$$ASCDR^j = \sum_{i=1}^{\infty} M_i^j \; C_i^s \quad (2)$$

Where M_i^j is the age-specific death rate of population j and C_i^s is the age-specific population weight of the standard population s. The German standard population is available for 5 year age intervals until age 90, after which the category 90+ is established. In order to compare to this, the single age death rates and population from the SOEP data are summarised into 5 year intervals. The individuals older than 90 are grouped into a final age group. Data from the standard population is restricted to age 30+ for methodological reasons, explained in Section 3.3.

4.2 Survival modelling

Survival analysis models time to event data. The outcome is the change in probability of survival over a time scale. Survival modelling requires two fundamental concepts: the survival function and the hazard rate. Other statistical models cannot handle time-to-event data due to the right censoring (Kleinbaum & Klein, 2012). The survival function expresses the probability that the event of interest has not yet occurred by a given time point. It is usually plotted as a survival curve. This can be programmed as such:

$$S(t) = P(T > t) \tag{3}$$

where $S(t)$ is the survival function, T is the survival time and t refers to a chosen point in time. In this case, the date of death is the time point. $S(t)$ gives the expected proportion of individuals for which the event has not yet happened by time t (Kleinbaum & Klein, 2012). The survival function decreases from 1 towards 0 because more individuals die as t increases. In most longitudinal studies, $S(t)$ will not reach 0 as the entire study population would have to be followed until their death. Time and financial constraints as well as the late publication of the results prohibit this.

The hazard rate refers to the probability of the event occurring at time t. It states the chance of experiencing the event at time t for individuals who have not yet experienced it (Kleinbaum & Klein, 2012). Also referred to as the conditional failure rate, the hazard rate can be computed in the following way:

$$h(t) = \lim_{\Delta t \to 0} \frac{P(t \leq T < t + \Delta t \mid \mathrm{T} \geq \mathrm{t})}{\Delta t} \tag{4}$$

where the numerator is the conditional probability that an individual's survival time T is between t and $t + \Delta t$, if the individual's survival time is greater than or equal to t. The denominator is a short time interval, which turns the probability into a rate. Taking the limit of the expression as time approaches 0 yields the instantaneous potential for failing at time t per unit time, if survival up to time t is reached (Kleinbaum & Klein, 2012). With natural ageing, increasing hazard rates are expected due to the increase in mortality. Unlike the survival function, the hazard rate does not necessarily decrease over time. The hazard rate is used within the Cox proportional hazards model which will be explained in Section 5.2.2.

4.2.1 Kaplan-Meier

The survival probability changes when a person in the population experiences the event. For this thesis this means that the survival probability changes when an individual dies. This creates the step-like shape in the Kaplan-Meier curves where each step represents a death. Contrary to some Kaplan-Meier curves, the steps are clearly visible in this thesis because the exact date of death, and for some individuals the exact date of birth is unknown. When only the year of birth and death are available, the mid-year date is used. Once a year, at mid-year, all individuals who die that year have their step marked, rather than on other days throughout the year.

Survival time is usually not normally distributed. Oftentimes the distribution is right-skewed as participants are lost to follow-up. For this reason, a non-parametric estimator is suitable. The Kaplan-Meier estimator, developed by Kaplan & Meier (1958) is the most frequently used method. Survival is measured as such:

$$\hat{S}(t) = \prod_{i:t_i \leq t} \left(1 - \frac{d_i}{Y_i}\right) \tag{5}$$

Where d_i are the deaths at time t_i, Y_i are the number of people at risk at time t_i which includes all individuals who are alive until just before time t_i. $\frac{d_i}{Y_i}$ estimates the conditional probability that an individual who survives to just before time t_i, dies at t_i. In consequence, $1 - \frac{d_i}{Y_i}$ estimates the probability that an individual who survives to just prior to time t_i survives at time t_i. The product of the survival probabilities at each point in time yields the estimated survival function $\hat{S}(t)$ (Kleinbaum & Klein, 2012).

Survival curves are calculated by sex. In a second calculation, the curves are modelled by BMI group for women and men. Age is used as the time scale, rather than time, in order to account for the confounding effect of age on mortality. The non-parametric log-rank test is chosen to test for significance as it compares the survival curves of multiple groups simultaneously and handles censored data, both of which are not possible when applying the Wilcoxon test, an alternative popular test for the Kaplan-Meier estimator (Kleinbaum & Klein, 2012).

4.2.2 Cox regression

Further survival analysis is conducted with regression modelling. A regression model can help to understand the relationship between covariates over time (Kleinbaum & Klein, 2012). It resembles a simple linear regression. The Cox proportional hazard model, named after its creator, Sir David Cox, is the most frequently used method to model the relationship of covariates to the hazard rate. This allows comparison of the survival outcomes of the covariate patterns. In its basic form the model can be written as:

$$h(t, Z) = h_0(t) e^{\sum_{i=1}^{p} \beta_i Z_i} \tag{6}$$

Z refers to the explanatory variables. h_0 is the baseline hazard rate; it is non-parametric. β_i is the coefficient of each covariate Z_i. A parametric form is assumed for the covariate effects. e^{β} refers to the HR. The HR between covariates is assumed to be constant over time in the Cox proportional hazards regression. This means the hazards are proportional. Schoenfeld residuals can be implemented to test the assumption of proportional hazards. If the proportional hazards assumption is met, Schoenfeld

residuals are not related to survival time (Kleinbaum & Klein, 2012). The residuals are calculated by subtracting the expected values of each covariate from the observed values (Moore, 2016).

HR are estimated using the semi-parametric Cox proportional hazard regression, using age as the time scale, while estimations with time are provided in the appendix. Six models are calculated, loosely based on Mehta & Chang (2009). Firstly, an unadjusted model distinguishing by BMI group is presented. The second model is adjusted by the demographic factor *partner status*. In the third model, the socio-economic factors *level of education* and *equivalised disposable income* are included. Fourth, the behavioural factors *frequency of physical activity* and *smoker status* are added. Interaction effects are tested for all variables together with BMI in the Cox regression but are insignificant.

Naturally, the risk of death is dependent upon the general level of health. Poor health increases the risk of death. To account for a confounding effect, level of health is incorporated in the final two models. As performed by Mehta & Chang (2009), health status is controlled for. Health status is added to the regression in Model 5 and Model 6. Model 5 includes the objective variable *general health* from the SF-12 whereas model 6 includes the subjective variable *satisfaction with health*. Due to a lack of further information about particular illnesses, this thesis does not include a model without individuals with a history of major illness.

4.2.3 Attributable mortality

Attributable mortality is a measure used to determine what percentage of deaths could have been avoided in the absence of the risk factor. If the percentage is positive, the HR is greater than 1 and mortality would decrease in the absence of the risk factor. On the contrary, if the percentage is negative, the HR is less than 1 and mortality would increase in the absence of the risk factor (Flegal et al., 2015). In this case, the risk factors are overweight and obesity. The risk fraction is calculated based on the prevalence of non-overweight, overweight and obesity among men and women in Germany by Schienkiewitz et al. (2022). The following formula is utilised:

$$PAF = \frac{P_i \times (HR - 1)}{P_i \times (HR - 1) + 1} \tag{7}$$

Where PAF is the population attributable fraction, P_i is the proportion of the population exposed to the risk factor and HR is the hazard ratio determined by the Cox regression (Flegal et al., 2015). For this thesis the proportion of the population exposed to the risk factor is synonymous with the prevalence. The HR from model 4 in Table 5 are used as model 4 is fully adjusted. Following from the risk fraction, the number of excess deaths is calculated. Equation 8 shows that the PAF is multiplied by the number of deaths in Germany.

$$d_{excess} = PAF \;\; D_i \tag{8}$$

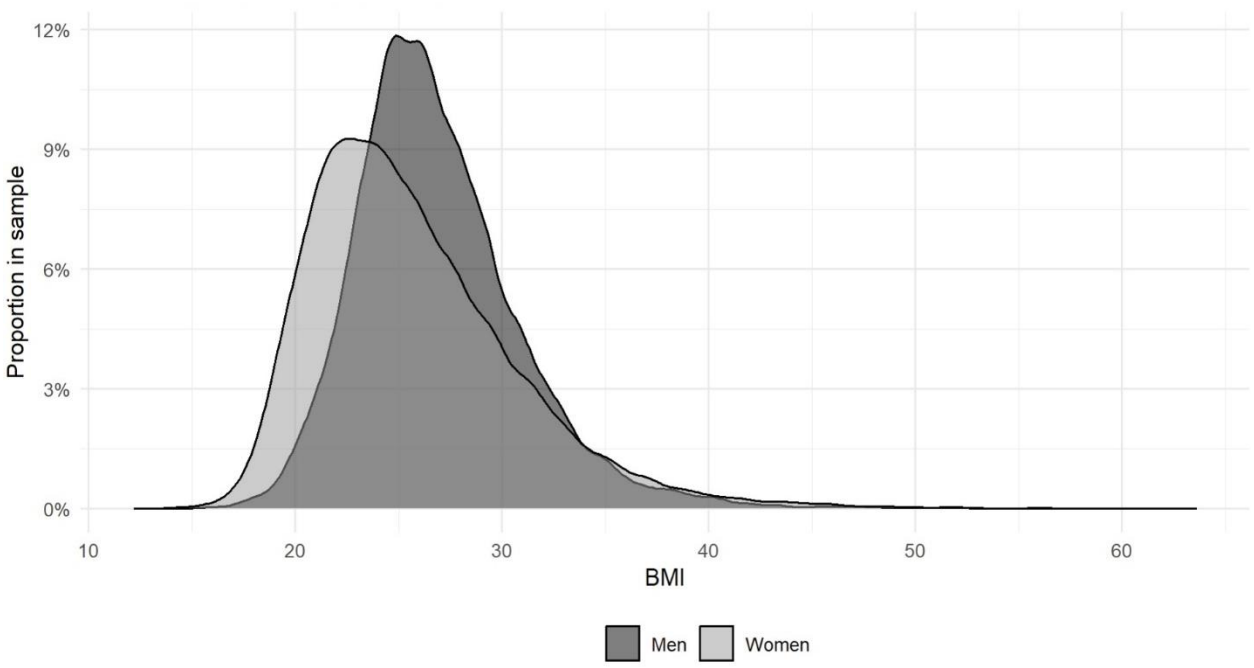
where d_{excess} is the number of excess deaths and D_i is the number of deaths in Germany in a given year. As most individuals died in the year 2020, the data from this year is chosen to perform the calculation. The number of deaths is restricted to adults who are at least 30 years of age to pertain to the age range used in this study. According to the German Statistics Office, 490,156 women and 488,266 men aged at least 30 died in 2020 (German Federal Statistics Office, 2023a).

5 RESULTS

5.1 Descriptive results

Kernel density estimates of BMI are plotted for women and men in Figure 1. Table 4 provides summary statistics to complement Figure 1. From a visual inspection, BMI appears to be normally distributed both among men and women. However, the distribution of BMI differs for men and women. Men have a higher BMI, on average. The mode is 24 kg/m^2 for women and 25 kg/m^2 for men. The median is 25 kg/m^2 for women and 26 kg/m^2 for men while the mean is 26 kg/m^2 for women and 27 kg/m^2 for men. BMI is more dispersed among women than it is among men. The standard deviation is 5 for women and 4 for men.

Figure 1. Kernel density plots of BMI by sex



Data source: SOEP core 1984-2020 (v.37), from DIW; calculations: author's own.

