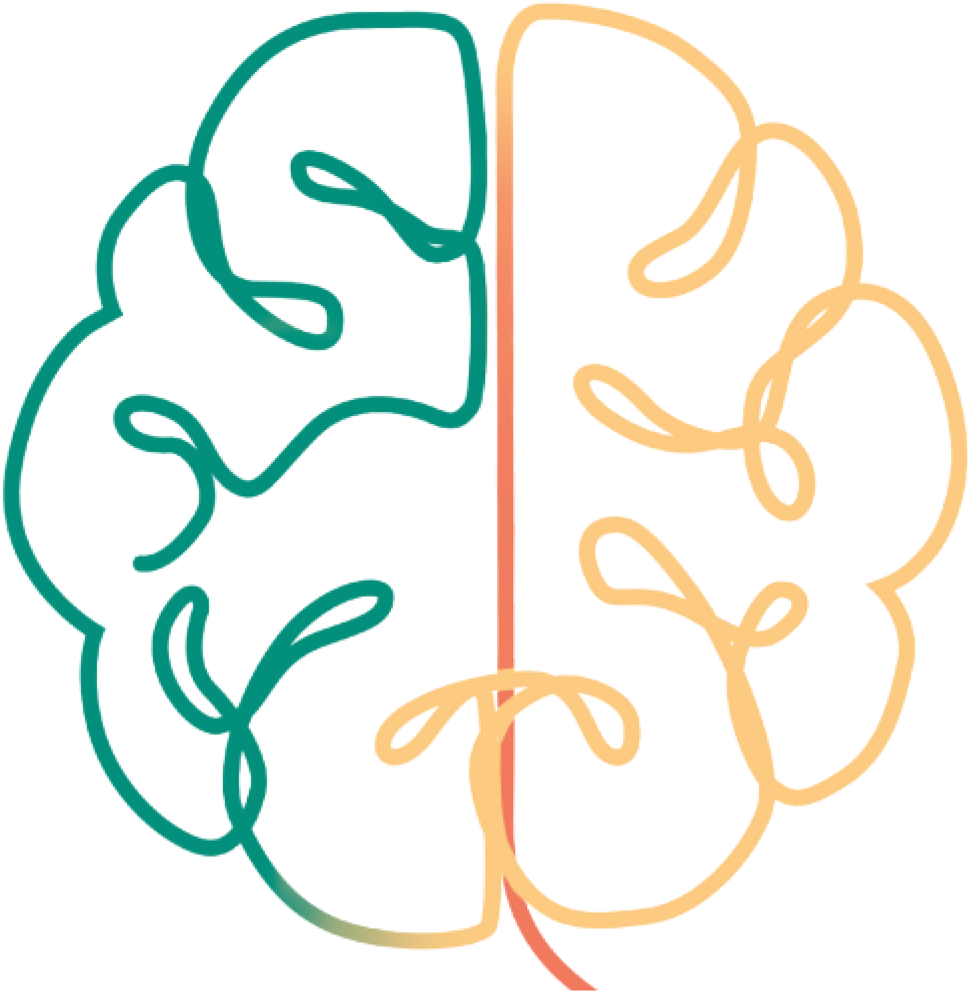
Decline in cognitive function of older adults:
The relative effects of lifestyle factors for Europeans aged 50+



(WHO, 2019)

Master thesis

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Abstract

Ageing naturally occurs with a decline of cognitive function, starting with a ‘silent’ phase without visible symptoms. Slowing down this process of cognitive decline is of great interest for a healthy life and wellbeing at older ages. The individual and clustered effects of the modifiable lifestyle factors nutrition, physical activity, alcohol use and smoking behaviour are associated with the rate of cognitive decline. This study analyses the relative importance of the individual and clustered effects of these lifestyle factors on cognitive decline for the population aged 50+ in Europe.

The effects of lifestyle factors on cognitive decline are estimated with linear regressions using longitudinal data from the Survey of Health, Ageing and Retirement in Europe (SHARE) and controlled for the effects of age, gender, number of chronic diseases, marital status, level of education and type of welfare state. Cognitive function is assessed via a 0-30 composite score based on immediate recall, delayed recall and verbal fluency and healthy lifestyle factors on daily fruit and vegetable intake, weekly physical activity, light to moderate alcohol use and non-smoking.

The results indicate only a significant individual negative effect of -.41 (CI -0.65 to -0.17) on the Cognitive Function Score from not engaging in physical activity at least once a week. When clustering the effects of lifestyle factors, only engaging in 3 or 4 unhealthy lifestyle behaviours as opposed to 0 has a significant negative effect of -0.53 (CI -0.99 to -0.07) on the Cognitive Function Score.

Physical activity is found to have the greatest relative importance for slowing down the process of cognitive decline in early phases over nutrition, alcohol use and smoking behaviour. The combination of healthy lifestyle behaviours has a greater potential for slowing down cognitive decline than focussing on only one or two of these behaviours. Therefore, health policy should stimulate a balanced healthy lifestyle with a central place for regular physical activity.

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Introduction

In its constitution, the World Health Organization (1946) puts forward a holistic definition of health as the combination of complete physical, mental and social well-being taking it beyond merely the absence of disease or infirmity. According to Kuh (2019) mental well-being refers to a combination of cognitive health and emotional function. Ageing comes with a gradual accumulation of molecular and cellular damage (Kuh, 2019) which leads to a lower physical and cognitive functioning. For older adults this means that their level of cognitive functioning has already peaked and keeps declining throughout the remainder of life (Calder et al. 2018). Cognitive decline starts with a 'silent' phase without visible symptoms (Monsch et al. 2019). If the cognitive decline is faster than expected, with regards to age and educational level, it is defined as mild cognitive impairment (MCI) and will have minor effects on activities of daily life (Moore et al. 2018). However, 50% of the individuals with MCI are estimated to develop dementia within 5 years (Moore et al. 2018). Dementia is a major cognitive impairment which is characterised by the progressive deterioration of cognitive domains resulting in impaired daily functioning (Moore et al. 2018). Slowing down the process of cognitive decline is important for persons to be able to reach their potential throughout the life course (World Health Organization, 2022). An important part of the potential is to remain healthy at the end of one's life and be able to function daily. Hereby cognitive health at older ages is of great interest for the wellbeing of individuals and their families. Furthermore, optimising cognitive health will reduce the burden of neurological disorders which hampers social and economic development around the globe (World Health Organization, 2022).

In the academic domain of healthy ageing, most research has focused on risk factors in relation to physical health outcomes like functioning, chronic disease and mortality (Sabia et al. 2012). However, health is a multidimensional concept (Sabia et al. 2012) and there is no treatment to modify the course of dementia (Dominguez et al. 2021). Therefore, the attention of this study is drawn to cognitive decline before the onset of dementia known as the 'silent' phase. Most studies addressing cognitive function use measures related to verbal memory, processing speed, executive function (Kuh, 2019). The main risk factors for cognitive decline are the non-modifiable factors of advanced age (Dominguez et al. 2021) followed by genetic susceptibility (Calder et al. 2018). Therefore the attention of this study is drawn to the potential of modifiable risk factors to slow down cognitive decline e.g. lifestyle. Lifestyle factors that are linked to cognitive decline include smoking, alcohol use, nutrition, physical inactivity and mentally and socially stimulating activities (Calder et al.2018). Also certain medical conditions like hypertension, diabetes, hypercholesterolemia, obesity and depression are found to increase cognitive decline (WHO, 2019). In the academic literature there is an increasing interest in the clustered effects of the aforementioned lifestyle factors on health outcomes (Sabia et al. 2012).

Despite the results of previous research on cognitive decline, more research is needed to specify the effects of lifestyle factors and their relative importance. Although Celedoni et al. (2017) found that memory and verbal fluency declines with age and especially after retirement, they stress that further research is needed to characterise the factors driving the heterogeneity which is still found in this association. To address the heterogeneity mentioned by Celedoni et al. (2017) this study uses the same extensive longitudinal dataset with similar assessment of cognition. Already in 2009, Sabia et al. (2009) found in a London-based sample that a combination of unhealthy behaviours leads to accelerated decline in cognitive function (based on memory and executive function) but their data suffers a 50% loss of the baseline population and some measures changed over the waves of data collection. Like Sabia et al. (2009) this study uses a summary score of lifestyle factors based on nutrition, physical activity, alcohol use and smoking behaviour to measure the effects on cognition. In this current study a dataset with a large cross-country pool of respondents is analysed which includes exposure and outcome variables being comparable over time and across countries. However, the current analysis of cognitive decline is a first measurement analysis and should be repeated over time to find within-subject effects over a longer period of time.

