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MEASURING AGEING BY A HANDSHAKE
THE IMPACT OF SARCOPENIA ON HEALTHY AGEING

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A Project carried out on the Masters in Economics Program, under the supervision of:
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This paper features a supplementary appendix, which contains more detailed data description and additional results.

This paper uses data from SHARE Waves 1, 2, 4, 5 and 6
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This paper uses data from the generated easySHARE data set, see Gruber et al. (2014) for methodological details. The easySHARE release 6.1.0 is based on SHARE Waves 1, 2, 3 (SHARELIFE), 4, 5 and 6
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Measuring Ageing by a Handshake

The Impact of Sarcopenia on Healthy Ageing

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Abstract

Sarcopenia, an age-related condition characterized by low levels of muscle mass, carries personal and financial costs. Understanding the condition and its consequences is essential to implement successful interventions for people with and people at risk of developing sarcopenia. Using data from SHARE of people aged 50 and older, the effect of sarcopenia on ageing is estimated. Results suggest that sarcopenia has a significant negative impact on ageing. Quantitatively, the effect of sarcopenia on the healthy ageing indices is equivalent to having aged approximately one decade. Through the estimation of a production function of sarcopenia, the importance of physical activity as prevention is confirmed.

Keywords: sarcopenia, healthy ageing, Selfie Aging Index, Active Ageing Index

1. Introduction

Ageing populations are among the greatest challenges of the 21st century. The European Commission (2017) projects the old-age dependency ratio to rise from 29.6% in 2016 to 51.2% in 2070, inter alia, due to increased life expectancy.[2] This transition poses new challenges for the future. For instance, increased costs of health care and a diminishing work force are creating a need for governments to address age-related health problems and to promote healthy ageing.

This work project is motivated by the hypothesis that sarcopenia has a negative impact on healthy ageing. Reduced muscle mass is an expected consequence of ageing, and sarcopenia is an age-related condition characterized by substantial loss in muscle mass. It is a fairly new concept, and there is no consensus on the definition. The European Working Group on Sarcopenia in Older People (EWGSOP) (Cruz-Jentoft et al. 2010) defines sarcopenia as: "*a syndrome characterized by progressive and generalized loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life and death*". According to EWGSOP, sarcopenia leads to falls and fractures, admission to nursing homes, loss of independence and high cost of health care. With the anticipated ageing population, the prevalence of sarcopenia is expected to rise.[3]

[2] Old-age dependency ratio: people aged 65 or more relative to those aged 15 to 64.

[3] EWGSOP estimates a prevalence of sarcopenia worldwide of more than 200 million in the next 30 years. According to EWGSOP, more than 50 million people worldwide had sarcopenia in 2010.

Results from this work project point towards sarcopenia having a negative impact on healthy ageing. The effect of sarcopenia on the healthy ageing indices is equivalent to approximately one decade of age increase, signalizing the importance and widespread consequences of the condition.

The work project is organized as follows: First, a literature review on the concept of healthy ageing, the Selfie Aging Index, the Active Ageing Index and a production function of sarcopenia is presented. Second, the methodologies used for the different approaches are described. Third, the results of the models are presented. Finally, limitations and concluding remarks with possible implications are discussed.

2. Literature Review

Healthy ageing is an extensively used term, although there is no complete consensus on the definition. The World Health Organization (WHO, 2015) defines healthy ageing as "*the process of developing and maintaining the functional ability that enables wellbeing in older age*". Functional ability captures an individual's ability to "*meet their basic needs, to learn, grow and make decisions, to be mobile, to build and maintain relationships and to contribute to society*" (WHO 2015). The Healthy Ageing Project, carried out by the Swedish National Institute of Public Health (2007), defines healthy ageing as "*the process of optimizing opportunities for physical, social and mental health to enable older people*".[4] In practice, healthy ageing is about acquiring a healthy life style, working longer and having an active life after retirement. Healthy ageing is not a static concept, as functional abilities are expected to decline with age, life choices and other interventions (WHO 2015).[5] Older people with an active lifestyle seem to be more motivated to participate socially, engage in healthy behaviors and have in general less problems dealing with difficulties (Paúl, Ribeiro, and Teixeira 2012). Optimizing the healthy ageing potential could potentially reduce health care costs.

[4] The Healthy Ageing Project is a project under the EU Public Health Programme aiming at promoting healthy ageing. The project was initiated by the Swedish National Institute of Public Health and is co-funded by the European Commission.

[5] In 2002 WHO replaced the term "active ageing" with "healthy aging". Some organizations may only refer to one of the concepts while others refer to both.

The Active Ageing Index (AAI) and the Selfie Aging Index (SAI) are two approaches used to measure healthy ageing. The effect of sarcopenia on healthy ageing can be measured using the two indices. The appliance of both methods may provide a more comprehensive notion of healthy ageing and add extra validity to the estimation results. Additionally, the usage of both proxies overcome the shortages of each method.[6]

The SAI, developed by Gonçalves et al. (2017), is a multidimensional index based on self-assessed health indicators allowing people to take a *selfie* of their ageing status. The index contains indicators of three domains: biological, psychological and social, and is based on the Biopsychosocial Assessment Model.[7] The SAI uses self-assessed health as the dependent variable to establish the sources of each element of the index. Numerous papers point to self-assessed health as a good proxy for healthy ageing. For example, Pfarr, Schmid, and Schneider (2012) find self-assessed health to be a suitable predictor of the old-age health status.[8]

The AAI is a tool created by United Nations Economic Commission for Europe (UNECE) and the European Commission (EC, 2015) to "*measure the untapped potential of older people for active and healthy ageing across countries*". The index is a weighted average of four domains: (1) employment, (2) participation in society, (3) independent, healthy and secure living and (4) capacity and enabling for active ageing. Each domain, composed of different indicators, represent discrete features of active ageing.[9]

Having presented the two indices that will be used to disclose if sarcopenia has an impact on healthy ageing, the focus is turned to the production function of sarcopenia. A production function may provide information on the relevant predictors of sarcopenia. Finding relevant factors may also help identifying intervention strategies. The production function is based on the well-known Grossman model (Grossman 1972), which establishes the relation between health

[6] Critique of the individual level AAI points to some of the indicators not being appropriate on the individual level. For example, being employed (1st domain: Employment) may not be relevant to analyse the respondent's perception of active ageing. Additionally, the individual level AAI do not exploit the full variation of the data because they are dichotomized (Gonçalves et al. 2017).