Table 4. Summary statistics of BMI

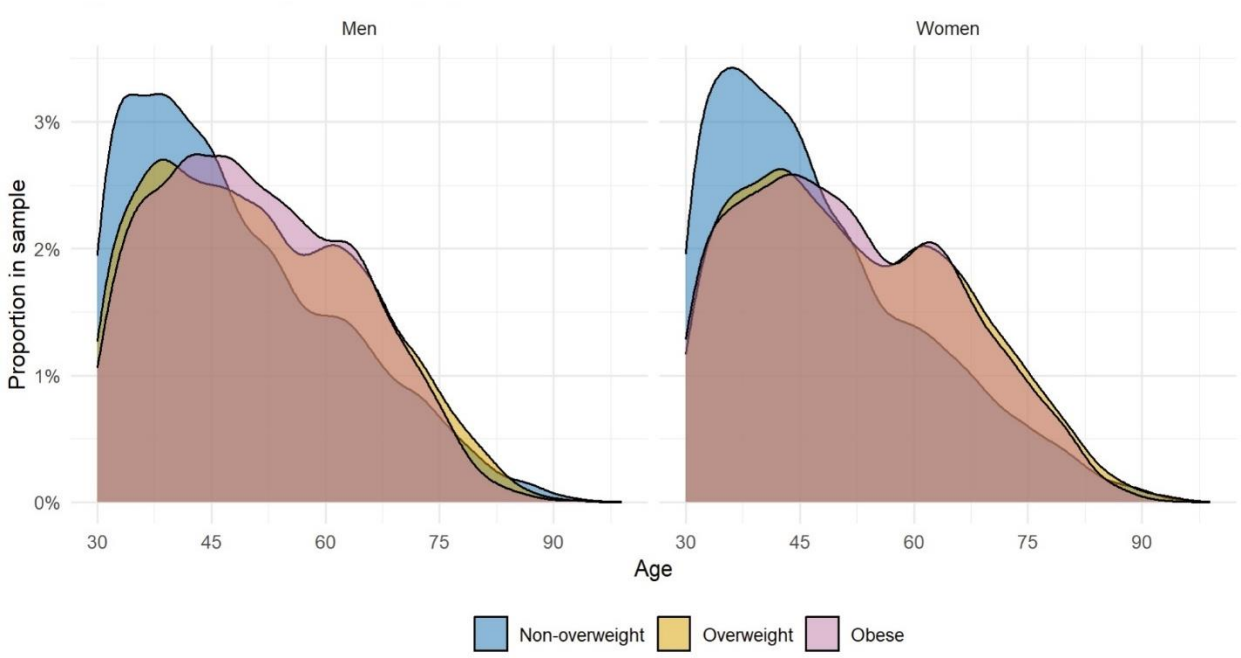
Measures of central tendency and dispersion							
WOMEN				**MEN**			
Mean (kg/m^2)	Median (kg/m^2)	Mode (kg/m^2)	SD	Mean (kg/m^2)	Median (kg/m^2)	Mode (kg/m^2)	SD
25.7	24.8	24.0	5.1	26.9	26.3	25.0	4.1

Notes. Individuals at age of entry between 2002 and 2020. SD: standard deviation. Data source: SOEP core 1984-2020 (v.37), from DIW.

The age distribution of the sample population is relevant due to the mortality effect of ageing. Figure 2 plots the age distribution of individuals at survey entry for men on the left and women on the right and Table 5 provides summary statistics. The distributions are available for each BMI group. The age distribution of all individuals is skewed to the right. Women have a mode of 37 whereas men have a mode of 39 years of age. The mean and median are higher than the mode for all categories. This is expected because the chance of participating in a survey decreases in old and very old age. Frailty and poor health can prevent survey participation. Another peak, although lower, can be seen at age 62. One

reason for the peak at this age could be recent retirement and the adjacent increase in time compared to the working population.

Figure 2. Age distribution at survey entry by BMI category for men and women



Data source: SOEP core 1984-2020 (v.37), from DIW; calculations: author's own.

Table 5. Summary statistics of age upon entry, SOEP participants 2002 – 2020

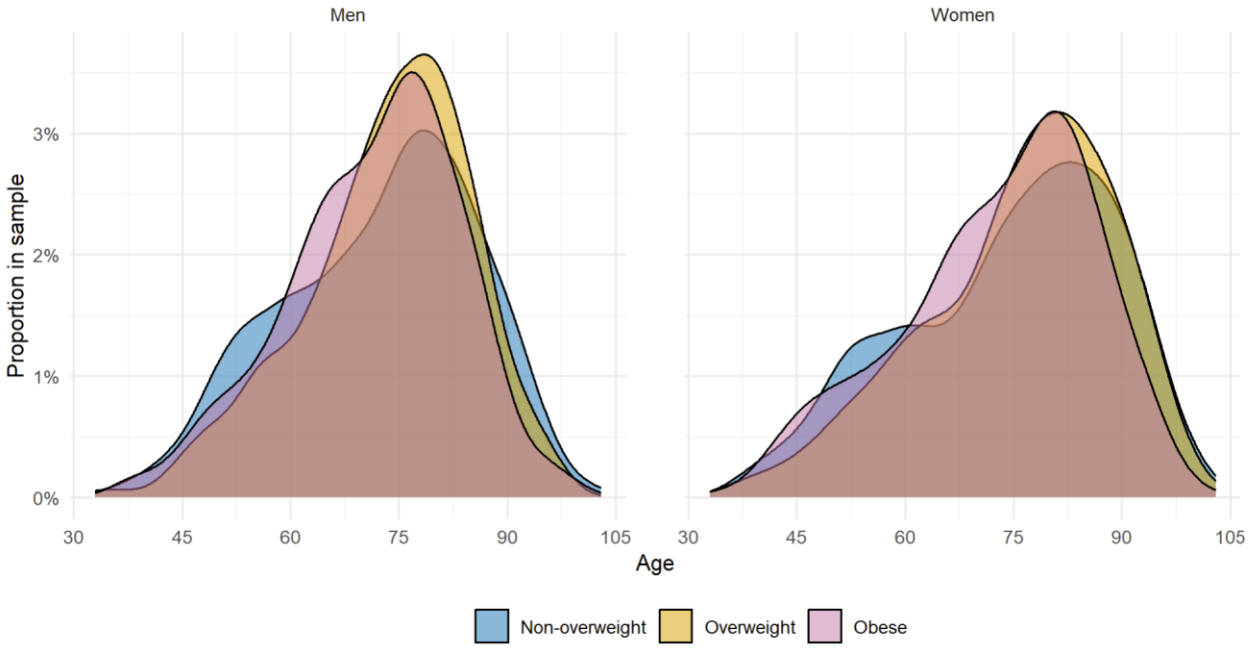
	Measures of central tendency and dispersion											
	WOMEN						**MEN**					
BMI	Mean	Median	Mode	Min	Max	SD	Mean	Median	Mode	Min	Max	SD
Non-overweight	47.9	45.0	37.0	30.0	97.0	13.6	48.3	45.0	39.0	30.0	99.0	13.6
Overweight	52.4	51.0	42.0	30.0	96.0	14.3	51.3	50.0	39.0	30.0	93.0	13.6
Obesity	51.8	50.0	43.0	30.0	93.0	13.8	51.1	50.0	47.0	30.0	94.0	12.7

Notes. Individuals at age of entry between 2002 and 2020. SD: standard deviation. Data source: SOEP core 1984 – 2020 (v.37), from DIW

Female and male non-overweight individuals have the lowest age distribution. Overweight and obese individuals have a similar age distribution in both sexes. Minor differences can be identified, nonetheless. The proportion of overweight men and women is higher at younger ages and old age whereas the proportion of obese women and men is higher at mid-age. Obese women and men have the oldest age distribution. The mode is 43 years of age among obese women, 42 among overweight

women and 37 among non-overweight women. Obese men have a mode of 47 years of age. Overweight and non-overweight men have a mode of 39. Non-overweight women and men both have a median age of 45, overweight women have a median age of 51 and obese women have a median age of 50. Overweight and obese men both have a median age of 50. The mean age of non-overweight women is 48 whereas the mean age of overweight and obese women is 52. The mean age of non-overweight men is also 48 whereas the mean age of overweight and obese men is 51. The age distribution could be an indication that mortality is highest among the obese population and lowest among the non-overweight population as mortality increases with age. For all BMI groups, the minimum age is 30; younger participants were excluded. The maximum age is highest among non-overweight women and men with 97 and 99 years of age respectively. The maximum age is 96 among overweight women and 93 among overweight men. Among obese women the maximum age is 93 and among obese men it is 94. The standard deviation is 14 for all female BMI groups. The standard deviation is 14 for non-overweight and overweight men and 13 for obese men. The high values of the standard deviation are expected as participant age at entry ranges from 30 to 99.

Figure 3. Age distribution at death by BMI category for men and women



Data source: SOEP core 1984-2020 (v.37), from DIW; calculations: author's own.

While the density plots (Figure 2) and summary statistics (Table 5) using age at entry provide valuable information about the entire study population, Figure 3 and Table 6 specify descriptive results for age of death. Compared to the age distribution at survey entry, the age distribution at death is left skewed. This skew indicates that deaths are most common at older age, which is what is seen in Germany in the 21st century. Until age 58, deaths are most common among non-overweight men. From there until age 73 deaths are most common among obese men before they become most common among overweight men until age 85. After that deaths are most common among non-overweight men again. The deaths are most dispersed among non-overweight and least dispersed among overweight men.

The pattern is similar for women, although there are some minor differences. Deaths are most common among non-overweight women until age 40. They are then most common among obese women for 7 years before becoming most common among non-overweight women again. From age 60 to 75 deaths are most common among obese women. From then on deaths are similarly common among obese and overweight women until age 80. Deaths are most common among overweight women alone until age 90 when they become equally common in non-overweight women. The distributions of the BMI groups are more similarly dispersed among women than among men.

The summary statistics in Table 6 provide more information. The mean age at death is highest among overweight and lowest among obese women and men. The average age at death is later for women than men in all BMI groups. On average, obese women die later than non-overweight men. The median age at death is highest for overweight women and men with an age of 78 for women and 75 for men, followed by non-overweight with 77 years of age for women and 74 years of age for men. The median age at death is lowest for obese women at 75.5 years of age and obese men at 73 years of age. The standard deviation is between 13 and 14 for women and between 11 and 13 for men. This resembles the summary statistics in Table 5.

Table 6. Summary statistics of age at death, SOEP participants 2002 – 2020

Measures of central tendency and dispersion												
	WOMEN						**MEN**					
BMI	Mean	Median	Mode	Min	Max	SD	Mean	Median	Mode	Min	Max	SD
Non-overweight	74.3	77.0	81.0	37.0	101.0	14.6	72.3	74.0	77.0	33.0	103.0	13.4
Overweight	75.9	78.0	84.0	36.0	103.0	13.2	73.5	75.0	74.0	33.0	98.0	11.7
Obesity	72.9	75.5	82.0	34.0	101.0	13.4	71.5	73.0	79.0	37.0	99.0	11.8

Notes. Individuals for whom death is recorded between 2002 and 2020. SD: standard deviation. Data source: SOEP core 1984 – 2020 (v.37), from DIW

The number of deaths per BMI group can provide an initial insight into the relationship between weight and mortality. The proportion of deaths per BMI group and the ASCDR for each BMI group are displayed for women and men in Table 7. For women, the proportion of deaths is highest in the non-overweight group with 44%. The overweight group accounts for 32% of all deaths and the obese group accounts for 24% of all deaths. The pattern is reversed among non-overweight and overweight men. 33% of male deaths occur in the non-overweight group and 44% occur in the overweight group. The obese group accounts for 23% of deaths, resembling the proportion of female deaths in this group. Table 7 further shows that the ASCDR is lower among women than men by more than 20 deaths per 1,000 people. In terms of BMI groups, the ASCDR is lowest among overweight women and men, followed by non-overweight and obesity. These rates suggest that overweight is associated with the lowest mortality. The difference between the death rates of overweight and non-overweight women is 3.1 deaths per 1000 people, whereas the difference between men is 12.3 deaths per 1000 people. The death rate for obese women is lower than that of non-overweight men.

Table 7. Age standardised death rates by BMI group for women and men, SOEP participants 2002 – 2020

	WOMEN				MEN			
	Non-overweight	Overweight	Obesity	Total	Non-overweight	Overweight	Obesity	Total
Proportion of deaths (%)	44	32	24	100	33	44	23	100
Death rate (per 1,000 people)	51.8	48.7	70.5	53.9	79.6	67.6	91.1	75.7

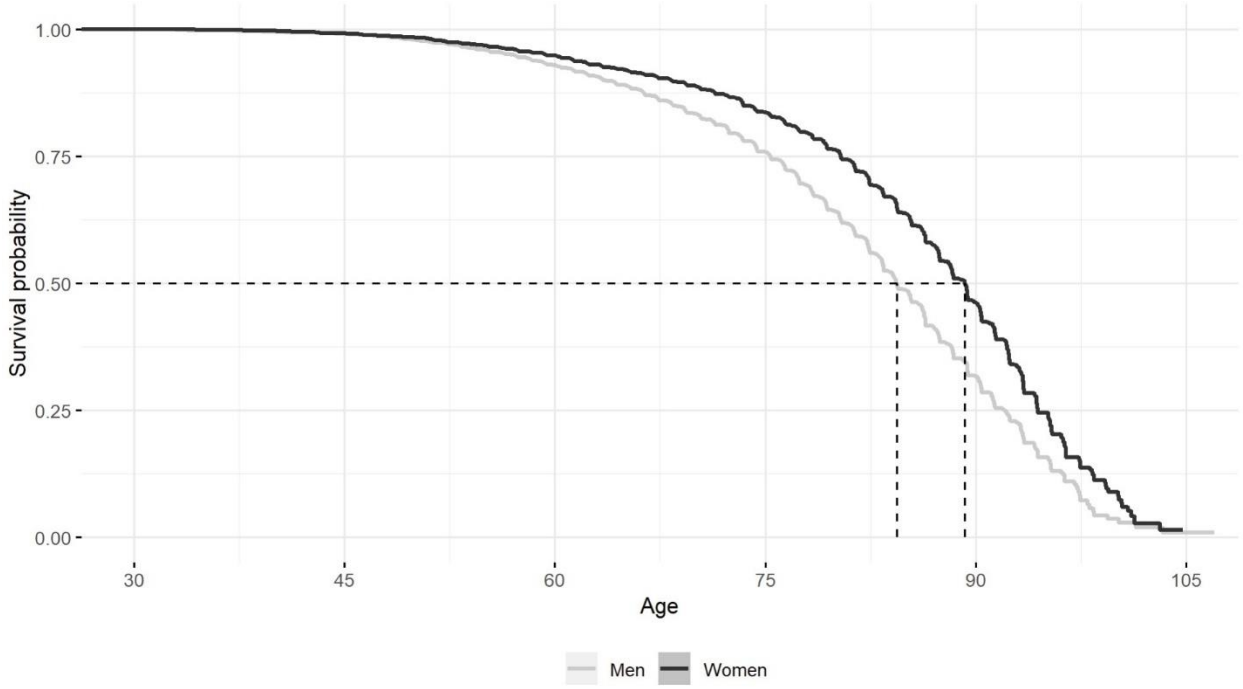
Notes. Death rate only includes individuals from age 30 upwards. Data source: SOEP core 1984 – 2020 (v.37), from DIW and Standardbevölkerung 2011, from Federal Health Monitoring System. Calculations: author's own.