Furthermore, this study contributes to the academic literature by expanding the evidence for the effects of clustered lifestyle factors as well as measuring the underlying effects of separate lifestyle factors. Measuring the effects of clustered lifestyle factors addresses the synergistic effects of clustered lifestyle factors as found by Dhana et al. (2020) where the combination of various unhealthy behaviours are worse than the sum of the separate unhealthy behaviours. However, also taking into account the effects of separate lifestyle factors contributes to the study by helping to identify which underlying lifestyle factors are driving the effects on cognitive decline the strongest. Another way in which this current study contributes to the academic literature is that it also looks at the 'silent' phase of cognitive decline. This is done by analysing the relationship between lifestyle and the level cognitive function rather than analysing the relationship between lifestyle and disease incidence.

The objective of this study is to analyse a panel study in order to quantify the effects of lifestyle on cognitive decline and make inferences about the relative importance of the included lifestyle behaviours. Insight into the relative importance of modifiable risk factors for cognitive decline, e.g. lifestyle behaviours, has the potential to help slow down cognitive decline and the associated impaired daily functioning. Therefore, the study aimed at measuring the effects of behavioural factors on cognitive decline at older ages in Europe. In order to measure the effects data from the Survey of Health, Ageing and Retirement in Europe (SHARE) is used containing information on the lifestyle and cognitive performance of Europeans aged 50+ with multiple waves of data collection. The analysis centres around general linear regressions. The sample consists of 1660 participants for which there are a total of 3322 observations.

Based on these lifestyle factors, the measures of cognitive decline and Europeans aged 50 and older being the study population, the main research question of the study is:
"What is the relative importance of the individual and clustered effects of nutrition, physical activity, alcohol use and smoking behaviour on cognitive decline for the population aged 50+ in Europe?"
The main research question will be answered using the following sub-questions:

- How do nutrition, physical activity, alcohol use and smoking behaviour independently influence cognitive decline at older ages?
- How do the clustered effects of nutrition, physical activity, alcohol use and smoking behaviour influence cognitive decline at older ages in Europe?

In the following chapter a theoretical framework on the effects of behavioural factors on cognitive decline at older ages is established based on academic literature, with a resulting conceptual model and leading to hypotheses. The methodology then sets out how the lifestyle effects on cognitive decline at older ages are estimated. In the results the estimates are presented, followed by the discussion where the research questions will be answered using the results. This all leads to the conclusion where recommendations for policy and future research are made.

Theoretical framework

Literature overview

Previous research on the effects of lifestyle factors on cognitive decline often uses dementia- and Alzheimer's disease incidence as a proxy for cognitive decline (Aggarwal et al. 2006; Anastasiou et al. 2017; Dhana et al. 2020; Hamer & Chida, 2009; Sabia et al. 2018). Other studies measured cognitive decline by assessing the function of cognitive domains, e.g. memory and executive function (Anastasiou et al. 2017; Celedoni et al. 2017; Sabia et al. 2009). In the next section various studies analysing the effects of separate lifestyle factors on cognitive decline are discussed, followed by studies focussing on the effects of clustered lifestyle factors. The lifestyle factors comprise nutrition, physical activity, smoking behaviour and alcohol use because these are among the top 10 leading risk factors for death and disability in Western countries (Sabia et al. 2012) and are included in the statistical analysis of this current study.

Nutrition

Nutrition throughout the life course plays a role in preserving cognition for older adults (Calder et al. 2018). Research into effects of nutrition on cognitive decline focuses on separate nutrients as well as on dietary patterns. Vital nutrients considered to prevent cognitive decline are omega-3 polyunsaturated fatty acids (PUFAs), polyphenols and D- and B-vitamins (Calder et al. 2018). Also eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are found to have positive effects on cognition (Moore et al. 2017). Concerning broader dietary patterns the intakes of fruits and vegetables and fish are related to better cognitive health (Calder et al. 2018). The Mediterranean diet is linked to lower cognitive decline (Calder et al. 2018) and is found to have a protective effect on the risk of Alzheimer's disease and to slow down the progression from mild cognitive impairment (MCI) to Alzheimer's (Moore et al. 2017). The Mediterranean diet is characterised by high intakes of fruits, vegetables, fish, olive oil and whole grains (Calder et al. 2018). Also Dietary Approaches to Stop Hypertension (DASH) is often studied (Kivipelto et al. 2018). Adherence to the DASH is associated with better cognition (Dominguez et al. 2021), these effects seem related to the increased risks of cognitive decline from hypertension (Kivipelto et al. 2018). The high intake of red meat, sweets, processed foods and sugar-sweetened beverages are associated with Western dietary patterns and negative health outcomes (Dominguez et al. 2021). Besides the effects of nutrition on cognitive decline, cognitive decline is also related to worsen nutrition intake (Calder et al. 2018) which can lead to a vicious circle with lower nutrient intake, eventually leading to more cognitive decline.

Cross-sectional research from Anastasiou et al. (2017) focussed on the effects of the Mediterranean diet on dementia. Anastasiou et al. (2017) used a 1-4 scale of adherence to the Mediterranean diet based on weekly food consumption for their sample of 1864 respondents. They found the odds ratio for having dementia being 65% lower for people with the highest adherence to the diet as compared to respondents with the lowest adherence. Furthermore, Anastasiou et al. found positive associations between adherence to the Mediterranean diet and the cognitive domains of memory, language, executive functioning and visuospatial perception.

Physical activity

Physical activity is found to prevent and slow down the pathological process of dementia and dementia-related problems (Dominguez et al. 2021). Physical activity leads to a decreased risk of cognitive decline, dementia and Alzheimer's disease (Kivipelto et al. 2018), having a sedentary lifestyle increases these risks (Monsch et al. 2019). Both midlife and late life regular physical activity is associated with a decreased risk of cognitive decline (Kivipelto et al. 2018). People who are already affected by dementia can improve cognition with physical activity and exercise (Dominguez et al.

2021). The optimal type, frequency, duration and intensity of physical activity to reduce cognitive decline is less researched (Kivipelto et al. 2018; Hamer & Chida, 2009).

In their meta-analysis of prospective cohort studies Hamer and Chida (2009) compared studies linking physical activity with incidence of dementia and Alzheimer's disease. The analysis included 163,797 non-demented participants at baseline, drawn from 16 prospective studies. Hamer and Chida (2009) found that respondents falling in the highest category of physical activity have a relative risk of 0.72 for dementia and 0.55 of Alzheimer's disease as compared to the lowest category of physical activity. Physical activity is suggested to reduce the risk of dementia by 28% and of Alzheimer's disease by 45% (Hamer & Chida, 2009).

Smoking behaviour

Tobacco smoking is a broad risk factor for dementia and Alzheimer's disease (Kivipelto et al. 2018). Approximately 14% of Alzheimer's disease incidence is partly attributable to smoking behaviour (Kivipelto et al. 2018). As compared to never having smoked, current smoking has significant negative effects on verbal memory and visual search speed (Davis et al. 2017).

Aggarwal et al. (2006) used a longitudinal analysis of smoking behaviour and Alzheimer's disease incidence. Using their sample of 1064 respondents Aggarwal et al. (2006) found the odds ratio of Alzheimer's disease being 3.4 for current smokers when compared to people without a smoking history. The difference in the risk of Alzheimer's disease between people without a smoking history and former smokers was not statistically significant.

Alcohol use

For alcohol use, not total abstinence but rather light to moderate consumption over the life course is linked to a reduced risk of cognitive decline in the form of dementia (Dominguez et al. 2021; Kivipelto et al. 2018; Sabia et al. 2018). Both abstinence and heavy drinking (>14 drinks/week) are associated with a higher risk of dementia and for people with MCI heavy drinking is also associated with a higher risk of progression to dementia (Dominguez et al. 2021). Therefore the association of alcohol consumption and cognitive decline is expected to be J-shaped or U-shaped (Sabia et al. 2018). Long-term excessive alcohol use increases risks to cognitive problems as mild forms of memory and executive dysfunctions to Wernicke–Korsakoff syndrome (Kivipelto et al. 2018). Excessive alcohol use is linked to a higher risk of cardiometabolic disease, which is in turn linked with a higher risk of dementia (Sabia et al. 2018).

A prospective cohort study from midlife to old age by Sabia et al. (2018) found an alcohol consumption of 1-14 drinks a week to result in the lowest risks of dementia. Based on 9087 participants Sabia et al. (2018) found that compared to long term consumption of 1-14 drinks a week the hazard ratio for dementia is 1.67 for long term abstinence and 1.5 for decreased consumption over the years. The results for long term consumption over 14 drinks a week was no longer significant when adjusted for cardiometabolic disease. However, for those drinking over 14 drinks a week the risk of dementia increases by 17% for each 7 unit increase in alcohol consumption (Sabia et al. 2018).