[7] The Biopsychosocial Assessment Model was first proposed by Engel (1977) whose main aim was to develop a model that captured the biological, psychological and social aspect of the individuals health.

[8] Self-assessed health has also been found to be a good predictor of mortality (Mossey and Shapiro 1982).

[9] The domains and corresponding weights are decided by a group of experts based on political relevance. The experts consist of academics, statisticians and representatives from international organisations such as OECD, EC and UNECE.

and different health inputs. This paper applies a simple production function approach in which sarcopenia is replacing health as the dependent variable. To obtain suitable explanatory variables, existing, but limited literature on sarcopenia is reviewed. Among the inputs of the production function of sarcopenia are physical activity, income and body mass index.

Physical activity could reduce the likelihood of developing sarcopenia. Sarcopenia is found to be preventable by early intervention through nutrition and physical activity (Martone et al. 2015; Yu et al. 2016). Ryu et al. (2013) also finds, after adjusting for covariates, that Koreans older than 65 years doing physical activity are less likely to have sarcopenia.

Income is also included in the production function. People with higher income are found to do more exercise (Downward 2007). Considering that existing literature points at physical activity being preventive of sarcopenia, it is of interest to check if income plays a role on the likelihood of developing sarcopenia.

The relation between body mass and sarcopenia is frequently mentioned in the literature, in particular, sarcopenia co-occurring with either a high or low body mass index (BMI). High BMI in older age, with increased risk of obesity and heart trouble, can increase the risk of sarcopenia (Ryu et al. 2013). Low BMI can be a sign of poor nutrition and little food intake, which in turn again can lead to loss of muscle mass and sarcopenia (Muscaritoli et al. 2010).

According to EWGSOP, sarcopenia is related to older age, poor life quality and admissions to nursing homes. All the aforementioned factors will be included to test if the relations found in existing literature hold for the SHARE sample.

3. Methodology

3.1 Data

To measure the impact of sarcopenia on healthy ageing, data from the Survey of Health, Ageing and Retirement in Europe (SHARE) is used. The dataset consists of data from six waves on health and socio-economic factors for Europeans aged 50 years and older.[10] SHARE contains data on handgrip strength which can be used to define sarcopenia. To measure the grip strength, respondents were asked to push as hard as they possibly could on a dynamometer while standing

[10] SHARE (collected from 2004-2015) was constructed to be representative for Europeans over 50.

up. Respondents with sarcopenia are identified using EWGSOP´s definition of sarcopenia; grip strength lower than 30 kg for men and 20 kg for women. Due to biological differences, men and women have different cut-off values, hence each gender is analyzed separately. The variable of interest, *sarcopenia,* is a dummy variable taking value 1 if the individual has sarcopenia and 0 otherwise. A selection of descriptive statistics is presented in Table I. Approximately 13% of the total sample have sarcopenia, 15.8% of all women and 9.8% of all men, respectively.[11]

Table I. Descriptive Statistics

	Total sample		**With sarcopenia**		**Without sarcopenia**	
	Obs.	**%**	**Obs.**	**%**	**Obs.**	**%**
Female	126 765	54.9	19 991	66.2	106 774	53.2
Male	104 066	45.1	10 202	33.8	93 864	46.8
Total	230 831	100	30 193	100	200 638	100
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Age	65.7	9.8	74.5	10.2	64.4	9.0
Grip strength female	26.3	7.1	15.2	3.4	28.3	5.5
Grip strength male	42.8	10.4	23.6	4.9	44.8	8.5
Body mass index	26.8	4.6	28.5	4.9	26.9	4.5
Household income[12]	€30 085	€48 960	€21 304	€43 596	€31 398	€49 579

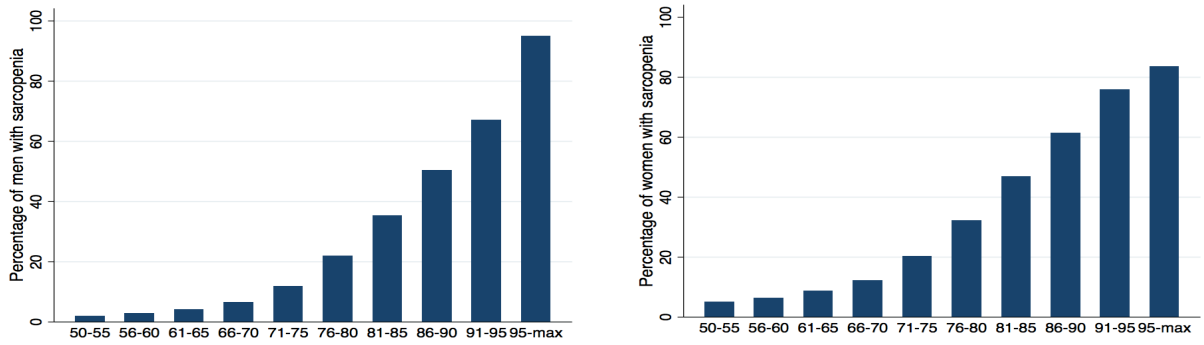
SHARE is an unbalanced panel. Although the panel structure allows to follow the same individuals over many waves, not all questions were asked in all waves and to all respondents. Additionally, attrition reduces the size of the sample. Table II in the appendix lists the variables that are crucial to build the econometric models and the documented loss of observations due to the inclusion of these variables. Note that the prevalence of sarcopenia is higher in the southern parts of Europe, confirming previous findings of Andersen-Ranberg et al. (2009). [13]