5.2 Kaplan Meier estimations

Survival probabilities are estimated and visualised in the form of Kaplan-Meier curves. Figure 4 allows provides a comparison of survival probability by sex. Until age 50, no difference can be detected as there are few deaths at younger age. However, from age 50 until very old age a clear difference can be observed. Women have a higher survival probability than men. As expected, men have a lower survival probability due to the higher male mortality rate. This is also reflected in the median survival time. The median survival time refers to the point in time at which there is a 50 % chance of survival, or after which half the population has experienced death and half has survived. Median survival occurs at age 89 for women and at age 84 for men.

A log-rank test is performed to test whether there is a significant difference between the survival functions of the groups. The test in Table 8 compared the male and female survival curves. The results suggest that male and female population survival functions differ; the differences between the Kaplan-Meier curves of men and women are statistically significant, both with the p-value and adjusted p-value. The adjusted p-value is useful for comparison between multiple groups, which is explained in more detail at the end of this section. Significance is tested with the log-rank test using age as time scale. In a separate attempt, duration in study is used as the time scale. As with age, the results are highly significant with time ($p < 0.001$); the computations of the survival curves can be found in appendix C.

Figure 4. Kaplan-Meier survival probability estimates by sex using age as time scale; median survival lines for each group, SOEP participants 2002 – 2020



Notes. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

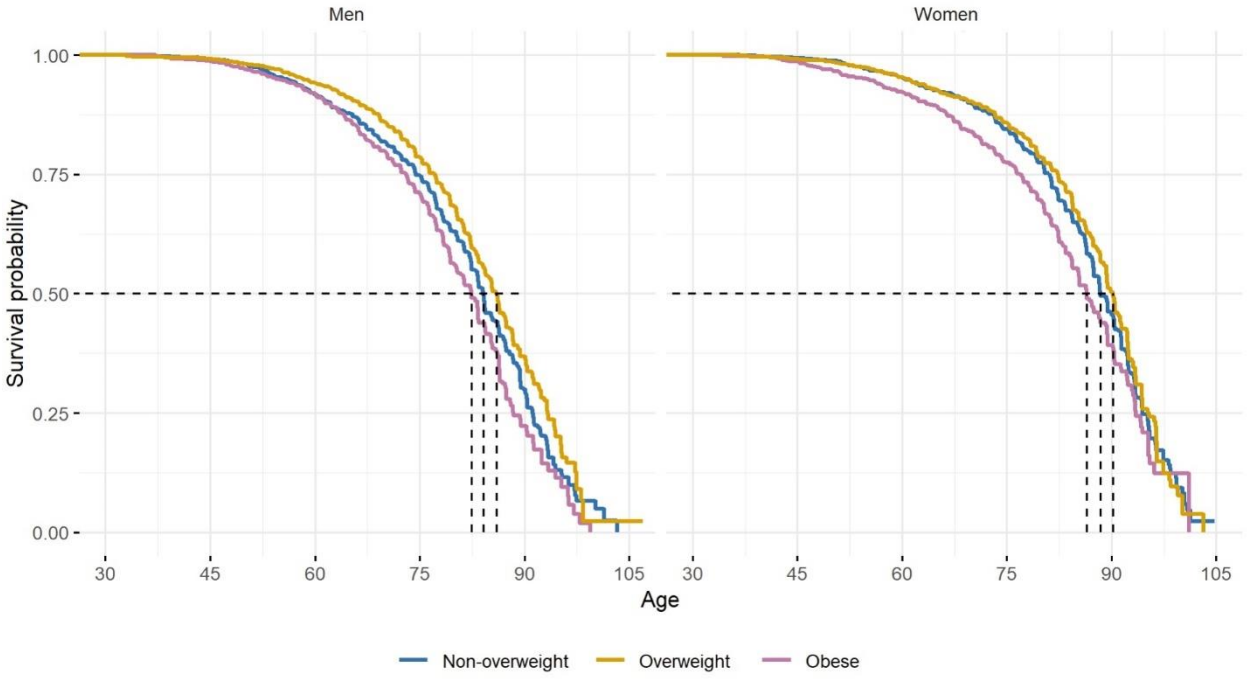
Table 8. Log-rank test; comparison between the female and male survival distribution functions

		MEN
WOMEN	p-value	**<0.0001**
	Adjusted p-value	**<0.0001**

Notes. Adjusted p-value is Dunn-Sidak adjusted p-value. Significant results are in bold. p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW.

The survival curves in Figure 5 illustrate the differences in survival probability by BMI group. Until age 50 for women and age 55 for men, survival is very high in all groups and thus differences are negligible. For women, obesity leads to a significantly lower survival chance than non-overweight and overweight. Overweight women have a higher survival probability than non-overweight women, even though the difference is minimal. The pattern is not the same for men. Of the men, overweight individuals have the highest survival probability at all times until very old age. A difference in survival probability between non-overweight and obese men only becomes noticeable at age 63. Overweight men have a higher chance of survival than obese men. At around age 90 for women and 95 for men the curves re-converge. The wide confidence intervals at very old age are expected due to the low number of survivors which leads to a lower certainty.

Figure 5. Kaplan-Meier survival probability estimates by BMI group for men and women using age as time scale; median survival lines for each group, SOEP participants 2002 – 2020



Notes. Kaplan-Meier survival probability estimates by BMI group per sex using age as time scale; median survival lines for each group. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

For women, median survival occurs at age 90 among overweight individuals, at age 88 among non-overweight individuals and at age 86 among obese individuals. For men, median survival is also highest

for the overweight population with an age of 86. Median survival is at age 84 for non-overweight men and age 82 for obese men. There is a 4-year difference in median survival time between men and women for all BMI groups. This reiterates the higher survival probability of women than men.

Table 9. Log-rank test; comparison between survival distribution functions of each BMI group for men and women

		WOMEN			MEN		
		Non-overweight	Overweight	Obesity	Non-overweight	Overweight	Obesity
Non-overweight	p-value		0.044	**<0.0001**		**0.013**	**<0.0001**
	Adjusted p-value		0.127	**<0.0001**		**0.039**	**<0.0001**
Overweight	p-value	0.044		**<0.0001**	**0.013**		**<0.0001**
	Adjusted p-value	0.127		**<0.0001**	**0.039**		**<0.0001**
Obesity	p-value	**<0.0001**	**<0.0001**		**<0.0001**	**<0.0001**	
	Adjusted p-value	**<0.0001**	**<0.0001**		**<0.0001**	**<0.0001**	

Notes. Adjusted p-value is Dunn-Sidak adjusted p-value. Significant results are in bold. p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW.

The results of the log-rank test associated with Figure 5 are seen in Table 9. Considering the p-value, the table shows that there is a significant difference between all groups for women. Nevertheless, the adjusted p-value suggests that there is a significant difference between non-overweight and obese women as well as between overweight and obese women but not between non-overweight and overweight women. The Dunn-Sidak adjusted p-value is more stringent than the regular p-value when conducting comparisons between multiple groups. This avoids committing a Type I error of obtaining a false positive result. The significance level (alpha) is raised according to the number of comparisons being made. There are significant differences between overweight and non-overweight, overweight and obese and between non-overweight and obese men. Both the p-value and the adjusted p-value confirm this.

5.3 Cox proportional hazard models

Cox proportional hazard ratios are calculated to better understand the dynamics of the patterns drawn by the Kaplan-Meier curves. The cox proportional hazard ratios for gender shown in Table 10 imply that the risk of death is roughly 1/3 lower for women than for men. As the crude model is adjusted for demographic, socio-economic and behavioural factors in Models 2 - 4, the gender gap becomes even wider.

Table 10. Cox proportional hazard ratios for gender, SOEP participants 2002 – 2020

		N = 41,339		
Variable	Model 1	Model 2 (+dem)	Model 3 (+SES)	Model 4 (+beh)
Gender (Ref: Men)				
Women	**0.66*****	**0.63*****	**0.59*****	**0.64*****
Partner status (Ref: Single)				
Partner		1.02	1.10	1.07
Married/registered partnership		**0.78*****	**0.81*****	**0.86*****
Education (Ref: Less than high school)				
High school			0.96	1.00
More than high school			**0.71*****	**0.83****
Income (Ref: Low)				
Medium			**0.85*****	**0.91***
High			**0.73*****	**0.82*****
Physical activity (Ref: Never)				
Rarely				**0.80*****
Once a month				**0.65*****
Once a week				**0.61*****
Daily				**0.63*****
Smoker status (Ref: non-smoker)				
Smoker				**1.80*****

Notes. Cox proportional hazard ratios using age as time scale. Model 2 adjusts for demographic characteristics (partner status). Model 3 adds socioeconomic factors (education and equivalised disposable income). Model 4 adds behavioural factors (physical activity and smoker status). Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW.

Cox proportional hazard ratios are calculated for each BMI group. Six cox proportional hazard models are presented for women and men in Table 11. The unadjusted model suggests that there is a strong relationship between obesity and risk of death for both women and men. Compared to non-overweight individuals, obese women have a 33 % increased risk of death while obese men have a 20 % increased risk of death. Overweight reduces the risk of death by 18 % for men and by 9 % for women, although the results are not statistically significant for the latter.

Adjusting for the demographic factor partner status in model 2, the results remain similar. Obese women have a 32 % increased risk of death compared to non-overweight women. Overweight women have the same risk of death as in the previous model. For obese men, the risk of death increases to 22 % whereas for overweight men, the reduced risk of death decreases to 16 %.

Socio-economic variables are added in the third model. For women obesity results in a 25 % increased risk of death. The risk of death for overweight women, compared to non-overweight women, also decreases. Overweight women have a 12 % lower risk of death. The risk of death from obesity decreases

to 11 % for men in Model 3. Overweight protects more from death in this model with a 19 % reduction of the hazard, compared to non-overweight.

Behavioural factors are added in the fourth model. The risk of death from obesity, compared to non-overweight, remains the same as in the previous model at 25 %. Overweight decreases the risk by 11 % for women. For men, the risk of death from obesity, compared to non-overweight, increases the risk of death increases again to 17 %. Overweight decreases the risk of death by 14 % for men, 5% less compared to Model 3.

The health measures *general health* and *satisfaction with health* are included in Model 5 and Model 6, respectively. Model 5 reveals that the risk of death is increased by 16 % for obese women and decreased by 11 % for overweight women. Obese men have a 14 % increased risk of death while overweight men have a 13 % decreased risk of death. Model 6 gives the same results for overweight. Obesity increases the risk of death by 19 % for women and by 15 % for men. When including these health measures, the hazard rate for obese women remains above 15 %. For obese men, the hazard rate remains above 10 %.

As with the Kaplan-Meier estimations, the log-rank test is used to test for overall significance of the model (see Appendix B). The p-values are highly significant for all models ($p < 0.001$). All cox regressions had similar scores on the likelihood ratio test, Wald test. This suggests that there is a significant difference in survival between the covariates.

Graphical visualisations of Schoenfeld residuals for women and men can be seen in appendix E. The graphs do not show any suspicious patterns, indicating that the proportional hazards assumption is met. However, Schoenfeld residuals are presented in Table 12. The p values suggest that overall, the proportional hazards assumption holds for men but not for women. BMI does not demonstrate proportional hazards for women. This is in accord with the Kaplan-Meier curves which do not cross for men but do cross in the case of non-overweight and overweight women. Partner status appears to be time dependent for both women and men, whereas physical activity also appears to be time dependent for women. The results for women are to be taken with further caution.