Clustered lifestyle factors

The clustered effects on cognition from a combination of lifestyle factors has an increasing interest in the academic literature (Sabia et al. 2012) and the effects appear to be higher than the separate effects on cognitive decline (Dhana). The lifestyle factors are likely to have synergistic effects on cognitive decline (Dhana et al. 2020), which means that the combined effect of lifestyle factors is greater than the sum of their independent effects.

Having multiple healthy lifestyle factors at the same time is found to reduce the risk of cognitive decline (Dhana et al. 2020; Sabia et al. 2009). Sabia et al. (2009) used a 0-4 range score of unhealthy lifestyle factors based on smoking, alcohol abstinence, low physical activity, and low fruit and vegetable consumption. Their longitudinal analysis with 5123 participants showed persons combining 3 to 4 unhealthy behaviours (as compared to 0) have an odds ratio for respectively poor executive function and memory of 1.84 and 1.5 in early midlife, 2.38 and 1.59 in midlife and 2.76 and 2.03 in late midlife. Dhana et al. (2020) used a 0-5 score of healthy lifestyle factors in their longitudinal analysis with 2765 participants, taking into account also cognitive activities in late-life. Dhana et al. (2020) found that compared to a 0-1 score having 2 to 3 healthy lifestyle factors has a 37% lower risk of Alzheimer's disease and having 4 to 5 healthy lifestyle factors reduces the risk with 60%. This suggests that the number of unhealthy lifestyle factors and their duration are associated with subsequent cognitive decline in later life (Sabia et al. 2009). Thus, it becomes apparent that the clustering of healthy lifestyle factors has a great potential to lower the risk of cognitive decline.

Other factors influencing cognitive decline

Besides lifestyle factors, other factors also have known effects on cognitive decline. These control variables with effects on cognitive decline comprise age (Kivipelto et al. 2018), gender (Kim, 2020), marital status (Sundström et al. 2016; Formanek et al. 2019), number of chronic diseases , level of education (Ngandu et al. 2008) and welfare regime (Formanek et al. 2019).

Age is included as a control variable as the biological risk factor of advanced age is found to be the most contributing factor to cognitive decline (Kivipelto et al. 2018). As men are found to be more likely to have higher overall levels of cognitive function and women are found to experience steeper decline in cognitive function at advanced ages (Kim, 2020), results are controlled for the effects of gender. These found gender differences are a result of a combination of biological and socio-economic factors (Kim, 2020). Cohabitation and marriage are found to have preventive effects on cognitive decline as a result of the social interaction (Sundström et al. 2016), therefore marital status is included as a control variable. Higher levels of education are, independent from lifestyle, associated with a higher level of cognitive function at older ages and postponement of clinical dementia (Ngandu et al. 2008). However, people with a higher level of education are found to experience a faster rate of cognitive decline (Formanek et al. 2019). To account for these effects, level of education is included as a control variable. The results are controlled for types of welfare regime as differences in cognitive function and cognitive decline remain across European regions after adjustment for sociodemographic and clinical characteristics (Formanek et al. 2019). The number of underlying chronic diseases are included to filter out the effects of other health problems on cognitive function.

Theory: Life course epidemiological approach

To understand the effects of lifestyle behaviours on cognitive decline this study applies a life course epidemiological approach. The life course epidemiological approach entails the understanding of the growth, maintenance and decline of cognitive, emotional and physical capacities throughout life and how this development is affected by social (e.g. behavioural) and biological factors across life, either independently or interactively (Kuh, 2019). Life course epidemiology is used to study the effects of risk exposures throughout the life course on later health or disease risk and is aimed at clarifying the underlying processes (Kuh et al. 2003). The underlying premise of life course epidemiology is that risk factors influence health and disease risk independently, cumulatively and interactively (Kuh et al. 2003).

This current study focuses on the independent and interactive effects of lifestyle behaviours on cognitive decline. Based on the literature review above, lifestyle behaviours have both separate (independent) effects and clustered (interactive) effects on cognitive decline. Because clustering unhealthy lifestyle behaviours is found to enhance the effect of separate lifestyle behaviours these effects are called synergistic (Kuh et al. 2003). This study analyses risk exposures and decline of cognitive capacities of people aged 50+ and older to estimate the separate and clustered effects of lifestyle behaviours on cognitive decline. According to Kuh (2019) a lifetime trajectory of cognitive function shows an increase until stagnating at maturity after which cognitive function slowly declines during adulthood and accelerates at older ages. Attaining a healthy lifestyle is found to have a protective effect on the trajectory of cognitive decline with a delayed and mitigated rate of decline (Monsch et al. 2019). Therefore, understanding of the separate and clustered effects of lifestyle behaviours on cognitive decline has the potential to optimise the protective effects of lifestyle on the trajectory of cognitive decline. However, despite the positive effects from a healthy lifestyle on cognitive decline, the largest effects are caused by the biological risk factor of advanced age (Kivipelto et al. 2018).

Conceptual model

Based on the literature review: nutrition, physical activity, tobacco smoking, alcohol usage can be concluded to have both independent and clustered effects over time on cognitive decline. Optimal health behaviours include a diet with high nutrient intake, regular physical activity, non-smoking and light to moderate alcohol use. Preferably, multiple healthy lifestyle factors are present at the same time. These findings lead to an accumulation model with risk clustering (Kuh et al. 2003). Included in the conceptual model are the control variables age, gender, marital status, chronic diseases, level of education and type of welfare regime. The above outlined factors with effects on cognitive decline are schematically presented in the conceptual model, see figure 1. The time element in the model takes into account the induction period between risk exposure and initiation of cognitive decline.

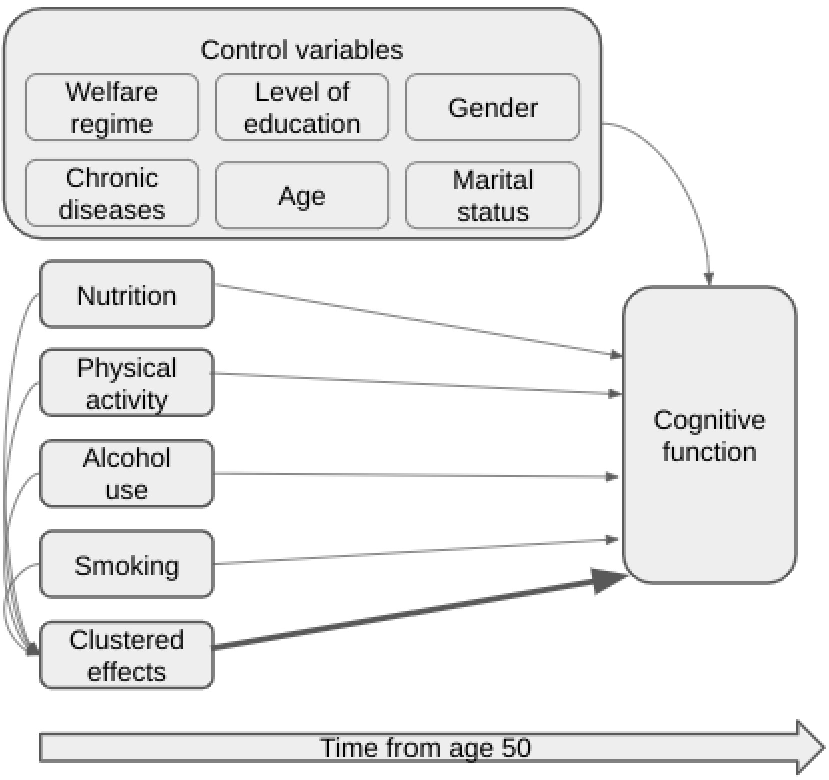

Figure1: Conceptual model visualising the independent and clustered effects of the lifestyle factors nutrition, physical activity, smoking and alcohol use on cognitive function over the life course, including the control variables age, gender, marital status, chronic diseases, level of education and type of welfare regime.

Hypotheses

Given the previous research, hypotheses on the effects of individual as well as clustered lifestyle factors on cognitive function are formulated. Hypotheses 1, 2, 3 and 4 concern the effects of individual lifestyle factors on cognitive function:

1. A healthy diet has a positive effect on cognitive function.
2. Physical activity has a positive effect on cognitive function.
3. Light to moderate alcohol use has a positive effect on cognitive function.
4. Smoking has a negative effect on cognitive function.