Figure I displays the percentage of individuals with sarcopenia of the total sample by age group and gender. As expected, people with sarcopenia are on average older. The charts demonstrate that sarcopenia is highly correlated with age and that the prevalence of sarcopenia

[11] The percentages are obtained from Table I and divided by the total sample.
13%: 30 193/ 230 831, 15.8%: 19 991/126 765, 9.8%: 10 202/104 066.
[12] *Household income* is a SHARE imputed variable based on total monthly household income.
[13] Table I in the appendix presents the proportion of individuals with sarcopenia by country. The prevalence of sarcopenia is higher in the southern parts of Europe. In particular, Spain, Portugal and Israel have high proportions of individuals with sarcopenia. This confirms the findings of Andersen-Ranberg et al. (2009) that grip strength in northern and continental Europe is higher than in southern Europe.

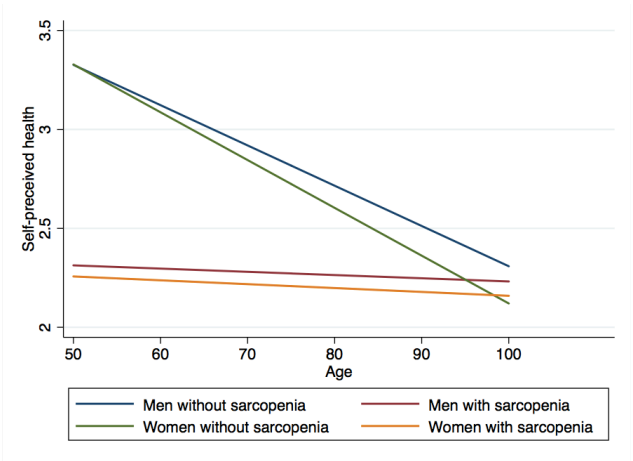
increases progressively with age for men and women. The pattern in Figure I motivates for a more detailed analysis of the relationship between ageing and sarcopenia.[14]

Figure I: Percentage of Sample with Sarcopenia by Age Group, for Men and Women



One of the hypotheses of this work project is that sarcopenia has a negative impact on healthy ageing. Prior to any estimations, Figure II plots the variables *self-assessed health* and *age* for men and women, with and without sarcopenia.

Figure II: Fitted Lines of Self-Assessed Health for Men and Women with and without Sarcopenia[15]



Three clearly visible effects are present. First, men and women with sarcopenia (the two "flat" lines) and men and women without sarcopenia (the two "steep" lines) do not have similar self-assessed health. Second, there is a substantial but declining difference between the self-assessed health for individuals with and without sarcopenia at the age of 50, pointing in favor of the hypothesized effect. The difference is declining with age, reaching zero just before 100 years.

[14] Figure II in the supplementary appendix with respective explanation illustrates the intensity of sarcopenia, hence how far away from the cut-off value the handgrip strength is. The intensity can be viewed as a measure of the severity of sarcopenia. Most individuals with sarcopenia in the SHARE sample have a less "severe" version of sarcopenia.

[15] The ordered variable *self-assessed health* has the following values: (1) poor, (2) fair, (3) good, (4) very good and (5) excellent. Note that Figure II is created for exposition purposes. In the econometric specifications, *self-assessed health* is handled as an ordinal variable.

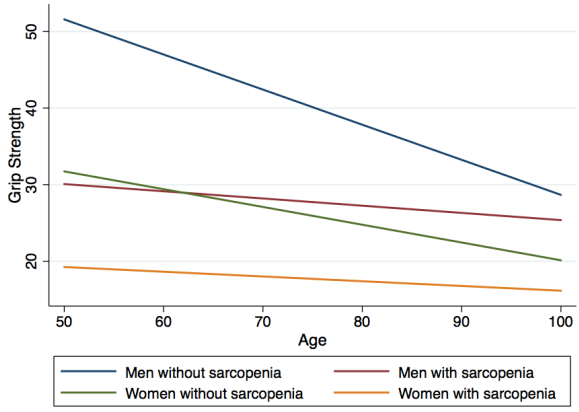
Third, the evolution of self-assessed health with age of individuals with sarcopenia is close to horizontal. A possible reason for this is that the self-assessed health status is, on average, so low that there is little room for deterioration.

Understanding how grip strength evolves over time also provides valuable insight on sarcopenia. A fixed effect model with grip strength as the dependent variable is estimated for men and women (see Table III in the appendix for estimation results).[16] The explanatory variables include age, sarcopenia and an interaction term between sarcopenia and age ($sarcoage$). The grip strength for men and women with and without sarcopenia is constructed as follows:

$$Grip\ strength_{it} = \beta_1(age) * age_{it} + \beta_2(sarcopenia_{it}) * sarcopenia_{it} + \beta_3(sarcoage_{it}) * sarcoage_{it} + \beta_4(constant) \quad (1)$$

Using linear prediction, the grip strength is plotted in Figure III. Grip strength decreases with age. There is a substantial difference in the slope of the grip strength, with a steeper slope for individuals without sarcopenia for both men and women. The evolution of grip strength with age follows the same pattern as displayed in Figure II of self-assessed health and age.[17]

Figure III: Grip Strength for Men and Women with and without Sarcopenia (in kg)



In sum, the trends revealed in the presented figures suggest that sarcopenia is related to poor health outcomes. The following section explains the methodology of the models used to test if this is

[16] A methodical detail worth mentioning is that none of the estimations in this paper include any kind of sampling weights. The decision to not use weights is primarily based on Solon, Haider, and Wooldridges (2015) discussion of weights appliance. First, the objective of this paper is to capture the causal effect of sarcopenia, which is independent of weights, not to reflect the total population. Second, applying weights to the highly unbalanced panel is not desirable as that would lead to the sample being reduced significantly. Third, as some of the variables in the estimation are also used in the creation of the weights (gender, age etc.), this may disturb the weight structure and reduce the accuracy of the estimation coefficients.