Table 11. Cox proportional hazard ratios, SOEP participants 2002 – 2020

	WOMEN (N = 21,226)						MEN (N = 20,113)					
Variable	**Model 1** (crude)	**Model 2** (+dem)	**Model 3** (+SES)	**Model 4** (+beh)	**Model 5** (+health 1)	**Model 6** (+health 2)	**Model 1** (crude)	**Model 2** (+dem)	**Model 3** (+SES)	**Model 4** (+beh)	**Model 5** (+health 1)	**Model 6** (+health 2)
BMI (Ref: Non-overweight)												
Overweight	0.91	0.91	0.88.	0.89.	0.89.	0.89.	**0.82*** **	**0.84** **	**0.81*** **	**0.86** **	**0.87** **	**0.87** **
Obese	**1.33*** **	**1.32*** **	**1.25** **	**1.25** **	**1.16***	**1.19** **	**1.20** **	**1.22** **	1.11	**1.17***	1.14.	**1.15***
Partner status (Ref: Single)												
Partner		**1.30***	**1.39***	**1.33***	1.34*	1.34*		0.83.	0.89	0.88	0.93	0.92
Married/registered partner		0.92	0.95	0.99	1.00	1.00		**0.66*** **	**0.69*** **	**0.74*** **	**0.75*** **	**0.75*** **
Education (Ref: Less than high school)												
High school			0.94	0.97	0.99	0.99			0.98	1.05	1.06	1.05
More than high school			**0.78***	0.88	0.92	0.91			**0.70*** **	0.84**.**	**0.87**	**0.85**
Income (Ref: Low)												
Medium			0.92	0.97	0.97	0.96			**0.80*** **	**0.86** **	**0.88***	**0.88***
High			**0.82** **	0.90	0.92	0.92			**0.67*** **	**0.75*** **	0.81**	0.81**
Physical activity (Ref: Never)												
Rarely				0.85.	0.87	0.86				**0.79** **	0.86.	0.85*
Once a month				**0.46*** **	0.49***	0.48***				0.79	0.89	0.88
Once a week				**0.61*** **	0.65***	0.65***				**0.63*** **	**0.70*** **	**0.70*** **
Daily				**0.64** **	0.67*	0.67*				**0.70** **	**0.75***	**0.73***
Smoker status (Ref: non-smoker)												
Smoker				**1.84*** **	1.87***	1.86***				**1.78*** **	**1.78*** **	**1.76*** **
General health (Ref: low)												
Medium					**0.59*** **						**0.52*** **	
High					**0.68** **						**0.36*** **	
Health satisfaction (Ref: very low)												
Low						**0.76** **						**0.72*** **
Medium						**0.51*** **						**0.51*** **
High						**0.49*** **						**0.41*** **
Very high						**0.48*** **						**0.37*** **

Notes. Cox proportional hazard ratios using age as time scale. Model 2 adjusts for demographic characteristics (partner status). Model 3 adds socioeconomic factors (education and equivalised disposable income). Model 4 adds behavioural factors (physical activity and smoker status). Model 5 and 6 test for health status (Model 5: general health level, Model 6: satisfaction with own health). Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW.

Table 11. Schoenfeld residuals for women and men, SOEP participants 2002 – 2020

Variable	**WOMEN**	**MEN**
BMI	0.03	**0.84**
Partner status	0.003	0.003
Household income	**0.54**	**0.86**
Level of education	**0.96**	**0.14**
Physical activity	0.002	**0.67**
Smoker status	**0.46**	**0.41**
Global	< 0.001	**0.16**

Notes. Based on Model 4 in Table 11. Significant results are in bold. p > .05 suggests that the proportional hazards assumption is met. Data source: SOEP core 1984 – 2020 (v.37), from DIW.

5.4 Attributable mortality

Based on the HR from the fully adjusted Model 4 in Table 11 above, the population-attributable risk fraction and number of excess deaths related to BMI group are calculated for women and men. The results are visualised in Table 13. Overweight-attributable mortality encompasses – 4 % for women and – 6 % for men. This results in over 19,000 fewer female deaths and almost 30,000 fewer male deaths in 2020. Obesity-attributable mortality entails 5 % for women and 3 % for men. This leads to 22,000 additional female deaths and 15,000 additional male deaths in 2020.

Table 12. Population-attributable risk fraction and excess deaths, SOEP participants 2002 – 2020

	WOMEN (total deaths under age 30, 2020 = 490,156)		**MEN** (total deaths under age 30, 2020 = 488,266)	
Variable	Attributable mortality (%)	Number of excess deaths, 2020	Attributable mortality (%)	Number of excess deaths, 2020
BMI (Ref: Non-overweight)				
Overweight	-3.9	-19,335	-6.1	-29,964
Obesity	4.5	22,227	3.1	15,355

Notes. Data source: SOEP core 1984 – 2020 (v.37), from DIW and German Federal Statistical Office (2023a). Calculations: author's own.

6 Discussion

The prevalence of overweight and obesity is high in Germany, sparking concerns from a public health perspective. The hypothesis that the prevalence of overweight is higher among men than women is confirmed by the SOEP data. 56 % of men are overweight whereas 30 % of women are overweight according to the descriptive characteristics. These results suggest that the prevalence of overweight for

both men and women is lower than BGS98 and DEGS1. The hypothesis that overweight has remained stable at a high level over time must be rejected. The low prevalence may arise due to self-reporting, which is avoided by the health surveys BGS98 and DEGS1. The prevalence of overweight among men is similar to that found by Schiekiewitz (2022) using the GEDA data. The prevalence of overweight among women is 16 % lower in this thesis than Schiekiewitz' (2022) results. The results for women are more comparable to the results from the micro census. This could mean that women who participated in the SOEP survey underestimated their weight more than in the GEDA study. A reason for this could be that the latter is a healthy survey whereas the former is a socio-economic survey. Equally, the micro census is not primarily health focused but designed to capture information on household and socio-economic factors. Participants may be inclined to provide a more accurate report of their anthropometric measurements in a health survey.

The prevalence of obesity is 17 % among women and 19 % among men. This does not confirm the hypothesis that women have a higher prevalence of obesity than men. The prevalence of obesity among men resembles the results from the micro census and GEDA, and is marginally higher than the BGS98. This supports the hypothesis that obesity has become more prevalent over time. However, the prevalence of female obesity is higher in DEGS1 and GEDA and lower in the micro census than in this thesis. The lower prevalence of obesity among women could be caused by sampling bias, for example through the healthy user bias. Ill people are less likely to participate in surveys. If the majority of ill individuals are obese, they will be underrepresented.

The high prevalence of overweight and obesity in Germany call for investigations into the health consequences associated with these risk factors. Mortality is the ultimate consequence and can be affected by BMI. Deaths are most common at old age in Germany, suggesting that the country is in the third or fourth stage of the Epidemiological Transition. The age-standardised crude death rates suggest that overweight is associated with the lowest mortality. The difference between the death rates of overweight and non-overweight women is minor, whereas overweight men have a substantially lower death rate then non-overweight men. This suggests that there may be a gender gap in mortality attributed to overweight. The ASCDR suggest that obese men have a higher mortality risk than obese women. This pattern is due to higher male mortality. This contradicts Muennig et al.'s (2006) findings. However, Muennig et al (2006) acknowledge that obese women have lower mortality than obese men until age 45. In the current study, the death rate for obese women is lower than that of non-overweight men. This emphasises the gender gap in mortality. The ASCDR are higher in this thesis than that of

Germany. The high ASCDR in this thesis is caused by a high age-specific death rate. This may be high because of the large number of cases with missing BMI values which were excluded. If deaths are frequently recorded for people with BMI, whereas not necessarily for individuals who were not asked or refused to report their BMI, the proportion of individuals who experience death are overrepresented in the study. In spite of this, the death rates between BMI groups can be compared, which is the goal of this thesis.

The Kaplan-Meier curves illustrate the probability of survival over age. The survival probability of women is always higher than that of men. The survival probability of obese women is significantly lower than that of women of lower weight at all ages until very old age. The survival probability of overweight women is marginally higher than that of non-overweight women. This is reinforced by the ASCDR. The death rate for overweight women is only marginally lower than that of non-overweight women. The Kaplan-Meier curves show that overweight men have the highest survival probability at all ages, followed by non-overweight men. Obese men have the lowest survival probability. The Kaplan-Meier estimations show similar results to the death rates. Mortality is higher among men than among women, lowest among overweight individuals and highest among obese individuals. Unlike the Kaplan-Meier curves for men, the curves of non-overweight and overweight women are very close, suggesting that there is no significant difference between the two. This is reinforced by the ASCDR. The death rate for overweight women is only marginally lower than that of non-overweight women.

The survival functions for obesity resemble those by Peeters et al (2003) using the Framingham Heart study data. However, the survival functions for overweight differ to those by Peeters et al (2003), where overweight women and men fare worse than non-overweight women and men. This discrepancy could be attributed to the different time scale used in the Kaplan-Meier estimator. In this thesis, age is used as a time scale whereas Peeters et al (2003) use follow-up time. Peeters et al (2003) restrict their participants to those with age 30 – 49 at baseline. The mortality effect of ageing may not be captured adequately by the follow-up time. Survival curves over time, rather than age, using the data from this thesis can be found in Figures C1 and C2 in appendix C. The female curves in the appendix resemble Peeters et al's (2003) curves in that non-overweight individuals have the highest survival probability. This is attributed to the younger age distribution of non-overweight women. However, the curves for men illustrate that there is no significant difference between the survival probability of non-overweight and overweight men. Both groups have a similar survival probability, one that is higher than that of obese men.

The results of the Cox regression in Table 10 support the pattern drawn by the Kaplan-Meier curves. Overall, men have a higher risk of death than women at all ages. Once BMI is included, obesity is associated with an increased risk of death both for women and for men while the risk is greater for women than for men. Compared to non-overweight individuals, women have at least a 20 % increased risk of death whereas men have at least a 15 % increased risk of death. The effect remains highly significant for women in all models. This suggests that BMI remains an important predictor of mortality. The higher mortality risk for women may be caused by the genetic differences in weight gain between men and women. Women gain more fat than men when gaining weight whereas men gain more lean tissue. The build-up of fat is unhealthier than lean tissue, and can cause numerous diseases, such as cardiovascular disease and eventually death (Nakamura et al., 2014). Epigenetic differences leading to a decrease in satiation are found in obese women (Lechner et al., 2023). Sex differences also play a role in craving, which could lead to the higher mortality risk for women. Ultra-processed and high sugar content food increase craving (Hallam et al 2016). The third stage of the Epidemiological Transition seems to have a more severe effect on women than on men.

Obesity becomes problematic from mid-age onwards. The impact of age is magnified in Table C1 in appendix C. The Cox regression is run, using time as the time scale instead of age. Obesity is associated with a 1.7 and 1.4 fold increase in the risk of death for women and men respectively. However, when age is added as covariate, the HR decreases to 1.3 for women and 1.2 for men. When the model is fully adjusted, the HR compare to the HR in Table 11. While the obesity prevalence among German seniors is lower than at mid-age, the risks of obesity remain until very old age. The low prevalence of obesity at older age could convey the novelty of the obesity epidemic. Older generations were born when the Epidemiological Transition was in its second phase in Germany. They may not have been affected by obesity when they were younger and therefore never became obese. Younger generations, however, have grown up with the obesity epidemic. The childhood obesity epidemic may have a stronger effect as well with research indicating that weight loss at adult age becomes less likely (Fildes et al. 2015). The replacement of cohorts ought to provide more information in the future.

Overweight, on the other hand, is associated with a decreased risk of death for men and women. No significant effect is found when testing for the risk of death among overweight women. The decreased risk of death among overweight men and women could be associated with the availability of medication and treatment for the underlying causes of overweight, including high blood pressure and cholesterol.

Although these treatments work for all weights, they may have a larger effect on the overweight population than on the non-overweight population (Afzal et al., 2016).

The insignificant effect of overweight compared to non-overweight women is supported by the log-rank test computed for the Kaplan-Meier curves. The adjusted p-value suggests that the groups are not statistically different and there is no significant difference in HR. This is reiterated by the Schoenfeld residuals for BMI. Being non-overweight and overweight may be equally healthy. The results suggest that being non-overweight as a man could pose a health risk. This inference could be influenced by men's height. On average, German men are 12 cm taller than German women. Being taller requires more weight to sustain the body. Height could also be an explanation for the increased risk of death of women due to obesity. A shorter height cannot sustain as much weight as a taller height. A modified BMI measure for each sex might be more informative.