Hypotheses 5 concerns the effect of clustered lifestyle factors on cognitive function:

5. When combining more unhealthy lifestyle behaviours the negative effects on cognitive function increase.

Methodology
Study design
The current study of a longitudinal panel study uses data from the Survey of Health Ageing and Retirement (SHARE) to analyse the relationship between lifestyle factors and cognitive decline. In order to find the relative importance of nutrition, physical activity, alcohol use and smoking behaviour on cognitive decline the effects of unhealthy behaviours on these lifestyle factors are estimated. Cognitive function is assessed with a composite score taking into account verbal memory and processing speed in order to ensure a balanced measure of cognitive function. To get an insight to the effects of lifestyle factors on cognitive function both the separate (individual) effects of the lifestyle factors and the combined (clustered) effects of lifestyle factors on cognitive function are analysed. Differentiating between the individual and the clustered effects helps to identify synergistic effects of the combination of unhealthy lifestyle behaviours and the most important underlying lifestyle behaviours. The analyses of the effects comprise the between-subject analyses of individual and clustered effects of lifestyle factors on cognitive function. Also other factors influencing cognitive decline are included in the analyses: age, gender, marital status, number of chronic diseases, level of education and welfare regime.

The between-subject analyses provide information on the general association between lifestyle factors and the level of cognitive function in order to make inferences on the effects of lifestyle factors on cognitive decline.

Source of data
For this current study of a longitudinal panel study is aimed to quantify the effects of lifestyle factors on cognitive decline. The data used for the analyses stem from the Survey on Health, Ageing and Retirement in Europe (SHARE) which includes participants from 27 European countries and Israel aged 50 years and older. From 2004 onwards SHARE has collected internationally comparable longitudinal data on a large scale with a strong emphasis on objective data collection designed by and for researchers (Share-project.org, 2023). Over the years SHARE has been repeatedly assessed and approved by the Ethics Committee of the University of Mannheim and all participants signed a written consent for the pseudo-anonymized use and storage of their data with the right to withdraw (Formanek et al. 2019). SHARE data is collected by computer-assisted personal interviewing (CAPI).

SHARE is built as a research infrastructure for studying the life course effects of health, social, economic and environmental policies. The SHARE project has a large scientific impact by setting new standards in research and scientific data collection, as well as by being the largest social science panel study (Share-project.org, 2023). Their aim is to improve people's quality of life by forming an observatory for policy effects to help make more targeted policies (Share-project.org, 2023).

The suitability of the SHARE dataset for this study is based on 1) the broad selection of variables about behavioural risk and cognitive function, 2) the international comparability and 3) the longitudinal data covering multiple years. These characteristics allow the analyses of the effects of multiple (clustered) lifestyle factors on broadly measured cognitive function, possibly over the years, for a large international sample. The initial sample size is 1632 participants from wave 6 (2015), wave 7 (2017) and 8 (2019/2020). Earlier waves of data collection are not included in the analyses because these waves do not contain information about all relevant lifestyle factors, especially the relevant variable for alcohol use was only included from wave 6 onwards.

Sample selection

The study sample is foremost selected on data availability of participants about cognitive function and behavioural risks to ensure a large sample with sufficient statistical power.

Because of the longitudinal design of the study and the focus on the effects of lifestyle on cognitive decline rather than just cognitive function at one point of time, the analysis only includes participants with data in at least two waves. This measure will enable the possibility to estimate the effects of lifestyle factors on accelerating, mediating or delaying cognitive decline

Below figure 3 shows the sample selection starting with 95,977 participants and resulting in 1660 participants with full information and participating in at least two waves. The 1632 individuals lead to 3266 observations as 1630 individuals participate in two waves and 2 individuals participate in three waves of data collection. The sample consists of males 1094 (67.03%) and females 538 (32.97%).

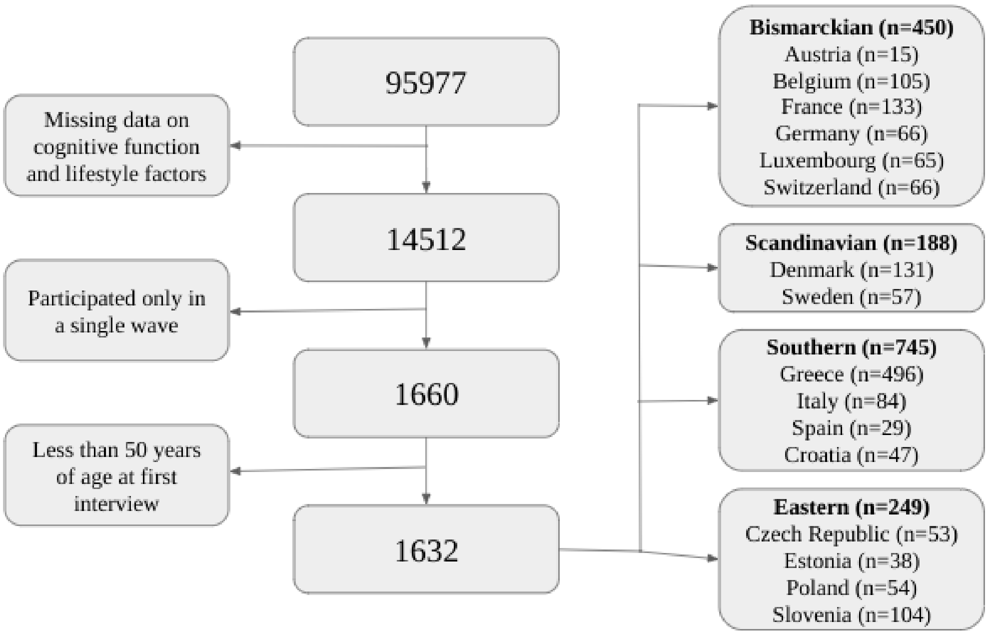

Figure 2: Selection of the analytical sample.

Assessment variables cognitive function

The assessment of cognitive function is based on 3 time-varying variables from the SHARE dataset: immediate recall, delayed recall and verbal fluency. To test immediate and delayed recall respondents are shown a list of 10 words after which the respondents are asked to reproduce the 10 words, this results in a 0-10 immediate recall score. Later during the same interview respondents are asked again to reproduce the 10 words, which results in the delayed recall score with a 0-10 range. The tests for immediate and delayed recall are a useful tool for assessing changes in cognitive function as it is a relatively sensitive method to distinguish between rates of cognitive decline (Harris & Dowson, 1982). According to Harris and Dowson (1982) participants with mild cognitive impairment will show reduced immediate recall where participants with severe cognitive impairment will show lower scores on both immediate and delayed recall. Therefore the combination of scores on immediate and delayed recall are useful for measuring cognitive decline over time as declining results differentiate between rates of cognitive decline (Harris & Dowson, 1982).

Verbal fluency is tested using an animal fluency test in which the participant is asked to name as many different animals as possible within one minute. The result is a verbal fluency score which is the sum of the number of animals listed by the participant. Animal fluency tests are found to be an effective tool in measuring verbal fluency with possibilities to distinguish between participants without cognitive impairment, with mild cognitive impairment and with severe cognitive impairment (Sebaldt et al. 2009).

In order to get insight on the patterns of overall cognitive function the scores of the 3 ratio variables measuring cognitive tests are combined in 1 summary score for overall cognitive function. The resulting Cognitive Function Score is a time-varying ratio variable, as it is built up of 3 time-varying ratio variables. To combine the immediate recall, delayed recall and verbal fluency tests, the verbal fluency test is rescaled to a 0-10 range like the recall scores to ascertain a balanced out overall cognitive function score. Because the animal fluency test does not have an a priori maximal possible score the highest value achieved in the data (100 animals) is set as the upper limit. As a result the verbal fluency scores are first all divided by 10 to arrive at a 0-10 scale. In the end all 3 0-10 scale scores are summed up to form the score on overall cognitive function. Therefore, ***Cognitive Function Score = immediate recall + delayed recall + verbal fluency / 10***. The resulting Cognitive Function Score is a ratio variable on a 0-30 scale. In their study Formanek et al. (2019) use the same composite score for cognition based on SHARE data. However, in the sample the maximum measured score at baseline was 23 as none of the participants achieved a perfect score on all three measurements of cognitive function. Furthermore, the average Cognitive Function Score in the sample is 11.90 and the lowest score found in the sample was 0. Below, in table 1 the measures of central tendency of immediate recall, delayed recall, verbal fluency and the Cognitive Function Score are shown.