[17] Due to biological differences, a 10 kg difference between men and women implies they are equally "well".

true. First, the SAI and AAI are presented to establish if sarcopenia has an effect on healthy ageing, followed by a production function of sarcopenia that may be useful to understand the determinants and potential interventions of the condition.

3.2 Selfie Aging Index

Using the work of Gonçalves et al. (2017) as reference, the SAI is replicated. The dependent variable, self-assessed health, reported as a five-level variable from poor to excellent, is recoded to three levels (poor or fair – good – very good or excellent). The SAI is based on an ordered probit model, predicting a *selfie* of each individual's ageing status.[18] The predicted latent variable is then normalized to a 0 to 1 scale, 1 being the best self-assessed health and 0 being the worst self-assessed health.[19]

The original SAI is constructed using SHARE. The variables used in the creation of the SAI can be found in Table V in the appendix. The individual SAI score is obtained by inserting personal characteristics into the model.[20] An additional feature is the data added on grip strength to analyze the effect of sarcopenia on the SAI. Another extension is the inclusion of all available waves in the model.[21] The SAI is originally developed for Portugal. To make it suitable for this paper all SHARE countries are included, with time- and country dummies to control for time- and place specific effect. Robust standard errors were used in all models to control for heteroscedasticity.

As previously mentioned, a limitation in using all waves is the large number of missing values for some of the variables. Consequently, the sample size is heavily reduced. Given the large number of missing variables, the SAI is predicted two times, one using the complete set of covariates and one excluding variables with many missing values.[22] The correlation between the

[18] None of the models, except for the estimation of the grip strength (Table III in the appendix), uses fixed effect specifications. Using fixed effect on a highly unbalanced panel will reduce the sample heavily. Even if fixed effect models capture the effect of unobserved heterogeneity, the number of unknown parameters will increase with the number of observations. Additionally, the specification do not allow for estimation of coefficients that have no within-subject variation (Hsiao 2007).

[19] The rescaling of the SAI allows for a more intuitive interpretation and is obtained by plugging in theoretical minimum and maximum values in the SAI, which is then normalized.

[20] See Figure III in and Figure IV in the supplementary appendix the distribution of the SAI and an illustration on the SAI in practice. For more details on the SAI, please refer to Gonçalves et al. (2017).

[21] All waves (1 to 6), except for Wave 3 (SHARELIFE), are included in the model. Wave 3 diverges from the other waves as it contains data on the respondents' life histories. The original SAI only uses the first four waves.

[22] Missing values >100 000.

two predicted variables is high, suggesting a similar effect for both models.[23] To capture the full effect of the SAI, the model with the complete set of covariates is presented.

3.3 Active Ageing Index

The AAI is based on country-level average values of active ageing. Nonetheless, information on micro-level can be useful to understand each individual's ageing status and outliers, such as people with sarcopenia. Therefore, following the method of Almeida and Barros (2015), the AAI is transformed from aggregate to individual level. Nine indicators from SHARE were selected to fit the four AAI domains. The number of missing values per variable was also considered in the selection to avoid losing too many observations. The variables and the composition of the domains can be found in Table V and Equation (4) in the appendix.

Two versions of the AAI are constructed, with different composition of the first domain. One follows the Zaidi et al. (2017), where the first domain consists of a binary variable with value 1 if the respondent is employed and 0 otherwise. In the other version, proposed by Almeida and Barros (2015), the first domain also includes an interaction term between the binary variables *Social participation* and *Retired*. Almeida and Barros argues that this version is more suitable at the individual level as respondents may be active after retirement.

All non-dummy variables are normalized to a 0-1 interval.[24] Linear regression is used to estimate the relation to socio-demographic characteristics, health care characteristics and social activity[25]. Additionally, a dummy variable for sarcopenia was included with the objective to find the impact of sarcopenia on the AAI:

$$AAI = f(\, sarcopenia_i, x_i) \qquad (2)$$

x_i denotes the other characteristics to estimate on the AAI (see Table VI in the appendix).

The transition from macro to micro-level poses challenges of finding appropriate variables for each indicator. The AAI's at the individual level are unique and depend on the variables selected. Adding up the AAI's do not produce an aggregate level AAI. Even if each domain

[23] Correlation between $y^{\text{Complete set of covariates}}$ and $y^{\text{Incomplete set of covariates}}$ is 0.967.

[24] Using $f(x_i)_N = \frac{f(x_i) - \min(f(x_i))}{\max(f(x_i)) - \min(f(x_i))}$.

[25] None of the variables used in the construction of the AAI are included in the estimation.

captures some of the dimensions of the AAI, some indicators are not reflected due to a lack of appropriate variables in the SHARE database.[26]

3.4 Production Function of Sarcopenia

The production function of sarcopenia is estimated using a binary probit model with sarcopenia as the variable of interest. The model has the following function:

$$P[y_i = 1|x_i] = f(x'_i\beta) \quad (3)$$

where x'_i denotes the determinants of sarcopenia, presented in Table II and y_i equals 1 if the individual has sarcopenia and 0 otherwise.