The results resemble Mehta & Chang (2009) who found that higher classes of obesity increase the risk of death whereas overweight decreases the risk of death. This suggests that the pattern in Germany is similar to that in the U.S. a decade earlier. Nevertheless, obesity class I is not associated with an increased mortality risk in Mehta & Chang's (2009) study. Rather, the authors found a decreased HR. Borrell & Samuel (2014) noticed a decreased mortality risk for men with obesity class I but not for women. The difference to this thesis could lie in the grouping of obesity classes. All obesity classes are grouped into one. Obesity class II and class III cases could influence the increased mortality risk. However, obesity class II and III are very rare in Germany (Schienkiewitz et al., 2022). Obesity class I has been associated with an increased mortality risk in Europe (Bellocco et al., 2010) and in the U.S. (Berrington de Gonzalez et al., 2010).

The more covariates are added to the regression model, the smaller the difference between men and women's mortality becomes. This could suggest that the gap is partially due to the confounding effect of the demographic, socio-economic and behavioural factors. When including partner status, the benefits of marriage are found for men but not for women. This is line with literature which theorises that married people, especially men, have the highest wellbeing (Waite, 1995). This translates to decreased mortality. For women, being single is associated with a lower risk of death than having a partner. These findings, which are not common in literature, could be influenced by the methodology of this thesis. Scrutinising the variable *partner status*, the false assumption is made that the partner status of an individual remains the same from the time they enter the study until they exit. The first observation for each individual is recorded and kept constant. Unregistered relationships are characterised by a lower

level of commitment and stability than marriages or registered partnerships. It is more likely that an unregistered relationship is dissolved by the following year than a marriage. Therefore, a woman who has a partner in the year she enters the study may be single the following year. Another explanation for the difference between having a partner and a married or registered partner could be the lower level of co-dependency among the former. Married or registered partners tend to live together whereas partners may see each other regularly but not be as heavily involved in each other's lives, including their health patterns (Schoen & Weinick, 1993).

Education and income play a larger role in survival for men than for women. Higher education protects both sexes. High household income affects women, whereas both a medium and a high household income have a significant effect on male mortality. These results are expected as women tend to crowd around the mean income. Women tend to engage in hypergamy or marrying "up", meaning they marry men who earn more than them (Almås et al., 2023). Such an effect is not noticed for education.

Behavioural factors play a role for both sexes. Engaging in no or almost no physical activity is associated with a higher risk of death. Exercising at least once a month and at least once a week are associated with the lowest mortality risk in women and men respectively. As mentioned earlier, exercising every day may suggest overexercising and therefore be an unhealthy behaviour. Smoking almost doubles the mortality risk. Being a smoker results in the highest HR of all covariates. This emphasises the dangers of smoking, which is the second largest risk factor in Germany. A similar conclusion is drawn by Flegal et al. (2005) and Mehta & Chang (2009) who suggest that smoking induces significantly more deaths than overweight and obesity. Contrary to Adair & Lopez (2020) the number of deaths attributed to obesity cannot be compared to those attributed to smoking. The risk of death due to behavioural factors is higher for women than for men. In terms of physical activity, this may be related to the sex-specific discrepancy in weight gain. As it is easier for men to build up lean tissue, more exercise is required for a woman to be fit than for a man. In terms of smoking, there is some evidence that smoking is more harmful for women than for men. Female smokers have a higher risk of coronary heart disease, vascular and respiratory disease than male smokers (Prescott et al. 1998). However, smoking leads to a high risk ratio for men too. When health level and satisfaction with health are accounted for in the model, the risk of death due to obesity remains. BMI has an independent association with death.

Robustness checks involve the inclusion of further covariates and the exclusion of participants with late entry. When nutrition is included in the model, the HR for overweight remain similar and the HR for obesity increase. Obesity is associated with a 22% increased risk of death and overweight is associated

with a 12% reduced risk of death for women. Obesity is associated with a 24% increased risk of death and overweight is associated with a 14% reduced risk of death for men. The full results can be found in the appendix F. When alcohol consumption is accounted for, obesity results in a 28% increased risk of death among women and a 32% increased risk of death among men. No significant difference between overweight and non-overweight is found in this model. The results are in appendix G. The regression is also carried out using only participants who entered the survey in the year 2002 to test whether late entry affected the results. Table D1 in Appendix D shows the HR for 8,554 women and 9,158 men for the same six models as Table 11. 977 female and 1,264 male deaths occurred between 2002 and 2020. The results resemble those in Table 11. Obese women have a 28 % increased risk of death in the crude model but this decreases to 22 % in the fully adjusted model 4. Obese men have a 25 % increased risk of death in Model 1 and a 19 % increased risk of death in Model 4. Overweight protects women by 5 – 10 % and men by 10 – 15 %.

The hypothesis that there would be more deaths attributed to obesity among women than among men is confirmed by the data. In comparison to Mehta & Chang (2009) more deaths can be attributed to obesity, both for women and for men. For overweight, I hypothesised that no mortality is attributed to this weight group for men. The results indicate that overweight attributable mortality is negative for men, confirming the hypothesis. The result of – 6 % is greater than Mehta & Chang's (2009) finding of –5 %. I hypothesised that some mortality could be attributed to overweight in women. As for men, the overweight attributable mortality is negative for women. The results imply that this hypothesis can be rejected. In comparison to Mehta & Chang's (2009) findings, less female deaths can be attributed to mortality.

As expected, there are more excess deaths among obese women than obese men. The findings are in line with Muennig et al. (2006) who found that obesity leads to more deaths in women than in men. The number of excess deaths in this study is higher than in the U.S (Mehta & Chang, 2009). This can be explained by methodological differences. This thesis considered deaths of all individuals who are at least 30 years old. Mehta & Chang (2009) restrict their sample to one cohort of individuals aged 50-61. For the calculation of the population attributable risk fraction, the authors include the number of deaths among that cohort. The number of excess deaths in Germany is better compared to Flegal et al's (2005) finding of 111,909 excess deaths in the U.S. in 2000. In this case there are more deaths in the U.S. than in Germany, as the prevalence of obesity is higher, and the population is larger in the former than in the latter.

No excess deaths were expected among overweight men, but some were expected among overweight women. Among both sexes, the number of excess deaths is negative. This means that there are fewer deaths among overweight than among non-overweight men and women. This pattern compares to Mehta & Chang's findings of – 7,933 female deaths and – 10,023 male deaths. Although the excess deaths are also negative for women, this figure is smaller for women than for men. The mortality risk is greater for men than for women if they are non-overweight, as opposed to overweight. Flegal et al. (2005) also found a reduction in the number of deaths among the U.S. overweight population. These results stray from Muennig et al.'s (2006) conclusion that overweight leads to additional deaths, for both women and men. A reason for this discrepancy could be the data variable construction. Muennig et al. (2006) confine the normal weight category to a BMI between 23 and 25 kg/m^2. Based on the National Health Interview Survey, the BMI associated with the lowest mortality in the U.S. in the period from 1990-1994 was 24.5 kg/m^2 (Wang et al 2017). Data from 1990 – 1992 from this survey was also used by Muennig et al. (2006). While the BMI associated with lowest mortality in the early 1990s in the U.S. is placed in the normal weight category according to the WHO's classification, Muennig et al. (2006) limits the individuals in this category. Individuals with a BMI between 18.5 and 23 kg/m^2 are excluded. This may be because mortality associated with lower BMI in the normal weight classification is higher. By excluding these cases, mortality for the whole class decreases. The gap between Muennig et al. (2006) and the results of this thesis is likely to be more pronounced due to the inclusion of underweight participants in the non-overweight category in the latter. The high mortality of underweight individuals dampens the lowest mortality of normal weight individuals.

Despite being significant, the effect of obesity on death might be considered minor compared to that of diseases such as cancer or an event like a myocardial infarction (heart attack). The large sample size enhances the statistical power: it enables the test of the nuanced relationship between weight status and death. The large number of cases (n = 41,399) increases precision and reduces the chance of sampling bias, such as undercoverage bias. The study period consisted of a total of 19 years (2002-2020). This is a lengthy period allowing for follow-up compared to longitudinal studies in health. These nationally representative findings are valuable for the German government and policymakers. As a form of sensitivity analysis, Mehta & Chang (2009) test the impact of time spent in study. They find no significant difference between early and later parts of the study. Contrary to Mehta & Chang (2009), the time does not reflect early vs. later time in the study as late entry is possible. Time reflects duration in study. Seeing as age is used as the time scale in the remaining study, time should not be an issue. Nevertheless, as the current study draws on longitudinal data from a period of 19 years, a sensitivity

analysis is conducted to test the impact of time. Time is split into 5-year intervals: up to 5 years, more than 5 years, more than 10 years and more than 15 years. A cox regression using time as the time scale is run interacting the time groups with BMI groups. Age is added as a covariate. The interaction between BMI and time is insignificant (see appendix H1). This implies that the time spent in the study does not have any effect. Another attempt using only two categories for time is tested. Time under 5 years to consider all individuals who drop out rather early. This interaction term is also insignificant (see appendix H2).

Returning to the Epidemiological Transition model, it can be argued that Germany belongs in the fourth stage. Mortality attributable to obesity is below 5% for women and men. No excess mortality can be attributed to overweight. The widespread availability of blood pressure medication is a likely reason for low mortality among the overweight population. The proportion of obese women and men is not as high as expected. This could support the argument that behavioural change to limit the risk factor is under way. However, underreporting of BMI is probable. Additionally, data from German health surveys, using anthropometric measurement tools, convey that obesity is in fact more prevalent than these results suggest and increasing over time. According to the results, the majority of Germans never exercise, which would be the primary way to prevent obesity, alongside a change in diet. If the overweight population remains the same but the obese population increases, the non-overweight population must be shrinking. While a plateaued level of overweight over time is better than an increase in overweight, the increase in the prevalence of obesity suggests that more individuals are moving from non-overweight to overweight and more individuals are moving from overweight to obesity. The obesity epidemic still exists and does not appear to be contained soon.

6.1 Limitations

Results must be taken with caution. Seeing as there is no information on the cause of death, individuals can die from non-weight related causes, inferring a competing risk problem. However, cause of death information is increasingly inaccurate. Medical records are not examined and autopsies are not carried out for every death (Mikkelsen et al., 2020). Even if the cause of death is known, the death may be a consequence of obesity, such as cardiovascular disease, rather than the risk factor itself. The Cox proportional hazards regression does not infer causality; it allows for a comment on the association between covariates and the event.

The exclusion of individuals with any missing variables decreased the sample size by a substantial amount. Instead, variables could have been imputed and thereby maintained the original size of the sample. Refraining from a time-dependent analysis assumes that all variables are held constant over time. This is faulty as BMI, partner status, income, level of physical activity and smoker status can change over time. This decreases the validity of the study. The measure of BMI is limited. Waist-to-hip ratio is a more accurate measure of health than BMI as abdominal obesity can be identified (Green, 2016). However, data on waist-to-hip ratio is rare in non-health centred surveys whereas BMI is measured in numerous social surveys. In the data used, BMI is calculated based on self-reported weight and height measurements in the individual questionnaire. Weight is systematically underestimated and height is overestimated by individuals, leading to a systematic underestimation of BMI (RKI, 2015). It is likely that BMI has a greater effect than stated.

7 CONCLUSION

Overweight is more common among men than among women in Germany. The prevalence of obesity is similar between the sexes. Nevertheless, women genetically have a higher chance of becoming obese. Obesity may induce a higher risk of death for women than for men. More female than male deaths in Germany can be attributed to obesity with 5 % and 3 % respectively. Albeit the results are positive for overweight women and men in Germany, the issue of obesity is urgent, with almost 24,000 excess deaths in one year. The prevalence of overweight has remained stable in Germany for the last 20 years whereas the prevalence of obesity has risen (RKI, 2015). As this trend continues, more Germans face the consequences of obesity and ultimately, a higher risk of death. It is vital that inequalities are addressed and that solutions are taught, particularly in terms of behavioural change. This could decrease cardiovascular deaths further and delay deaths to very old age and thereby place Germany in Olshanksy & Ault's (1986) fourth stage of the Epidemiological Transition Model. Preventive health should be explored to a greater extent in Germany. After all, overweight may not be detrimental, but it is on the path to obesity. As mentioned earlier, studies have shown that returning to healthy weight after experiencing obesity is highly unlikely.

The risk factors overweight and obesity are not frequently found in demographic journals anymore. Mehta & Chang's (2009) paper in *Demography* is a valuable study which has not been replicated until now. As the German population and many other countries are facing a worsening obesity epidemic,

more research should be conducted into the consequences of the risk factors to the population. Similar to tobacco and alcohol consumption, overweight and obesity are topics which need studying from a demographic perspective.

7.1 Future research and recommendations

Future research should consider measuring individuals to get more accurate weight and height measurements than from self-reports. In that case, waist-to-hip ratios can also be measured, which have been found to be more useful in assessing health in relation to weight for women (Bellocco et al. 2010). Further covariates that can be included in a Cox regression in the future are dietary patterns, alcohol consumption, frequency of walks and other low-level activities.