Variable	**Mean**	**No. (%)**	**Std. Dev.**	**Min**	**Max**
Immediate recall	5.683211		1.534244	0	10
Delayed recall	4.301471		1.965003	0	10
Verbal fluency	19.69975		7.852053	0	100
Cognitive Function Score	11.95466		3.602651	0	23
Fruits and vegetables: - Healthy - Unhealthy		 1125 (68.93) 507 (31.07)		0	1
Physical activity: - Healthy - Unhealthy		 889 (54.47) 743 (45.53)		0	1
Alcohol use: - Healthy - Unhealthy		 1353 (82.90) 279 (17.10)		0	1
Smoking behaviour: - Healthy - Unhealthy		 698 (42.77) 934 (57.23)		0	1
Lifestyle Index: - 0 - 1 - 2 - 3 - 4		 538 (16.47) 1126 (34.48) 1066 (32.64) 468 (14.33) 68 (2.08)		0	4
Age	68.87132		8.484594	50	97

Gender: - Male - Female		 1094 (67.03) 538 (32.97)		0	1
Nr. chronic diseases	1.498162		1.421132	0	10
ISCED: - None - Level 1 - Level 2 - Level 3 - Level 4 - Level 5 - Level 6		 108 (6.62) 133 (8.15) 278 (17.03) 615 (37.68) 61 (3.74) 419 (25.67) 18 (1.10)		0	6
Marital status: - Married, living together - Registered partnership - Married, living apart - Never married - Divorced - Widowed		 1233 (75.55) 31 (1.90) 24 (1.47) 77 (4.72) 166 (10.17) 101 (6.19)		0	5
Welfare regime: - Bismarckian - Scandinavian - Southern - Eastern		 450 (27.57) 188 (11.52) 745 (45.65) 249 (15.26)		0	3

Table 1: Sample description of the baseline population (N=1632).

Assessment variables lifestyle factors / exposure

To explore the relationship between lifestyle factors and overall cognitive decline, participants' lifestyles are assessed based on 4 factors: intake of fruits and vegetables, physical activity, alcohol consumption and current smoking behaviour. The 4 lifestyle factors in the analysis are given a threshold to distinguish between the exposure to either healthy or unhealthy behaviour. The lifestyle factor variables are time-varying and lifestyles can change over the waves of data collection.

Intake of fruits and vegetables are used as a parameter to assess the nutrition intake of the participants. This parameter is chosen with regards to data availability from the survey and also is in line with nutritional assessments in other research on the topic (Sabia et al. 2009). The base-variable about intake of fruits and vegetables in the dataset is a time-varying ordinal variable. For the analysis the threshold of healthy intake of fruits and vegetables is set at daily intake, with participants consuming fruits and vegetables less than daily are considered to have an unhealthy behaviour. The original fruits and vegetable variable in the dataset is therefore recoded into a dummy variable with the values 0 for healthy behaviour and 1 for unhealthy behaviour.

Physical activity is assessed by the frequency of engaging in vigorous activities. Also in comparable studies vigorous activity is used as a parameter for physical activity (Dhana et al. 2020; Sabia et al. 2009). The dataset contains a time-varying ordinal variable which indicates participants' frequency in which they play sports, or engage in physical labour for a job or around the house. Engaging in vigorous activities at least once a week is counted as healthy behaviour in this study. So, the ordinal variable of the dataset is recoded into a dummy variable with values 0 for healthy behaviour and 1 for unhealthy behaviour.

Alcohol consumption is based on a time-varying ratio variable counting the weekly number of alcoholic drinks of the participants. Based on research of Dominguez et al. (2021) participants have the lowest risk of cognitive decline when consuming between 1 and 14 glasses of alcohol a week. Participants with a weekly alcohol consumption within this range are considered to be exposed to a healthy lifestyle. The ratio variable of the dataset is recoded into a dummy variable with value 0 meaning the participant consumes 1 to 14 glasses of alcohol a week and 0 meaning the participant drinks 0 or more than 14 glasses of alcohol a week.

Smoking behaviour is based only on the ordinal variable stating current smoking behaviour, which is a time-varying variable. Not smoking being considered as healthy behaviour. Smoking history is left out of consideration as the survey has little response on smoking history as compared to current smoking behaviour and a lot of cases would be dropped otherwise. The ordinal variable is recoded into a dummy variable with 0 for having healthy smoking behaviour and 1 for having unhealthy smoking behaviour.

The above discussed transformations of variables results in 4 time-varying dummy variables about the participants' lifestyle behaviour. For the analysis of the individual effects of lifestyle factors on cognitive decline the dummy variables are used as covariates. In the sample most unhealthy behaviour is found respectively for smoking behaviour and physical activity with about half having unhealthy behaviour, whereas only 16% has unhealthy behaviour on alcohol use.

In order to check to what extent the lifestyle factors intertwine pairwise correlation tests are performed using the dummy variables as computed above. The results of the correlation tests below in table 2 show no problematic correlations of the lifestyle factors as all correlation coefficients stay way below 8.

	Smoking	**Physical Activity**	**Fruits and Vegetables**	**Alcohol**
Smoking	1.000			
Physical Activity	0.0632*	1.000		
Fruits and Vegetables	0.1720*	-0.0031	1.000	
Alcohol	0.0696*	-0.0170	0.0382*	1.000

Table 2: Pairwise correlation matrix for the behavioural dummy variables concerning smoking, physical activity, fruits and vegetables and alcohol using a Spearman's Rho test. All tests include 3266 observations. Significant results are indicated with a * with a significance level set at 0.05.

The effects of clustered lifestyle factors on cognitive decline is measured using a computed Lifestyle Index. This index score summarises the number of unhealthy lifestyle factors based on the previously discussed dummy variables on intake of fruits and vegetables, physical activity, alcohol consumption and smoking behaviour. Therefore, ***Lifestyle Index = fruits and vegetables + physical activity + alcohol consumption + smoking behaviour***. The resulting lifestyle index score has a 0-4 range where 0 indicates participants having a healthy lifestyle without unhealthy lifestyle factors and where 4 means participants score unhealthy on all 4 lifestyle factors. To avoid having too small groups the categories for having 3 and for having 4 unhealthy lifestyle factors are combined into 1 category. This eventually results in a time-varying ordinal variable with a 0-3 scale with a higher score indicating a higher number of unhealthy lifestyle behaviours.Counting the number of unhealthy behaviours is done for a more straightforward interpretation of the direction of the effects on cognitive decline.

Control variables
The control variables in the analysis comprise age, gender, marital status, number of chronic diseases, level of education and welfare regime. Marital status and number of chronic diseases are time-varying variables and age, gender, level of education and welfare regime are time-constant variables.

Age and the number of chronic diseases are ratio variables where age is measured at time of the participants' first interview. Gender, marital status and welfare regime are nominal variables in the dataset where gender is a dummy variable divided into males and females. Level of education is based on an ordinal variable using the ISCED-97 coding of education. The initial variable of participants' nationality is used to compute a categorical variable with groups based on welfare regime. The 4 included welfare regimes (Eikemo et al. 2008; Ferrera et al. 2005) are Scandinavian (Denmark and Sweden), Bismarckian (Austria, Belgium, France, Germany, Luxembourg and Switzerland), Southern (Greece, Italy and Spain) and Eastern (Czech Republic, Estonia, Poland and Slovenia). All participants in the sample have full information about the control variables and therefore no cases are lost due to adding the variables in the analysis.

Statistical analyses
The statistical analyses are built up with the aim to answer the main research question: "What is the relative importance of the individual and clustered effects of nutrition, physical activity, alcohol use and smoking behaviour on cognitive decline for the population aged 50+ in Europe?". The main research question is answered by the sub-questions: 1) "How do nutrition, physical activity, alcohol use and smoking behaviour independently influence cognitive decline at older ages?" and 2) "How do the clustered effects of nutrition, physical activity, alcohol use and smoking behaviour influence cognitive decline at older ages in Europe?".

Before looking at the relative importance, it is determined whether there is a statistically significant relationship between the separate and clustered lifestyle factors on the one hand and cognitive function on the other hand. Therefore the statistical analyses start with a cross-sectional description of differences in average cognitive function between groups based on lifestyle behaviour. To answer the first sub-question 4 two sample t-tests are conducted to interpret the relationship between the separate lifestyle factors and cognitive function. Cognitive Function Score (ratio variable) is used as the dependent variable in the two sample t-tests with groups based on the binary lifestyle variables concerning fruits and vegetable intake, physical activity, alcohol use and smoking behaviour. To answer the second sub-question the same analysis is used for the Lifestyle Index but with an one-way ANOVA as the Lifestyle Index consists of more than 2 groups. The null hypotheses of the two sample t-tests and one-way ANOVA state that in the population there is no relationship between Cognitive Function Score and the factor variables in the tests. The tests only include the first observation of each participant to meet the assumption of independent observations. Before interpreting the results a Levene's test is carried out to determine whether the variances for the groups in the tests are equal. If the one-way ANOVA turns out to be significant the post-hoc analysis comprises a Scheffe test to check which groups cause the significant ANOVA.