Table II: Variables for the Production Function of Sarcopenia

Variable Descriptions	
Dependent variable	
Sarcopenia$_i$	= 1 if grip strength <20 kg (female) or <30 kg (male), 0 otherwise, $i \in \{male, female\}$
Independent variables	
Age	Age of respondent at the time of the interview
Moderate physical activity	Respondent´s engagement in moderate physical activity categorized as follows: more than once a week, once a week, 1-3 times a month, (almost) never
Vigorous physical activity	Respondent´s engagement in moderate physical activity categorized as follows: more than once a week, once a week, 1-3 times a month, (almost) never
BMI	Body mass index categorized as follows: undernourished (<18.5), normal (18.5-25), overweight (25-30), obese (>30)
Nursing home	= 1 if the respondent has been in a nursing home the last 12 months, 0 otherwise
Chronic diseases	Number of chronic diseases (self-reported)
Self-assessed health	= 1 if the respondent has good, very good or excellent self-assessed health, 0 otherwise
Number of difficulties in the ADLs	Number of limitations with activities of daily living (in units)
Number of difficulties in the IADLs	Number of limitations with instrumental activities of daily living (in units)
Years of education	Number of years of education
Income	Monthly household income (in euros)
Married	= 1 if the respondent is married or lives in a partnership, 0 otherwise

In sum, the SAI and AAI are constructed indices to measure healthy ageing. The SAI is an ordered probit based on self-assessed indicators and the AAI a weighted average of four domains capturing different aspects of healthy ageing. The explanatory variables included in the production function are based on existing literature on sarcopenia. The next section presents results of the SAI, the AAI and the production function of sarcopenia, respectively.

[26] For instance, SHARE do not contain useful information on physical safety, which is a part of the third domain of AAI, *Independent, Healthy and Secure Living*.

4. Results

4.1 Selfie Aging Index

Table III presents the marginal effect of sarcopenia and age for the ordered probit estimation of the SAI.[27] Consistent with the hypothesis, having sarcopenia is associated with a lower SAI score. Men and women with sarcopenia have a higher probability of reporting poor or fair self-assessed health and a lower probability of reporting good, very good or excellent self-assessed health compared to men and women without sarcopenia. For instance, being a man with sarcopenia increases the probability of reporting poor or fair self-assessed health by approximately 6 percentage points on average, ceteris paribus.

Table III: Marginal Effect of Sarcopenia on the Selfie Aging Index

	Poor or fair	Good	Very good or excellent
$Sarcopenia_{male}$	0.059*** (0,012)	-0.007*** (0,001)	-0.052*** (0,011)
$Sarcopenia_{female}$	0.061*** (0,010)	-0.007*** (0,001)	-0.053*** (0,009)
Age	0.022*** (0,012)	-0.003*** (0,007)	-0.019*** (0,011)
Age^2	-0.0001*** (0,000)	0.00002***(0,000)	0.0001*** (0,000)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

To have a reference of the magnitude of the impact, the marginal effect of sarcopenia is compared to the marginal effect of age. As previously illustrated (Figure I), age has a strong association with sarcopenia, hence age may be useful for comparison. Table IV presents the computed equivalent age effect.[28] For each self-assessed health state, the marginal effect of sarcopenia on the SAI is equivalent to having approximately seven to ten years of age increase.[29]

Table IV: Age Equivalent Effect of Sarcopenia on the Selfie Aging Index

	Poor or fair	Good	Very good or excellent
Male	6 years and 9 months	10 years	10 years
Female	7 years	9 years	10 years

[27] The estimation results for the SAI can be found in Table VII in the appendix.
[28] For details of how the equivalent age effect of sarcopenia on the SAI is found, please refer to the appendix and Equation (5) with respective explanation.
[29] The effect of sarcopenia on the SAI may be perceived as small compared to the fitted lines of self-assessed health for men and women in Figure II. To test this, an ordered probit model on self-assessed health with sarcopenia and age as explanatory variables is estimated. While the marginal effect of age is similar in both regressions, the marginal effect of sarcopenia increases substantially. This may imply that the other indicators in the SAI capture some of the effect and that Figure II overestimates the effect of sarcopenia. See Table IV and V in the supplementary appendix for estimation results and marginal effects.

4.2 Active Ageing Index

Table V presents the estimation results of the AAI following the approach of Almeida and Barros.[30] Model 2 excludes non-significant variables. Sarcopenia has a negative impact on the AAI. The effect is greater for men than women. The marginal effect of sarcopenia is compared to the marginal effect of age. Note that the outcome value needs to be converted from the normalized values to the age to find the equivalent age effect.[31] The impact of sarcopenia on the AAI is equivalent to having aged nine additional years for women and thirteen additional years for men, on average, ceteris paribus.[32]

Table V: Factors Associated with the Active Ageing Index

VARIABLES	**Model 1**		**Model 2**	
$Sarcopenia_{male}$	-0.045***	(0.005)	-0.045***	(0.005)
$Sarcopenia_{female}$	-0.033***	(0.003)	-0.034***	(0.003)
Gender: female	-0.025***	(0.002)	-0.025***	(0.002)
Age	-0.185***	(0.016)	-0.165***	(0.006)
Age^2	0.036	(0.032)		
BMI	-0.116***	(0.017)	-0.119***	(0.017)
Low education	-0.059***	(0.002)	-0.060***	(0.002)
Married	0.002	(0.002)		
Health limitations	-0.022***	(0.002)	-0.022***	(0.002)
Mental health	-0.008***	(0.002)	-0.008***	(0.002)
Receive help	-0.008***	(0.002)	-0.008***	(0.002)
Give help	0.027***	(0.002)	0.027***	(0.002)
Constant	0.517***	(0.009)	0.516***	(0.008)
Observations	45 748		45 768	
R-squared	0.159		0.159	
Country dummies	YES		YES	
Year dummies	YES		YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

To understand what domains are more affected by sarcopenia, individual regressions for each domain are estimated.[33] Table VI shows the coefficients of sarcopenia for the four domains used to construct the AAI. The mean, maximum and minimum value for the domains are included to better assess the magnitude.