Childhood obesity is on the rise. Adipose children and teens have been found to have an increased cardiovascular risk profile at their age already (RKI, 2015). Prospective cohort studies should therefore begin from childhood onward. Craving at young age is not psychological as it is to a part in adults. Children know when they are satiated. If children engage in overeating at an early age, they lose the sensation of satiation forever. This is irreversible (Deggerich et al., 2023). Time-dependent studies would provide more valuable information about changes in the mortality risk from overweight and obesity over the life course. It is of essence that obesity is prevented, particularly among the young and overweight population (Ochner et al., 2015).

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9 APPENDIX

9.1 Appendix A

Appendix A1. Abstract (English)

The high prevalence of overweight and increasing prevalence of obesity among German women and men is worrying. The risk of death due to obesity has been compared to that of smoking, yet has not been investigated to the extent of other notable risk factors, such as tobacco and alcohol consumption. Particularly, research into the mortality of overweight and obese men and women is sparse in Germany. Mehta & Chang (2009) provide estimates for weight attributable mortality in the U.S. in their paper published in *Demography*. Using data from the Socio-Economic Panel (SOEP) Germany (2002 – 2020), overweight and obesity attributable mortality is estimated for German women and men, and compared to that found by Mehta & Chang (2009) in the U.S. 5% of female and 3% of male deaths in Germany can be attributed to obesity. Overweight does not cause any excess deaths. The findings suggest that overweight is no concern in Germany but action is needed to prevent further loss of life from obesity, especially among women. The obesity epidemic is still relevant, not only in the U.S. but also in Germany.

Appendix A2. Abstract (German)

Sowohl die hohe Prävalenz von Übergewicht und als auch die zunehmende Prävalenz von Adipositas bei deutschen Frauen und Männern sind besorgniserregend. Das durch Adipositas bedingte Sterberisiko wird mit dem des Rauchens verglichen, es ist jedoch nicht so gründlich untersucht worden wie andere nennenswerte Risikofaktoren wie Tabak- und Alkoholkonsum. Es mangelt im Besonderen an Studien, die sich mit der Sterblichkeit von Übergewicht und Adipositas bei Frauen und Männern in Deutschland auseinandersetzen. Mehta & Chang (2009) liefern in ihrer in der Zeitschrift *Demography* veröffentlichten Arbeit Schätzungen zur gewichtsbedingten Sterblichkeit in den USA. Daten des Sozio-ökonomischen Panels (SOEP) von 2002 bis 2020 werden verwendet, um die auf Übergewicht und Adipositas zurückzuführende Sterblichkeit deutscher Frauen und Männer zu berechnen und mit der von Mehta & Chang (2009) für die USA ermittelten Sterblichkeit zu vergleichen. 5 % der weiblichen und 3 % der männlichen Todesfälle lassen sich auf Adipositas zurückführen. Übergewicht verursacht keine zusätzlichen Sterbefälle. Die Ergebnisse deuten darauf hin, dass Übergewicht in Deutschland kein Grund zur Besorgnis ist, dass aber Maßnahmen erforderlich sind, um weitere Todesfälle, besonders bei Frauen, durch Adipositas zu verhindern. Die Adipositas-Epidemie ist nach wie vor aktuell, nicht nur in den USA, sondern auch in Deutschland.

9.2 Appendix B

Table B1. Log-rank test of Cox proportional hazards regressions, SOEP participants 2002 – 2020

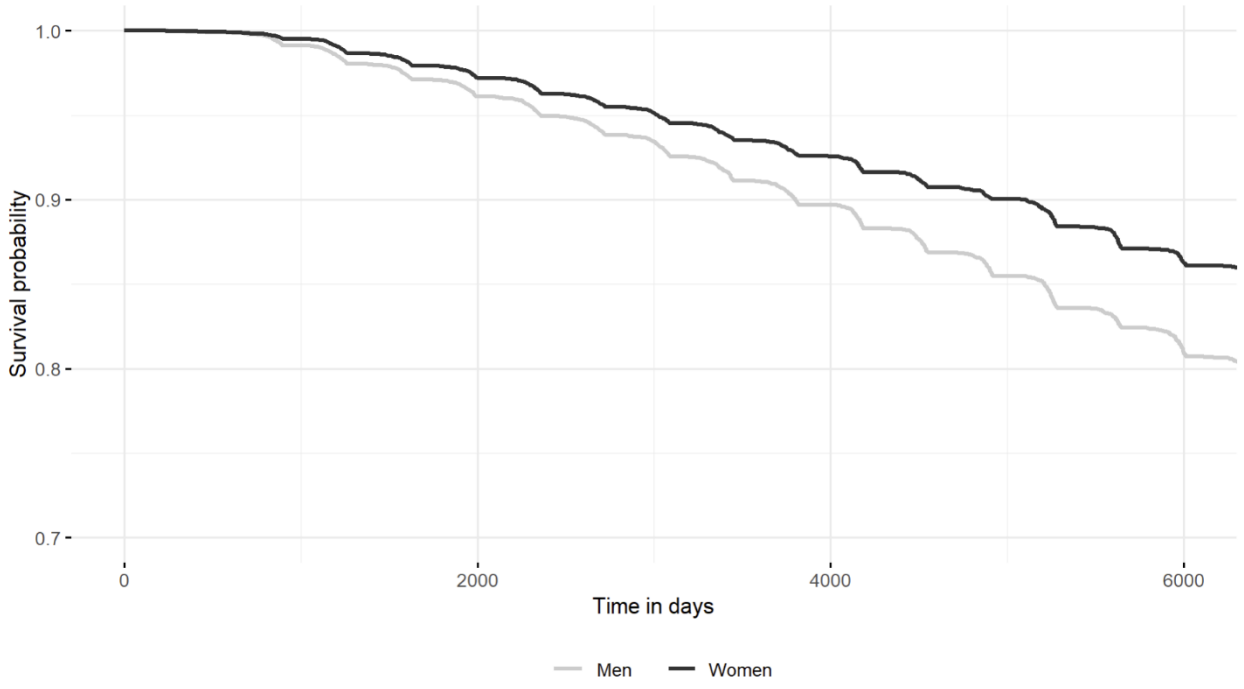
	Women	Men
Model	p-value	
1	**< 0.001**	**< 0.001**
2	**< 0.001**	**< 0.001**
3	**< 0.001**	**< 0.001**
4	**< 0.001**	**< 0.001**
5	**< 0.001**	**< 0.001**
6	**< 0.001**	**< 0.001**

Notes. Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW.

All models are highly significant for women and men.

9.3 Appendix C

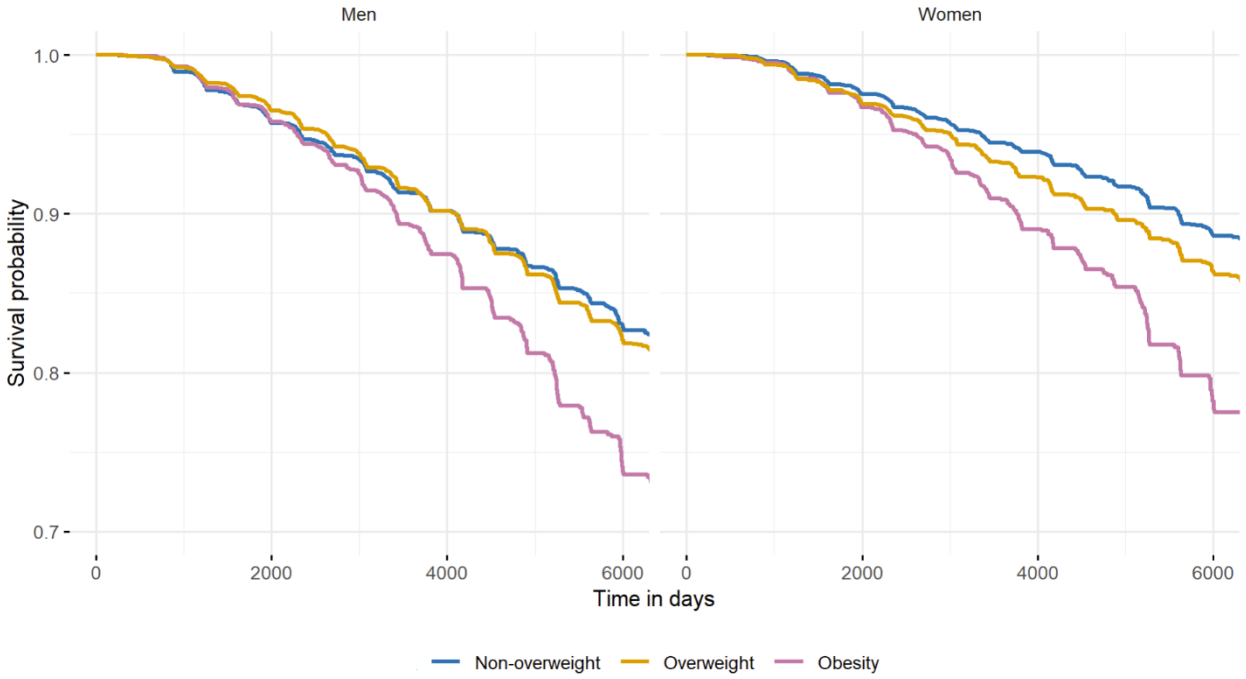
Figure C1. Kaplan-Meier survival probability estimates per sex using time in days as time scale, SOEP participants 2002 – 2020.



Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

The Kaplan-Meier curves in Figure C1 visualise the female survival advantage over men. The survival probability is more than 0.05 higher for women than for men by the end of the study period.

Figure C2. Kaplan-Meier survival probability estimates by BMI group for men and women using time in days as time scale, SOEP participants 2002 – 2020.



Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

Female Kaplan-Meier curves clearly show that non-overweight is associated with the highest survival probability and obesity is associated with the lowest. There is a difference of more than 0.1 by the end of the study period. Male Kaplan-Meier curves show the same pattern for obesity, yet a less clear difference between non-overweight and overweight. Initially, overweight is associated with highest survival probability, yet after 4000 days or 11 years, non-overweight is associated with the highest chance of survival. The Kaplan-Meier curves of non-overweight and overweight men cross, suggesting that there is no significant difference between the two groups.

Table C1. Cox proportional hazard ratios, using time as time scale, SOEP participants 2002 – 2020.

	Women (N = 21,226)						Men (N = 20,113)					
Variable	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh)	**Model 5** (+ health 1)	**Model 6** (+ health 2)	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh)	**Model 5** (+ health 1)	**Model 6** (+ health 2)
BMI (Ref: Non-overweight)												
Overweight	**1.24*** **	**0.88***	**0.84****	**0.84****	**0.84*** **	**0.85*** **	0.99	**0.82*** **	**0.80*** **	**0.84****	**0.84****	**0.84****
Obesity	**1.73*** **	**1.27*** **	**1.20****	**1.17***	1.08	1.11	**1.37*** **	**1.21****	1.10	**1.14***	1.09	1.10
Age		**1.09*** **	**1.09*** **	**1.09*** **	**1.09*** **	**1.09*** **		**1.09*** **	**1.09*** **	**1.09*** **	**1.09*** **	**1.09*** **
Partner status (Ref: Single)												
Partner		1.12	1.17	1.13	1.13	1.13		**0.76***	0.81.	0.81.	0.86	0.85
Married/registered partner		**0.77*** **	**0.80*** **	**0.83****	**0.84****	**0.84****		**0.62*** **	**0.64*** **	**0.69*** **	**0.69*** **	**0.70*** **
Education (Ref: Less than high school)												
High school			**0.88***	0.93	0.94	0.94			0.90	0.97	**0.98**	**0.96**
More than high school			**0.72*** **	**0.83***	0.85	0.84.			**0.64*** **	**0.79***	**0.80***	**0.79***
Income (Ref: Low)												
Medium			0.93	0.99	1.00	1.00			**0.79*** **	**0.86****	**0.89***	**0.88***
High			0.86.	0.97	0.99	0.99			**0.68*** **	**0.78****	**0.84****	**0.83****
Physical activity (Ref: Never)												
Rarely				1.75	**0.77****	**0.76****				0.72	**0.77*** **	**0.76*** **
Once a month				0.41	**0.43*** **	**0.43*** **				0.70	**0.80.**	**0.78.**
Once a week				**1.53****	**0.57*** **	**0.57*** **				**0.59***	**0.65*** **	**0.65*** **
Daily				**0.57*** **	**0.59****	**0.59****				**0.65*** **	**0.72***	**0.71****
Smoker status (Ref: non-smoker)												
Smoker				**1.71*** **	**1.72*** **	**1.71*** **				**1.67*** **	**1.64*** **	**1.62*** **
General health (Ref: low)												
Medium					**0.58*** **						**0.49*** **	
High					**0.67****						**0.31*** **	
Health satisfaction (Ref: very low)												
Low						**0.69*** **						**0.70*** **
Medium						**0.46*** **						**0.48****
High						**0.43*** **						**0.38*** **
Very high						**0.43*** **						**0.33****