After the cross-sectional analyses to determine the presence of the relationships between the lifestyle factors and cognitive function, all observations of the participants in the panel data are used for longitudinal analyses of the strength of the determined relationships. The strengths of the relationships help to identify the relative importance of the lifestyle factors and thereby answer the main research question. The longitudinal between-subject analyses use a multiple linear regression with standard errors clustered across individuals and controlled for time. To control for the effects of time the variable containing the wave number of the observation is included in the regression. With the multiple linear regression two different full models will be tested in order to answer the first and the second research sub-question separately. Both models have the Cognitive Function Score as the dependent variable but one model takes the binary lifestyle variables (fruits and vegetables, physical activity, alcohol and smoking) as main explanatory variable and the other takes the cumulative Lifestyle Index as the main explanatory variable. Both full models are controlled for the effects of age, gender, number of chronic diseases, marital status, level of education and type of welfare regime. The null hypotheses of the regressions state that there is no linear relationship between the Cognitive Function Score on the one hand and the explanatory- and control variables on the other hand. After running the regressions, the Akaike's and Schwarz's Bayesian information criteria are used to assess the data fit improvements of the full model as compared to the null model.

Results

In this chapter the results of the statistical tests discussed in the methodology are presented. First, in the descriptive statistics the results of several two sample t-tests and an ANOVA comparing mean cognitive function across groups based on lifestyle are presented. Secondly, two multiple linear regression models are presented with either separate lifestyle factors or a combined Lifestyle Index are used as explanatory variables for differences in Cognitive Function Score. Lastly, in the additional analyses results of the panel regressions with fixed effects are presented, also with differences in Cognitive Function Score explained by either separate lifestyle factors or a combined Lifestyle Index.

Descriptives

In the descriptives section the differences in mean Cognitive Function Scores are analysed across groups based on participants having a healthy or unhealthy score on fruits and vegetable intake, physical activity, alcohol use and smoking using two sample t-tests. The same differences in cognitive function between groups based on the count of the number of unhealthy behaviours are tested with an one-way ANOVA. For the t-tests equal variances are assumed as the Levene's tests indicate no significant differences in variances, results of the Levene's tests are placed in the appendix as table 7. The results of the t-tests are presented below in table 3. From the results it can be concluded that there are significant differences in Cognitive Function Scores between people having a healthy and people having an unhealthy amount of physical activity. Based on these tests the same differences in cognitive function cannot be found for groups with differences in fruits and vegetable intake, alcohol use and smoking behaviour.

Grouping variable	**Fruits and vegetables**	**Physical activity**	**Alcohol**	**Smoking**
T-statistic	1.8382	2.7763	0.3914	0.9742
Significance	0.0662	**0.0056****	0.6956	0.3301

Table 3: Results of 4 two sample t-tests testing the difference in mean Cognitive Function Score between groups based on healthy or unhealthy behaviour on lifestyle factors. All 4 tests include 1632 cases. *p<.05 **p<.01 ***p<.001.

Before looking at the one-way ANOVA with the Lifestyle Index as the grouping variable the insignificant Levene's test indicates equal variances between the groups. The following ANOVA tests significant with a p-value of 0.0124 (<0.05) and leads to the conclusion that in the population there is a difference in the Cognitive Function Score between groups based on the number of unhealthy lifestyle behaviours. Looking at the post-hoc Scheffe test, the significant ANOVA is caused by the difference in Cognitive Function Score between the groups having 3 to 4 and having 0 unhealthy lifestyle behaviours. The results of the Levene's test, one-way ANOVA and Scheffe test are included in the appendix as table 8.

Longitudinal between-subject effects of lifestyle factors on cognitive function

Separate lifestyle factors

The effects of separate lifestyle factors on the Cognitive Function Score are presented in the compressed regression table below, see table 4. The results of the multiple linear regressions show the regression coefficients of the null model, including only the lifestyle factors and a time variable, and the full model with all the control variables. The lower AIC and BIC statistics for the full model indicate an improved model fit for the full model over the null model and the full model has an explained variance of 24.12%. The significant models indicate that in the population there is a linear relationship between the Cognitive Function Score and the combinations of explanatory variables. The full regression models are included in the appendix as tables 9 and 10.

Looking at the effects of the separate lifestyle factors on the Cognitive Function Score there only is a significant effect found for unhealthy levels of physical activity. Having an unhealthy level of physical activity results in a .41 (CI -0.65 to -0.17) drop in Cognitive Function Score when controlled for age, gender, number of chronic diseases, marital status, level of education and type of welfare regime. The effects of unhealthy intake of fruits and vegetables, alcohol use and smoking behaviour remains insignificant. So, in the population there is a significant negative effect of not reaching a healthy amount of physical activity on the Cognitive Function Score.

Variable	**Coefficients null model (95% CI)**	**Coefficients full model (95% CI)**
Fruits and Vegetables	**-.2311419 (-.5227146 to 0604309)**	**.0852209 (-.1728301 to .3432719)**
Physical Activity	**-.7987194*** (-1.079759 to -.5176795)**	**-.4096596** (-.6528723 to -.1664469)**
Alcohol	**-.0930926 (-.4713136 to .2851284)**	**-.0404582 (-.3942147 to .3132983)**
Smoking	**-.0087835 (-.3099564 to .2923894)**	**-.085078 (-.3467758 to .1766197)**
Wave	-.0775248 (-.1821705 to .0271209)	-.0072658 (-.1073661 to .0928345)
Age		-.120129*** (-.1385203 to -.1017377)
Gender (ref. male)		
Female		1.078363*** (.7701735 to 1.386553)
Number of chronic diseases		-.1140195* (-.2095721 to -.0184668)
Marital status (ref. married)		
Registered partnership		-.7031155 (-1.670692 to .2644613)
Married, living apart		-.2947997 (-1.647467 to 1.057868)
Never married		-.5340833 (-1.306362 to .2381952)
Divorced		-.2739711 (-.7084076 to .1604655)
Widowed		-.0796759 (-.66605 to .5066981)
ISCED (ref. Level 0)		

Level 1		-.805394* (-1.501594 to -.1091938)
Level 2		-.0814004 (-.689605 to .5268042)
Level 3		.5169885 (-.0621278 to 1.096105)
Level 4		.4863285 (-.4170212 to 1.38967)
Level 5		1.508168*** (.9034837 to 2.112852)
Level 6		1.964829* (.4166768 to 3.512981)
Welfare Regime (ref. Bismarckian)		
Scandinavian		.0267289 (-.4776843 to .5311421)
Southern		-1.823777*** (-2.17647 to -1.471085)
Eastern		-1.217844*** (-1.68166 to -.7540276)
Constant	12.93548*** (12.13339 to 13.73756)	20.22179*** (18.68 to 21.76358)
Model F-statistic	**7.39**	**37.54*** **
N	**3266**	**3266**
R-squared	**0.0136**	**0.2412**
AIC	**17688.26**	**16865.54**
BIC	**17724.8**	**17005.64**

Table 4: Coefficients for the multiple linear regression models with Cognitive Function Score as dependent variable and separate lifestyle factors as explanatory variables, with 95% confidence interval. Standard error adjusted for 1632 clusters in ID. *p<.05 **p<.01 ***p<.001.

Clustered lifestyle factors

The effects of clustered lifestyle factors on the Cognitive Function Score are presented in the compressed regression table below, see table 5. The null model includes only the Lifestyle Index and a time variable and the full model includes all the control variables. The lower AIC and BIC statistics of the full model indicate an improved model fit of the full model over the null model and has an explained variance of 23.99%. From the significant models it can be concluded that in the population there is a linear relationship between the Cognitive Function Score and the combinations of explanatory variables. The full regression tables are included in the appendix as tables 11 and 12.

The multiple linear regression of the full model shows a significant effect on Cognitive Function Score of having 3 or 4 unhealthy lifestyle behaviours over having none. Engaging in 3 or 4 unhealthy lifestyle behaviours results in a .53 (CI -0.99 to -0.07) drop in Cognitive Function Score as compared to not engaging in unhealthy lifestyle behaviour concerning fruits and vegetable intake, physical activity, alcohol use and smoking. Engaging in 1 or in 2 unhealthy lifestyle behaviours as compared to 0 does not show a significant effect on cognitive function when controlled for age, gender, number of chronic diseases, marital status, level of education and type of welfare regime. To conclude, in the population there is a significant negative effect of engaging in 3 or 4 unhealthy lifestyle behaviours as compared to 0 on the Cognitive Function Score.