[30] Table I and Figure V in the supplementary appendix present the estimation results and the distribution of the AAI following the method of Zaidi et al. (2017). Both versions of the AAI give similar estimation results. The version inspired by Almeida and Barros is presented in the main text, as it is found to be more appropriate for the sample.
[31] Table II in the supplementary appendix converts normalized values to age.
[32] For details of how the equivalent age effect of sarcopenia on the AAI is found, please refer to the appendix and Equation (6) with respective explanation.
[33] Complete estimation results on the domains can be found in Table III in the supplementary appendix.

Table VI: Output of Coefficients on Regression of the Active Ageing Index Domains

AAI domains	Mean	Min	Max	$Sarcopenia_{male}$	$Sarcopenia_{female}$
D1: Employment and active retirement	0.215	0	0.5	-0.052*** (0.003)	-0.022*** (0.002)
D2: Participation in society	0.284	0	1	-0.057*** (0.006)	-0.042*** (0.005)
D3: Independent, healthy and secure living	0.907	0	1.3	-0.079*** (0.002)	-0.112*** (0.002)
D4: Capacity and enabling environment for active ageing	0.733	0	1	0.0016 (0.004)	-0.0011 (0.003)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As in the previous section, the effect of sarcopenia is compared to the effect of age. Each domain is subject to separate normalization. Table VII presents the approximate comparable effect of ageing on the domains for both genders.[34] The non-linear relation between age and the AAI produces results where, at old ages, the effect of sarcopenia is equivalent to getting younger.[35] A possible rational for this is that the oldest individuals represent outliers or survivors of the population. Their health may stand out from the average population causing the odd relationship. When analyzing the effect of the AAI and the domains, it is important to remember that the indices are constructed using variables that are suitable to replicate the original AAI. The validity of the indices cannot be guaranteed and the results need to be interpreted with caution. For all significant results, there is a positive age effect equivalent to having sarcopenia. There is, however, no clear trend for gender or for the domains. Further research could study if the gender gap is random and caused by the specific sample used or if there exists gender differences within the domains.

Table VII: Age Equivalent Effect of Sarcopenia on the Active Ageing Index Domains[36]

Domain	Effect (male)	Effect (female)
D1. Employment and active retirement	5 years	2.5 years
D2. Participation in society	2.5 years	4 years
D3. Independent, healthy and secure living	3 years	1 year
D4. Capacity and enabling environment for active ageing	No statistical significant effect	

To sum up, both healthy ageing indices find consistent results suggesting that sarcopenia has a significant negative impact on healthy ageing. The equivalent age effect of sarcopenia is similar in both indices, signalizing robust results. Having established this relationship, the focus is moved to the production function of sarcopenia for an analysis of the determinants of the condition.

[34] See Equation (5) in the appendix for computation of the equivalent age effect of the domains.
[35] The effect of sarcopenia is equivalent to getting younger at approximately 85 years in the second and third domain.
[36] The outcome value needs to be converted to the real age using Table II in the supplementary appendix.

4.3 Production Function of Sarcopenia

The marginal effect of the production function is presented in Model (1) of Table VIII.[37] In line with existing literature, the results suggests that doing less (compared to doing more) moderate and vigorous activity increases the likelihood of sarcopenia. However, physical activity may be related to reverse causality. It is difficult to determine if people who exercise have a lower probability of developing sarcopenia, or if people who do not have sarcopenia are more likely to exercise. Time spent on physical activity has a positive effect on health outcomes and can slow down the effects of ageing by increasing the number of healthy days in the future. Similarly, being physically inactive is likely to cause loss of muscle mass at the same time as low muscle mass may cause physical inactiveness. To the extent of my knowledge, no existing literature addresses this issue.

The risk of endogeneity is addressed by using the lag of the potential endogenous explanatory variables in the model.[38] Model (2) presents the marginal effects of the production function in which the variables of physical activity are proxied by lagged variables. The marginal effects from the model with lagged variables are overall in line with the original variables, hence the potential source of endogeneity is not a serious problem.[39]

Never doing, or hardly ever doing vigorous physical activity (compared to doing vigorous physical activities more than once a week) has the same effect on the likelihood of developing sarcopenia as if the individual had 10 (men) and 21 (women) chronic conditions.[40] This comparison emphasizes the importance of physical activity as a preventive tool and a possible intervention strategy. Moreover, the cost of implementing exercise plans are likely to be marginal compared to the health care costs of chronic conditions.

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[37] Estimation results from the production function can be found in the supplementary appendix, Table VI.

[38] In detail, an ordered probit model is estimated with moderate and vigorous activity as the dependent variables and lagged explanatory variables. Variables from a previous period can be used as an instrument because it is less likely to be correlated with the future. The latent variables of physical activity are predicted and transformed into the same categories as the originals. The production function is estimated again, replacing the suspected endogenous variables with the predicted to compare. The sign and magnitude of the marginal effects for the two models have the same sign and magnitude, with some exceptions. For men, the lagged variable of vigorous physical activity, "Hardly ever, or never", has a negative, but non-significant, sign (and differs from the original variable by <0.02), contradicting the existing literature. See estimation results in Table VII in the supplementary appendix.

[39] Since the predicted variables are proxies, the estimation results may lose precision.

[40] Equivalent effect is confirmed using a linear hypothesis test in Stata.