Cox proportional hazard ratios using age as time scale. Model 2 adjusts for demographic characteristics (age and partner status). Model 3 adds socioeconomic status (education and equivalised disposable income). Model 4 adds behavioural factors (physical activity and smoker status). Model 5 adds general health level. Model 6 adds satisfaction with own health. Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

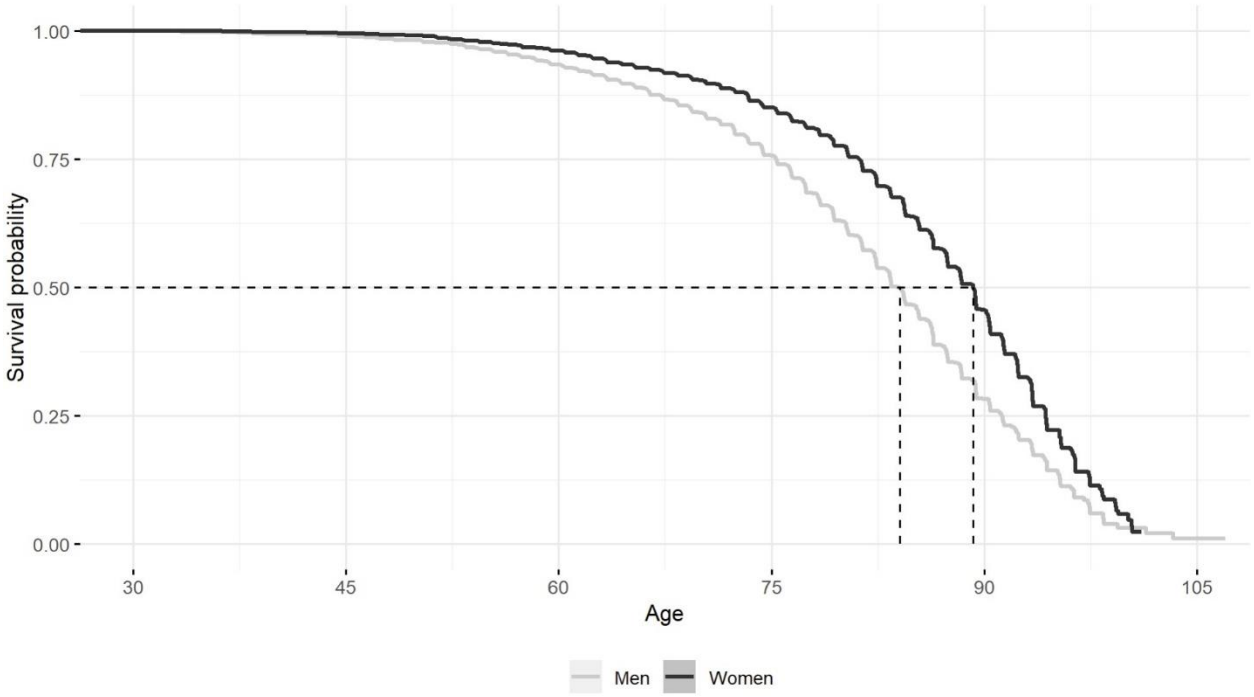
The unadjusted model in Table C1 suggests that there is a strong relationship between both overweight and obesity and risk of death for women. Overweight females had a 24% increased risk of death compared to women of normal weight. Obese females had a 73% increased risk of death. For men, there is a significant effect among the obese individuals but not among the overweight individuals. Obesity increases the hazard by 37% for men.

Adjusting for demographic factors in model 2, the results change in some respects. The risk of death decreased to 27% for obese women. Overweight women have a 12% decreased risk of death compared to women of normal weight. Age is positively associated with an increased risk of death (9%). This could imply that age played a significant role in the HR of overweight women. As non-overweight women have a younger age distribution than overweight women, they have a lower risk of death. However, when controlling for age, this phenomenon disappears and overweight is associated with a lower risk of death than non-overweight. For all further models this holds.

Socio-economic variables are added in the third model. For women obesity results in a 20% increased risk of death. Among overweight women the hazard is reduced by 16%. The risk of death of obesity decreases by 10% for men whereas overweight reduces the hazard by 20%. Behavioural factors are added in the fourth model. Obesity increases the risk of death by 17% for women and by 14% for men. Overweight decreases the risk by 16% for both sexes. The fifth and sixth models control for health status. For women, overweight still protects from the mortality risk by 16% whereas obesity increases the risk by 8 and 11% in Model 5 and Model 6 respectively. The results are similar for men with the same protective factor for overweight and a 9% and 11% increased risk of death for obesity.

9.4 Appendix D

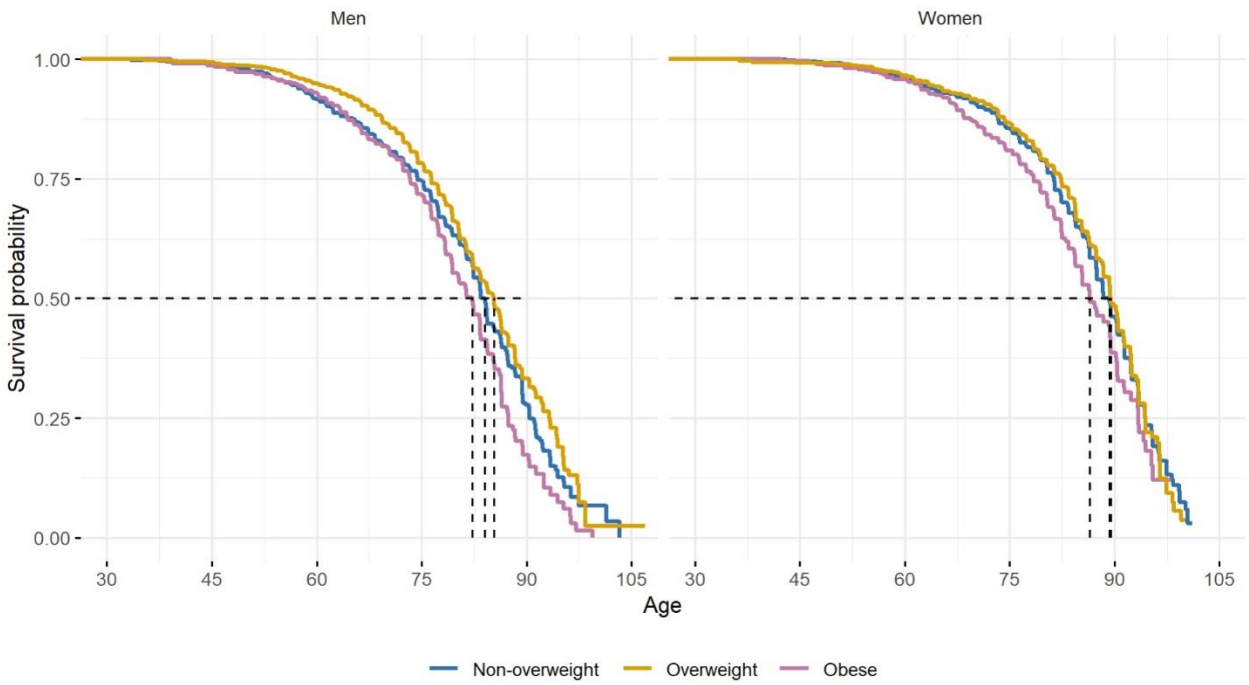
Figure D1. Kaplan-Meier survival probability estimates per sex using age as time scale SOEP participants 2002 – 2020



Notes. Only participants who entered in 2002. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

The Kaplan-Meier curves visualise the female survival advantage across the lifespan (above age 30). The median survival probability of women is at age 88 whereas it is four years lower for men.

Figure D2. Kaplan-Meier survival probability estimates by BMI group for men and women using age as time scale, SOEP participants 2002 – 2020.



Notes. Only participants who entered in 2002. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

Female Kaplan-Meier curves clearly show that obesity is associated with the lowest survival probability. The survival curves of overweight and non-overweight women are almost identical. The Kaplan-Meier curves of overweight and non-overweight women cross, suggesting that there is no significant difference between the two groups. Male Kaplan-Meier curves show a more distinct higher survival probability among overweight men. The non-overweight and obese curves cross at an early age which could be due to underweight cases included in the non-overweight group or due to the few number of deaths at mid age. From age 70 onwards obesity is associated with the lowest survival probability among men.

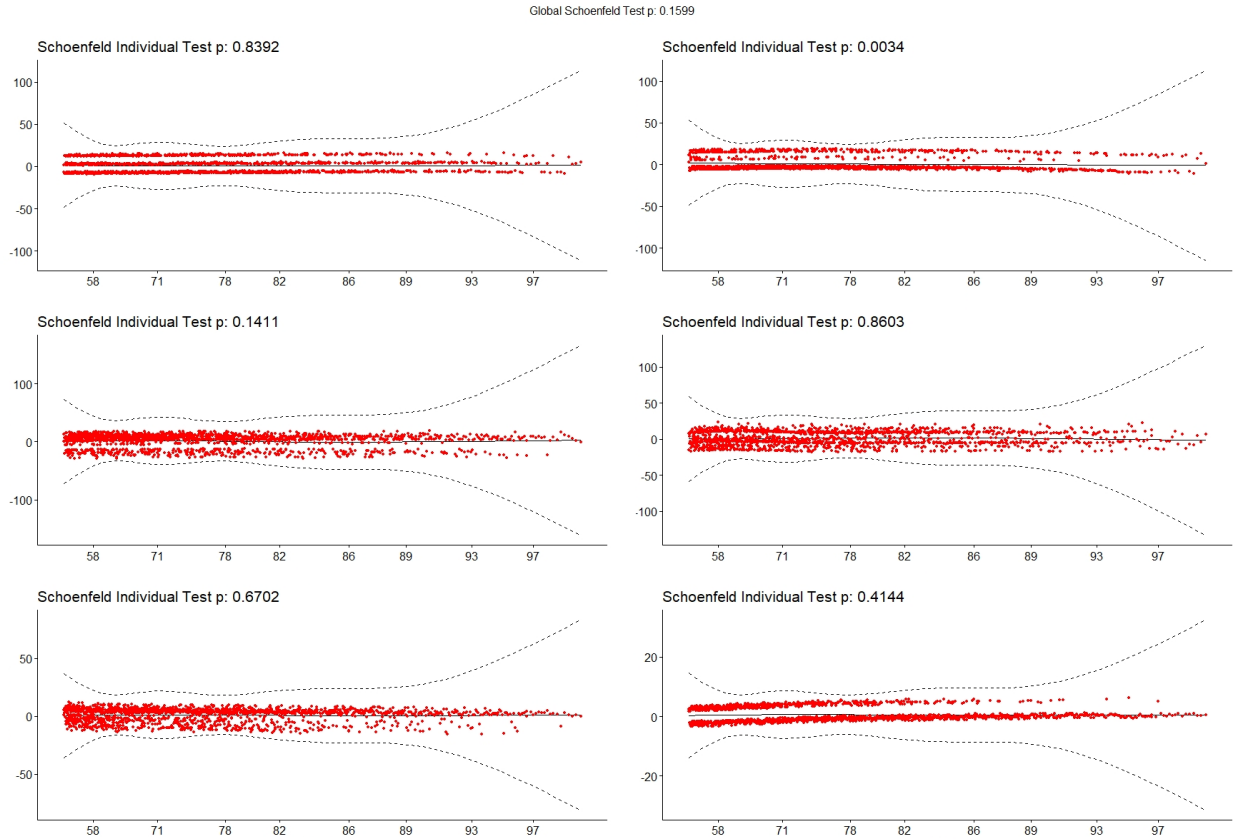
Table D1. Cox proportional hazard ratios, SOEP participants 2002 – 2020. Survey entry in 2002