Variable	**Coefficients null model (95% CI)**	**Coefficients full model (95% CI)**
Lifestyle Index (ref. 0)		
1	**-.4054464** **(-.8192205 to .0083277)**	**-2.172806** **(-.5766689 to .1421078)**
2	**-.5434653*** **(-.9796587 to -.1072718)**	**-.117427** **(-.5063692 to .2715151)**
3 or 4	**-1.009975***** **(-1.521903 to -.4980466)**	**-.5268886*** **(-.9868944 to -.0668828)**
Wave	-.100605 (-.2049176 to .0037076)	-.0110786 (-.1110126 to .0888554)
Age		-.1232468*** (-.1416687 to -.1048249)
Gender (ref. male)		
Female		1.020133*** (.7188967 to 1.321369)
Number of chronic diseases		-.1246299* (-.2200003 to -.0292595)
Marital status (ref. married)		
Registered partnership		-.6777749 (-1.639183 to .2836334)
Married, living apart		-.243182 (-1.61014 to 1.123776)
Never married		-.4776635 (-1.250168 to .2948413)
Divorced		-.2653015 (-.6984257 to .1678226)
Widowed		-.0751721 (-.6663672 to .516023)
ISCED (ref. Level 0)		
Level 1		-.802553* (-1.500805 to -.1043004)
Level 2		-.0711825

		(-.6808291 to .5384641)
Level 3		.5320675 (-.0498098 to 1.113945)
Level 4		.4807209 (-.4205537 to 1.381996)
Level 5		1.511806*** (.9036474 to 2.119965)
Level 6		1.969643* (.418655 to 3.520632)
Welfare Regime (ref. Bismarckian)		
Scandinavian		.0902253 (-.4106779 to .5911284)
Southern		-1.8093*** (-2.154289 to -1.46431)
Eastern		-1.199063*** (-1.660143 to -.7379836)
Constant	13.1043*** (12.28416 to 13.92445)	20.42883*** (18.87806 to 21.97959)
Model F-statistic	**4.68*** **	**38.62*** **
N	**3266**	**3266**
R-squared	**0.0073**	**0.2399**
AIC	**17707.03**	**16869.29**
BIC	**17737.49**	**17003.3**

Table 5: Coefficients for the multiple linear regression models with Cognitive Function Score as dependent variable and clustered lifestyle factors as main explanatory variable, with 95% confidence interval. Standard error adjusted for 1632 clusters in ID. *p<.05 **p<.01 ***p<.001.

Discussion

The analyses show the negative effects of unhealthy amounts of physical activity and of clustered lifestyle factors on cognitive decline. The results indicate that people aged 50+ have a greater risk of lowered cognitive function if they do not engage in healthy amounts of physical activity as opposed to individuals who do engage in healthy amounts of physical activity. Low physical activity is found to have a negative effect of -.41 (CI -0.65 to -0.17) on the Cognitive Function Score. For fruits and vegetables intake, alcohol use and smoking behaviour no significant individual effects on cognitive function were found. However, the clustered effects of lifestyle factors indicate greater risk of poor cognitive function at older ages for individuals who engage in 3 to 4 unhealthy lifestyle behaviours as opposed to individuals without unhealthy lifestyle behaviours. Combining 3 to 4 unhealthy lifestyle behaviours as opposed to having no unhealthy lifestyle behaviours is found to decrease the Cognitive Function Score by -.53 (CI -0.99 to -0.07) points. The effects of the lifestyle factors are controlled for the effects of age, gender, number of chronic diseases, marital status, level of education and type of welfare state.

With regards to the research question, the results show that the individual effects of physical activity have the greatest relative importance on cognitive decline compared to the individual effects of nutrition, alcohol use and smoking behaviour. The results also show the importance of the clustered effects of lifestyle factors as compared to having no unhealthy lifestyle behaviours, having 1 or 2 unhealthy behaviours does not lead to lower cognitive function but having 3 to 4 unhealthy behaviours does.

The negative effect of low physical activity on cognitive function as found in the results point in the same direction as findings of Hamer and Chida (2009) who found increased risk of dementia as a result of low physical activity. The results especially support the positive effects of late life physical activity on the preservation of cognitive function as stressed by Kivipelto et al. (2018). As Kivipelto et al. (2018) stress regular physical activity to decrease the risk of cognitive decline, the straightforward measurement of frequency of physical activity could explain why this current study found the same effects.

The reason why this study does not find significant individual effects of the lifestyle factors nutrition, alcohol use and smoking behaviour could possibly be explained by the measurement of cognitive function during the 'silent' phase. Monsch et al. (2019) already stressed that cognitive decline starts with a 'silent' phase without visible symptoms. As this current study measures cognitive function before the onset of dementia, the lack of visible symptoms during the first phase of cognitive decline make it more difficult to find significant effects of lifestyle factors on cognitive decline. Previous studies focussing on disease incidence of e.g. dementia or Alzheimer's disease did find negative effects of unhealthy lifestyle behaviours concerning nutrition, alcohol use and smoking. Further along in the process of cognitive decline a healthy diet is found to decrease the risk of dementia (Anastasiou et al. 2017) and moderate alcohol use (Sabia et al. 2018) and non-smoking (Aggarwal et al. 2006) to reduce the risk of dementia and Alzheimer's disease. Therefore, the results of this study suggest the effects of nutrition, alcohol use and smoking behaviour on cognitive function to be less clear when cognitive function is measured before onset of dementia. For nutrition as a lifestyle factor, the lack of effects found in this current study could also partly be explained by the indirect measurement of a healthy diet by using fruits and vegetables intake as a proxy for a full diet.

This current study adds to the previous evidence by showing that the combination of multiple unhealthy lifestyle factors increase the risk of poor cognitive function while the separate effects of lifestyle factors on cognitive function suggest only low physical activity to have a negative effect. These findings suggest synergistic effects from combining unhealthy behaviours that are in line with negative synergistic effects of multiple lifestyle factors on risk of Alzheimer's disease found by Dhana et al. (2020). The findings of this study support the findings of Sabia et al. (2009) that the number of unhealthy behaviours is associated with lower cognitive function in later life and complements it by finding the same association when measuring the effects of clustered lifestyle factors on cognitive function rather than measuring the effects of clustered lifestyle factors on the odds of poor cognitive function.

The strengths of this current study include estimating the effect size of individual and clustered lifestyle factors on cognitive function instead of estimating the effect of individual or clustered lifestyle factors on the risk of certain conditions e.g. dementia. Benefits of estimating effect size rather than risk are possibilities to find effects of lifestyle factors on cognitive function before it reaches thresholds like poor cognitive function or disease incidence. Another strength of this study is that it both looks at the effect of clustered lifestyle factors on cognitive function as well as it looks at the effects of the individual lifestyle factors in the same dataset. Using the same data to analyse clustered and individual effects provides an opportunity to identify the most important individual effects to drive the clustered effect.

Besides the aforementioned difficulties with measurement of cognitive decline before disease incidence, limitations of this study include the short follow-up period of participants in the data with mainly 2 measurements with a 4 year interval. The short follow-up makes it difficult to find significant within-subject change in cognitive function as a result of lifestyle factors. As a result the findings of this study are more concerned with the association between lifestyle factors and cognitive function than directly with the effect of lifestyle factors on cognitive decline over time. Also, the lack of information about within-subject change in cognitive function makes it hard to separately analyse differences in cognitive decline across gender and geographic regions because overall levels of cognitive function differs between the groups before the onset of decline (Kim, 2020; Formanek et al. 2019). Therefore, using only between-subject effects of lifestyle factors on cognitive decline it becomes hard to distinguish between effects due to higher overall levels of cognitive function and effects due to a higher rate of cognitive decline. Another limitation of the study is that it does not account for health behaviours during mid-life. The analysis of cumulative risk of lifestyle behaviours is limited as the data only provide information about the lifestyle during late-life when cognitive function also slowly declines.

Conclusion

Physical activity is found to have the greatest relative importance for slowing down the process of cognitive decline in early phases with more effects than nutrition, alcohol use and smoking behaviour. Yet, focussing on a broad healthy lifestyle based on a combination of these lifestyle behaviours has a greater potential for slowing down cognitive decline than focussing on only one or two of these behaviours. Hereby the findings of this study expand the academic literature with more evidence of the synergistic effects of clustered lifestyle factors on cognitive decline and suggesting physical activity to be the strongest underlying factor. Successful policy interventions targeting these modifiable risk factors of cognitive decline help to retain cognitive health of older adults and thereby improve the wellbeing of the individuals and their families. Furthermore, increased cognitive health alleviates the global burden of neurological disorders which is slowing down social and economic development.