The results suggest that age increases the likelihood of developing sarcopenia, supporting Figure I and the observations made in existing literature that the prevalence of sarcopenia increases with age.[41] Sarcopenia is also associated with living in nursing homes. Having at least good self-assessed health is negatively related to sarcopenia. The number of difficulties in the ADLs and IADLs are positively related to sarcopenia. However, one also need to interpret these three latter factors with caution as they may be related to reverse causality.[42]

The marginal effect of BMI suggests that if a respondent´s BMI is different from normal (*undernutrition, overweight* or *obese*), he or she is less likely to have sarcopenia (with the exception of undernourished women). This association suggests that, using SHARE, low or high BMI are not determinantants of sarcopenia.

Income has no significant effect on the onset of sarcopenia. Descriptive statistics (Table I) illustrate that people with sarcopenia have lower mean values of income. As previously mentioned, there is a substantial difference of sarcopenia between the south and north of Europe, with a higher prevalence in the south, where income is, on average, lower. Therefore, it could be that the difference in income is due to the higher proportion of people with sarcopenia in the south of Europa, and that this is accounted for by country dummies in the estimation.

Summing up, the results from the production function point towards physical activity being an important predictor of sarcopenia, and that doing less physical activity increases the liklihood of developing the condition. While there is no clear relation between BMI and sarcopenia or income and sarcopenia, the condition is found to be positively associated with limitations in daily living activities and low self-assessed health, confiming existing literature.

[41] The model is also estimated including the variables *Retired* (dummy variable) and $Age,^2$ and with only Age^2, see Model (1), (2) and (3) Table VI and Table VII in the supplementary appendix. Age^2 is only significant when combined with *Retired*. This means *Retired* introduces a non-linearity on age. Being retired is age-related, hence *Retired* can be viewed as a proxy for age.

[42]There is a risk that *Self-assessed health, Number of difficulties in the ADLs- and IADLs* suffer from revered causality. It is for instance difficult to establish if low self-assessed health causes sarcopenia, or if it is the other way around. Due to this suspicion, the production function was estimated without *Self-assessed health, Number of difficulties in the ADLs-* and *IADLs* in Table VII and VIII (Model (4) in the supplementary appendix).

Table VIII: Marginal Effects (ME) from the Production Function of Sarcopenia

VARIABLES	ME Male (1)	ME Male (2)	ME Female (1)	ME Female (2)
Age	0.002***	0.002***	0.002***	0.002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Moderate physical activity (ref: More than once a week)				
Once a week	-0.0007		0.004*	
	(0.002)		(0.002)	
Once to three times a month	0.001		0.006*	
	(0.002)		(0.003)	
Hardly ever, or never	0.003**		0.011***	
	(0.002)		(0.002)	
Lagged moderate physical activity (ref: More than once a week)				
Once a week		0.006**		0.016***
		(0.002)		(0.004)
Once to three times a month		0.011**		0.036***
		(0.004)		(0.005)
Hardly ever, or never		0.015**		0.057***
		(0.004)		(0.006)
Vigorous physical activity (ref: More than once a week)				
Once a week	0.0002		0.009***	
	(0.002)		(0.002)	
Once to three times a month	0.002		0.006**	
	(0.002)		(0.021)	
Hardly ever, or never	0.010***		0.021***	
	(0.001)		(0.002)	
Lagged vigorous physical activity (ref: More than once a week)				
Once a week		0.038		0.012**
		(0.004)		(0.006)
Once to three times a month		0.003		0.016
		(0.007)		(0.011)
Hardly ever, or never		-0.008		0.009
		(0.007)		(0.015)
BMI (ref: normal weight)				
Undernourished	-0.011	-0.016***	0.035***	-0.029**
	(0.004)	(0.004)	(0.008)	(0.014)
Overweight	-0.004***	-0.001***	-0.017***	-0.021***
	(0.001)	(0.002)	(0.002)	(0.003)
Obese	-0.008***	-0.006***	-0.015***	-0.017***
	(0.002)	(0.002)	(0.002)	(0.003)
Nursing home	0.011***	0.016***	0.031	0.031*
	(0.006)	(0.010)	(0.010)	(0.016)
Chronic diseases	0.001***	0.001***	0.001**	-0.001
	(0.0004)	(0.0001)	(0.001)	(0.001)
Years of education	0.0001	0.0002	-0.002***	-0.002***
	(0.003)	(0.0002)	(0.0001)	(0.0003)
Income/10 000	-0.0001	-0,0000007	-0.00003	(0.00005)
	(0.0002)	(0,0001)	(0.0001)	(0.003)
Married	0.013***	0.016***	-0.020***	-0.022***
	(0.024)	(0.002)	(0.001)	(0.002)
$L.sarcopenia_{male}$ [43]	0.106***	0.108***		
	(0.029)	(0.026)		
$L.sarcopenia_{female}$			0.158***	0.173***
			(0.002)	(0.002)
Self-assessed health	-0.012***	-0.009***	-0.023***	-0.068***
	(0.001)	(0.002)	(0.002)	(0.003)
Number of difficulties in the ADLs	0.002***	0.002***	0.004***	0.004***
	(0.001)	(0.001)	(0.001)	(0.002)

[43] $L.sarcopenia_i$ is a lag operator controlling for if the respondent already has sarcopenia in the previous wave.

Number of difficulties in the IADLs	0.005***	0.007***	0.006***	0.005***
	(0.001)	(0.001)	(0.001)	(0.002)
Observations	84 611	38 239	84 611	38 239
Country dummies	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5. Limitations

SHARE is a rich, but unbalanced dataset. The unbalanced structure poses challenges in finding appropriate variables without losing too many observations. Moreover, the structure of the data has implications for the econometric specifications, for instance the decision to not use sample weights and fixed effect models.

Another challenge is related to how to measure healthy ageing. Because there is no explicit way of measuring healthy ageing, both the SAI and the AAI are used. As both the indices produce consistent results with regards to the effect of sarcopenia, it is taken as a promising sign that the healthy ageing concept is captured.[44]

Additionally, literature on sarcopenia and its determinants is limited, as most of it is focused on biological and medical sciences rather than health and socioeconomic aspects. This posed challenges in determining which variables to include in the production function.