	Women (N = 8,554)						Men (N = 9,158)					
Variable	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh)	**Model 5** (+ health 1)	**Model 6** (+ health 2)	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh)	**Model 5** (+ health 1)	**Model 6** (+ health 2)
BMI (Ref: Non-overweight)												
Overweight	0.94	0.95	0.91	0.92	0.92.	0.92.	**0.86****	**0.88***	**0.83****	0.88.	**0.90****	**0.90****
Obesity	**1.29****	**1.28****	**1.22***	**1.22***	**1.13***	**1.16****	**1.25***	**1.26****	1.12	**1.19***	1.18.	**1.18***
Partner status (Ref: Single)												
Partner		1.18	1.26	1.25	**1.26***	**1.27***		**0.70***	0.78	0.77.	0.83	0.81
Married/registered partner		**0.84***	**0.86***	0.90	0.91	0.92		**0.62*****	**0.65*****	**0.71*****	**0.96*****	**0.72*****
Education (Ref: Less than high school)												
High school			0.96	0.99	1.02	1.01			0.89	0.97	0.96	0.95
More than high school			0.84	0.93	0.96	0.95			**0.78*****	**0.75***	0.76	0.74
Income (Ref: Low)												
Medium			0.99	1.04	1.05	1.04			**0.80*****	**0.85***	**0.87***	**0.87***
High			**0.78****	0.86	0.87	0.88			**0.65*****	**0.74*****	**0.79****	**0.79****
Physical activity (Ref: Never)												
Rarely				0.81.	0.83	0.83				**0.72*****	0.79.	**0.78***
Once a month				**0.42*****	**0.45*****	**0.46*****				0.84	0.98	0.96
Once a week				**0.56*****	**0.60*****	**0.61*****				**0.56*****	**0.63*****	**0.63*****
Daily				**0.57****	**0.60***	**0.61***				**0.60****	**0.67***	**0.65***
Smoker status (Ref: non-smoker)												
Smoker				**1.85*****	**1.91*****	**1.91*****				**1.80*****	**1.82*****	**1.83*****
General health (Ref: low)												
Medium					**0.57*****						**0.49*****	
High					**0.77****						**0.33*****	
Health satisfaction (Ref: very low)												
Low						**0.73****						**0.65*****
Medium						**0.50*****						**0.46*****
High						**0.47*****						**0.36*****
Very high						**0.43*****						**0.35*****

Cox proportional hazard ratios using age as time scale. Late entry is excluded. Model 2 adjusts for demographic characteristics (partner status). Model 3 adds socioeconomic status (education and equivalised disposable income). Model 4 adds behavioural factors (physical activity and smoker status). Model 5 adds general health level. Model 6 adds satisfaction with own health. Significant results are in bold. p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

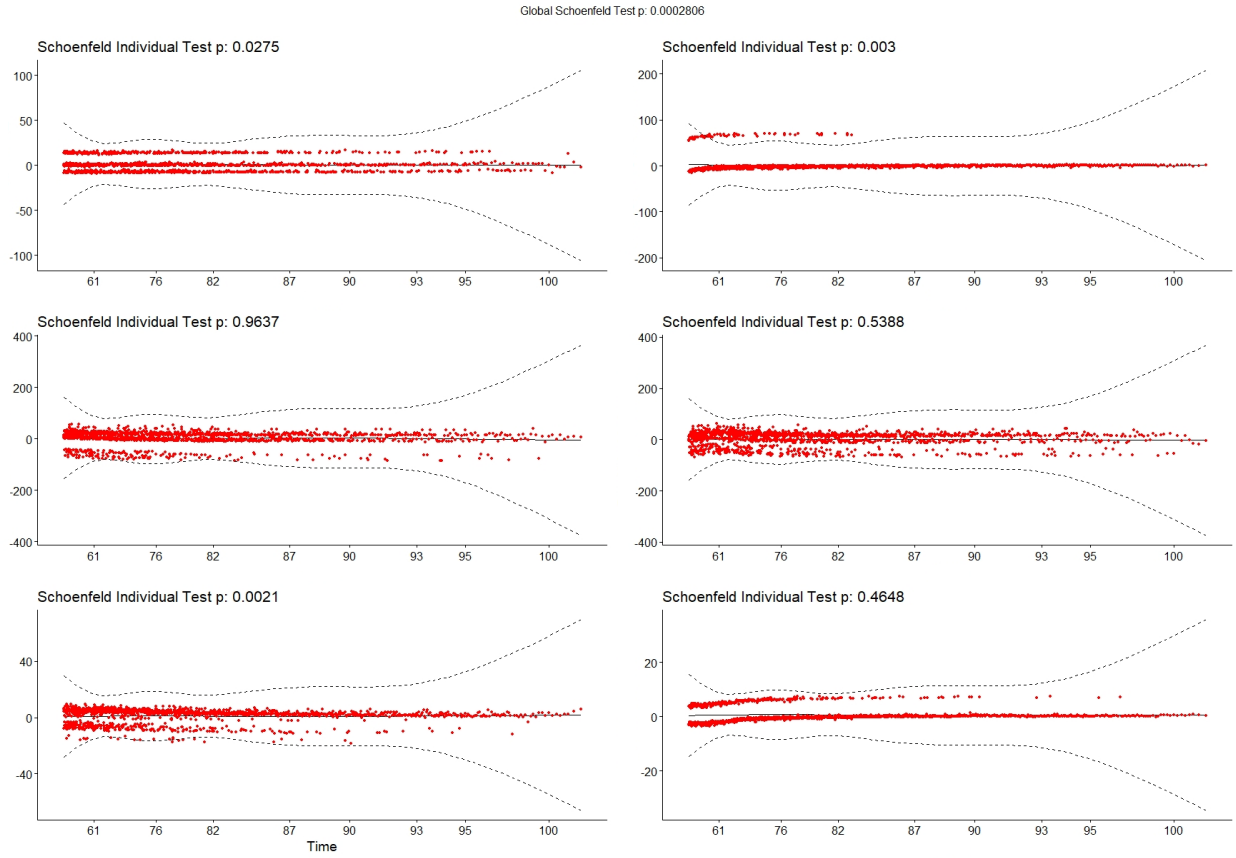
9.5 Appendix E

Figure E1. Schoenfeld residuals for all covariates from Model 4 for men in Table 11



Notes. Beta for covariates; in clockwise direction: BMI, partner status, household income, smoker status, level of physical activity, level of education. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

Figure E2. Schoenfeld residuals for all covariates from Model 4 for women in Table 11



Notes. Beta for covariates; in clockwise direction: BMI, partner status, household income, smoker status, level of physical activity, level of education. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

9.6 Appendix F

Table F1 on the next page shows that the mortality risk of obesity remains significant when nutrition is accounted for. In the fully adjusted model 4, obese women have a 22% increased risk of death compared to non-overweight women. Overweight women have a 12% decreased risk of death. In the fully adjusted model, obese men have a 24% increased risk of death compared to non-overweight men. Overweight men have a 16% decreased risk of death. These results resemble the HR in Table 11.

Table F1. Cox proportional hazard ratios, including nutrition as covariate, SOEP participants 2002 – 2020

	Women (N = 8,554)				Men (N = 9,158)			
Variable	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh)	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh)
BMI (Ref: Non-overweight)								
Overweight	0.91	0.91	0.88.	0.88.	**0.83****	**0.85****	**0.81*****	**0.86***
Obesity	**1.31*****	**1.30****	**1.23****	**1.22****	**1.27*****	**1.29****	**1.16***	**1.24****
Partner status (Ref: Single)								
Partner		1.24	**1.33***	1.28.		0.92	1.00	1.00
Married/registered partner		0.90	0.94	0.98		**0.69*****	**0.72*****	**0.79*****
Education (Ref: Less than high school)								
High school			0.96	0.99			0.94	1.02
More than high school			**0.79***	0.89			**0.69*****	0.83.
Income (Ref: Low)								
Medium			0.91	0.96			**0.83****	**0.88***
High			**0.79****	0.88			**0.61*****	**0.70*****
Physical activity (Ref: Never)								
Rarely				0.88				**0.82***
Once a month				**0.50*****				0.85
Once a week				**0.56*****				**0.62*****
Daily				**0.60****				**0.68****
Smoker status (Ref: non-smoker)								
Smoker				**1.86*****				**1.89*****
Health conscious diet (Ref: none)								
Somewhat				0.78.				0.92
Strictly				**0.73***				0.85.
Very strictly				0.90				0.99

Notes. Cox proportional hazard ratios using age as time scale. Late entry is excluded. Model 2 adjusts for demographic characteristics (partner status). Model 3 adds socioeconomic status (education and equivalised disposable income). Model 4 adds behavioural factors (physical activity, smoker status and nutrition). Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

9.7 Appendix G

Table G1 on the next page shows that the mortality risk of obesity remains significant when alcohol consumption is accounted for. In model 4 including beer consumption, obese women have a 30% increased risk of death compared to non-overweight women. Overweight women have a 1% decreased risk of death, although this is not statistically significant. In model 5 incorporating wine consumption, obese women have a 28% increased risk of death. Overweight women have a 3% decreased risk of death, which is not statistically significant. In model 4 and model 5, obese men have a 32% increased risk of death compared to non-overweight men. Overweight men do not appear to have a different mortality risk to non-overweight men. The results for the BMI group obesity reinforce the HR in Table 11. The results for the BMI group overweight are not as powerful

Table G1. Cox proportional hazard ratios, including alcohol consumption as covariates, SOEP participants 2002 – 2020

	Women (N = 9,752)					Men (N = 9,026)				
Variable	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh1)	**Model 5** (+ beh2)	**Model 1** (crude)	**Model 2** (+ dem)	**Model 3** (+ SES)	**Model 4** (+ beh1)	**Model 5** (+ beh2)
BMI (Ref: Non-overweight)										
Overweight	**1.26****	**1.24****	1.09	0.99	0.97	1.06	1.08	1.06	1.01	1.00
Obesity	**1.93*****	**1.82****	**1.56****	**1.30****	**1.28****	**1.61*****	**1.63*****	**1.49*****	**1.32****	**1.32****
Partner status (Ref: Single)										
Partner		**0.27*****	**0.41*****	**0.32*****	**0.33*****		**0.43*****	**0.48*****	**0.52*****	**0.53*****
Married/registered partner		**0.38*****	**0.31*****	**0.41*****	**0.42*****		**0.72*****	**0.76*****	**0.76*****	**0.75*****
Education (Ref: Less than high school)										
High school			**0.55*****	**0.69*****	**0.75*****			0.92	1.16	1.15
More than high school			**0.34*****	**0.47*****	**0.53*****			**0.72***	1.07	1.06
Income (Ref: Low)										
Medium			0.97	1.09	1.16.			**0.69****	**0.82****	**0.81****
High			0.85	1.14	1.11			**0.50*****	**0.63*****	**0.63*****
Physical activity (Ref: Never)										
Rarely				**0.44*****	**0.46*****				**0.38*****	**0.38*****
Once a month				**0.24*****	**0.25*****				**0.38*****	**0.38*****
Once a week				**0.32*****	**0.33*****				**0.32*****	**0.32*****
Daily				**0.35****	**0.36*****				**0.43*****	**0.43*****
Smoker status (Ref: non-smoker)										
Smoker				**0.72*****	**0.70*****				0.89.	**0.86***
Beer consumption (Ref: none)										
Rarely				**0.70*****					**0.79***	
From time to time				**0.76***					**0.66*****	
Regularly				1.22					**0.83***	
Wine consumption (Ref: none)										
Rarely					**0.66*****					**0.77*****
From time to time					**0.62***					**0.80****
Regularly					0.70.					1.05

Notes. Cox proportional hazard ratios using age as time scale. Late entry is excluded. Model 2 adjusts for demographic characteristics (partner status). Model 3 adds socioeconomic status (education and equivalised disposable income). Model 4 adds behavioural factors (physical activity, smoker status and beer consumption). Model 5 adds behavioural factors (physical activity, smoker status and wine consumption). Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

9.8 Appendix H

Table H1. Interaction of BMI with time, using four time intervals, SOEP participants 2002 – 2020

	WOMEN (N = 21,226)	**MEN** (N = 20,113)
BMI (Ref: Non-overweight)		
Overweight	**0.87***	**0.80*****
Obesity	**1.27*****	**1.18***
Age	**1.09*****	**1.09*****
Overweight × **Time** (Ref: Less than 5 years)		
5 – 10 years	1.23	0.97
10 – 15 years	1.25	1.12
More than 15 years	1.07	0.97
Obesity × **Time** (Ref: Less than 5 years)		
5 – 10 years	0.91	1.20
10 – 15 years	0.77	1.10
More than 15 years	0.92	1.51.

Notes. Cox proportional hazard ratios using time as time scale. Age is included as a covariate. Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

The HR in Table H1 suggest that the interaction effect between time and BMI is not significant for women or men.

Table H2. Interaction of BMI with time, using two time intervals, SOEP participants 2002 – 2020

	WOMEN (N = 21,226)	**MEN** (N = 20,113)
BMI (Ref: Non-overweight)		
Overweight	**0.87***	**0.80*****
Obesity	**1.27*****	**1.18***
Age	**1.09*****	**1.09*****
Overweight × **Time** (Ref: Less than 5 years)		
More than 5 years	1.07	0.97
Obesity × **Time** (Ref: Less than 5 years)		
More than 5 years	0.92	1.51.

Notes. Cox proportional hazard ratios using time as time scale. Age is included as a covariate. Significant results are in bold. .p < .1; *p < .05; **p < .01; ***p < .001. Data source: SOEP core 1984 – 2020 (v.37), from DIW; calculations: author's own.

The HR in Table H2 resemble the results in the previous Table H1. There appears to be no significant interaction effect between time and BMI.