Policy recommendations to preserve cognitive function include stimulating a balanced healthy lifestyle with enough physical activity, a healthy diet, low to moderate alcohol use and without smoking. Stimulating regular physical activity should have a central place in such policies. Future research should address gaps in the academic literature like the optimal level of physical activity for older adults to preserve cognitive function. Overall, more research on the effects of lifestyle on the pathways of early phases of cognitive decline is of great importance e.g. by directly focussing on within-subject change.

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Appendix

	Fruits and Vegetables	Physical Activity	Alcohol	Smoking
F	0.07297158	0.39677485	0.00000677	0.15771909
Significance	0.7870925	0.52884786	0.99792407	0.69131723
Observations	1632	1632	1632	1632

Table 7: Results of 4 Levene's tests with Cognitive Function Score as dependent variable and groups based on: fruits and vegetables; physical activity; smoking behaviour; alcohol use.

Levene's test					
W0	0.26354216	df(3, 1628)	P>F = 0.85169559		
W50	0.25369414	df(3, 1628)	P>F = 0.85873786		
W10	0.25873030	df(3, 1628)	P>F = 0.85514026		
ANOVA					
Source	Partial SS	df	MS	F	P>F
Model	140.83396	3	46.944652	3.63	0.0124
LSIcat	140.83396	3	46.944652	3.63	0.0124
Residual	21028.071	1,628	12.916505		
Total	21168.905	1,631	12.979095		
Scheffe					
	0	1	2		
1	-.580748 0.189				
2	-.639271 0.123	-.058524 0.995			
3	-.998399 0.015	-.417651 0.490	-.359128 0.619		

Table 8: Results of a Levene's test, one-way ANOVA and Scheffe test with Cognitive Function Score as dependent variable and Lifestyle Index as grouping variable and 1632 observations.

CFS	Coefficient	Robust std. err.	t	P>t	95% conf. interval	
Fruits and Vegetables	-.2311419	.1486539	-1.55	0.120	-.5227146	.0604309
Physical Activity	-.7987194	.1432839	-5.57	0.000	-1.079759	-.5176795
Alcohol	-.0930926	.1928303	-0.48	0.692	-.4713136	.2851284
Smoking	-.0087835	.1535484	-0.06	0.954	-.3099564	.2923894
Wave	-.0775248	.053352	-1.45	0.146	-.1821705	.0271209
Constant	12.93548	.4089322	31.36	0.000	12.13339	13.73756
Observations	3266					
F (5, 1631)	7.39					
Prob > F	0.0000					
R-squared	0.0136				AIC	17688.26
Root MSE	3.6258				BIC	17724.8

Table 9: Multiple linear regression with Cognitive Function Score as dependent variable and separate lifestyle factors as explanatory variables. Standard error adjusted for 1632 clusters in ID.

CFS	Coefficient	Robust std. err.	t	P>t	95% conf. interval	
Fruits and Vegetables	.0852209	.1315634	0.65	0.517	-.1728301	.3432719
Physical Activity	-.4096596	.1239983	-3.30	0.001	-.6528723	-.1664469
Alcohol	-.0404582	.1803574	-0.22	0.823	-.3942147	.3132983
Smoking	-.085078	.1334226	-0.64	0.524	-.3467758	.1766197
BaseAge	-.120129	.0093765	-12.81	0.000	-.1385203	-.1017377
Wave	-.0072658	.0510346	-0.14	0.887	-.1073661	.0928345
Mstat						
Registered partnership	-.7031155	.4933044	-1.43	0.154	-1.670692	.2644613
Married, living apart	-.2947997	.6896369	-0.43	0.669	-1.647467	1.057868
Never	-.5340833	.3937345	-1.36	0.175	-1.306362	.2381952

married						
Divorced	-.2739711	.2214909	-1.24	0.216	-.7084076	.1604655
Widowed	-.0796759	.2989539	-0.27	0.790	-.66605	.5066981
Chronic	-.1140195	.0487161	-2.34	0.019	-.2095721	-.0184668
Female	1.078363	.1571258	6.86	0.000	.7701735	1.386553
ISCED-97						
Level 1	-.805394	.3549471	-2.27	0.023	-1.501594	-.1091938
Level 2	-.0814004	.3100839	-0.16	0.793	-.689605	.5268042
Level 3	.5169885	.2952537	1.75	0.080	-.0621278	1.096105
Level 4	.4863285	.4605592	1.06	0.291	-.4170212	1.389678
Level 5	1.508168	.3082891	4.89	0.000	.9034837	2.112852
Level 6	1.964829	.7893019	2.49	0.013	.4166768	3.512981
Welfare Regime						
2	.0267289	.2571674	0.10	0.917	-.4776843	.5311421
3	-1.823777	.1798149	-10.14	0.000	-2.17647	-1.471085
4	-1.217844	.2364698	-5.15	0.000	-1.68166	-.7540276
Constant	20.22179	.7860579	25.73	0.000	18.68	21.76358
Observations	3266					
F (22, 1631)	37.54					
Prob > F	0.0000					
R-squared	0.2412				AIC	16865.54
Root MSE	3.1885				BIC	17005.64

Table 10: Multiple linear regression with Cognitive Function Score as dependent variable and separate lifestyle factors as explanatory variables. Standard error adjusted for 1632 clusters in ID.

CFS	**Coefficient**	**Robust std. err.**	**t**	**P>t**	**95% conf. interval**	
LSIcat						
1	-.4054464	.2109564	-1.92	0.055	-.8192205	.0083277
2	-.5434653	.2223866	-2.44	0.015	-.9796587	-.1072718

3	-1.009975	.2609989	-3.87	0.000	-1.521903	-.4980466
Wave	-.100605	.0531822	-1.89	0.059	-.2049176	.0037076
Constant	13.1043	.4181366	31.34	0.000	12.28416	13.92445
Observations	3266					
F (4, 1631)	4.68					
Prob > F	0.0009					
R-squared	0.0073				AIC	17707.03
Root MSE	3.6368				BIC	17737.49

Table 11: multiple linear regression models with Cognitive Function Score as dependent variable and clustered lifestyle factors as main explanatory variable. Standard error adjusted for 1632 clusters in ID.

CFS	**Coefficient**	**Robust std. err.**	**t**	**P>t**	**95% conf. interval**	
LSIcat						
1	-.2172806	.1832287	-1.19	0.236	-.5766689	.1421078
2	-.117427	.1982963	-0.59	0.554	-.5063692	.2715151
3	-.5268886	.234527	-2.25	0.025	-.9868944	-.0668828
BaseAge	-.1232468	.0093921	-13.12	0.000	-.1416687	-.1048249
Wave	-.0110786	.0509498	-0.22	0.828	-.1110126	.0888554
Mstat						
Registered partnership	-.6777749	.4901594	-1.38	0.167	-1.639183	.2836334
Married, living apart	-.243182	.6969227	-0.35	0.727	-1.61014	1.123776
Never married	-.4776635	.3938499	-1.21	0.225	-1.250168	.2948413
Divorced	-.2653015	.2208218	-1.20	0.230	-.6984257	.1678226
Widowed	-.0751721	.3014119	-0.25	0.803	-.6663672	.516023
Chronic	-.1246299	.0486231	-2.56	0.010	-.2200003	-.0292595
Female	1.020133	.1535806	6.64	0.000	.7188967	1.321369
ISCED-97						
Level 1	-.802553	.3559935	-2.25	0.024	-1.500805	-.1043004

Level 2	-.0711825	.3108191	-0.23	0.819	-.6808291	.5384641
Level 3	.5320675	.2966613	1.79	0.073	-.0498098	1.113945
Level 4	.4807209	.4595012	1.05	0.296	-.4205537	1.381996
Level 5	1.511806	.3100607	4.88	0.000	.9036474	2.119965
Level 6	1.969643	.7907479	2.49	0.013	.418655	3.520632
Welfare Regime						
2	.0902253	.2553779	0.35	0.724	-.4106779	.5911284
3	-1.8093	.1758876	-10.29	0.000	-2.154289	-1.46431
4	-1.199063	.2350745	-5.10	0.000	-1.660143	-.7379836
Constant	20.42883	.7906347	25.84	0.000	18.87806	21.97959
Observations	3266					
F (21, 1631)	38.62					
Prob > F	0.0000					
R-squared	0.2399				AIC	16869.29
Root MSE	3.1908				BIC	17003.3

Table 12: Multiple linear regression models with Cognitive Function Score as dependent variable and clustered lifestyle factors as main explanatory variable. Standard error adjusted for 1632 clusters in ID.