Due to the suspicion that physical activity, self-assessed health, living in a nursing home and the number of difficulties in the ADLs and IADLs are endogenous, one needs to interpret the estimates with caution. Further research should address the potential endogeneity bias and look for suitable instrumental variables to test for endogeneity. Additionally, further research could test and potentially confirm the established negative relationship between healthy ageing and sarcopenia, for example using difference-in-difference or matching estimation approaches.

6. Concluding Remarks

This work project finds evidence suggesting that sarcopenia has a significant negative effect on healthy ageing, measured using the Selfie Aging Index and the Active Ageing Index. Sarcopenia has the same impact as having aged an additional of seven to ten years on the SAI and nine to

[44] The Selfie Aging Index is based on self-assessed measures while the Active Ageing Index is based on UNECE and EC´s method and converted from the aggregate to the individual level.

thirteen years on the AAI.[45] The equivalent age effect is similar for both indices, enhancing the external validity of the estimation results. Considering the importance of healthy ageing and that self-assessed health is a proxy for healthy ageing, the low self-assessed health of people with sarcopenia may imply considerable loss of healthy ageing potential.

Results from the production function suggest that doing physical activity decreases the likelihood of developing sarcopenia. Sarcopenia is also found to be associated with limitations of daily living activities and living in nursing homes. The findings could indicate that people with sarcopenia have a high dependency on others, which may imply extra costs for the society, for example through additional caretaking. Interventions should target those at risk of developing sarcopenia, for example by creating targeted exercise plans and encourage people to engage in physical activities.[46] This can for instance be implemented in nursing homes, especially for people under recovery, where the activity level may be lower than usual and people are extra prone to muscle loss.

With the demographic shift the world is facing today, the prevalence of sarcopenia is expected to rise significantly. The established negative relationship between healthy ageing and sarcopenia must be addressed. Focus should be on reaching a commonly agreed definition of the condition to establish effective treatment. Moreover, research should look for possible interventions to prevent the condition, minimize the negative consequences and increase the number of healthy life years for people with sarcopenia.

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[45] Sarcopenia is equivalent to having aged an additional of thirteen years for men and nine years for women, using the AAI estimations.

[46] Resistance training interventions for older people have been shown to be highly effective, with particularly large positive effects on muscle strength (Liu and Latham 2009).

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APPENDIX

Table I: Proportion of Individuals with Sarcopenia Per Country[47]

Country	Proportion	Country	Proportion	Country	Proportion
Germany	7,5%	Luxembourg	10,7%	Greece	14,2%
Netherlands	8,1%	Belgium	10,8%	France	14,2%
Denmark	8,2%	Croatia	12,2%	Italy	15,1%
Sweden	9,0%	Slovenia	12,3%	Hungary	16,6%
Czech Republic	9,4%	Poland	13,0%	Portugal	22,8%
Switzerland	9,6%	Estonia	13,1%	Israel	23,0%
Austria	10,0%	Ireland	13,6%	Spain	26,9%

Table II: Critical Variables Used in the Construction of the Indices

Variable included	Sample size	Index
Sleep	191 506	SAI
Lack of interest	170 435	SAI
Social participation	169 950	AAI
Cognitive difficulties	122 521	AAI
Complaints: general	111 056	SAI
Complaints: emotions	84 266	SAI
Size of social network	51 734	SAI

Table III: Estimation Results from Regression of Grip Strength Used for Figure III

VARIABLES	Grip strength (male)		Grip strength (female)	
$Sarcopenia_{male}$	-39.720***	(0.679)		
$Sarcoage_{male}$[48]	0.364***	(0.009)		
$Sarcopenia_{female}$			-21.00***	(0.288)
$Sarcoage_{female}$			0.170***	(0.004)
Age	-0.458***	(0.003)	-0.232***	(0.002)
Observations	94,902		115,615	
R^2	0.2743		0.269	
Number of merge_id	44 638		53 806	
Controls	YES		YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table IV: Indicator Variables of the Selfie Aging Index

Biological subdomains	Variable	Variable description
Complaints about one´s health status	Complaints: general	Number of complaints, (falling, fear of falling, fatigue, other symptoms)
	Complaints: digestive system	= 1 if the respondent is bothered by stomach or intestine problems, including constipation, air, diarrhea, 0 otherwise
	Complaints: eyesight	= 1 if the respondent has fair or poor eyesight, 0 otherwise
	Complaint: hearing	= 1 if the respondent has fair or poor hearing, 0 otherwise
	Complaints: circulatory system	= 1 if the respondent is bothered by heart trouble or swollen legs, 0 otherwise
	Complaints: musculoskeletal system	= 1 if the respondent is bothered by pain in back, knees, hips or any other joints, 0 otherwise
	Complaints: nervous system	= 1 if the respondent is bothered by dizziness, faints or blackouts, 0 otherwise

[47] See Figure I in the supplementary appendix for the proportion of people with sarcopenia per wave.
[48] $Sarcoage_i$ ($Sarcopenia_i$*Age) is an interaction term between age and sarcopenia.

	Complaints: respiratory system	= 1 if the respondent is bothered by breathlessness or persistent cough, 0 otherwise
	Complaints: urinary system	= 1 if the respondent is incontinence, 0 otherwise
Nutrition status	BMI	Body mass index categorized into the following intervals: undernourished (<18.5), normal (18.5-25), overweight (25-30) and obese (>30)
	Difficulties moving around	= 1 if the respondent has difficulties walking across a room, 0 otherwise
Mobility	Number of difficulties in the ADLs[49]	Number of difficulties the respondent has out of the following: difficulties bathing or showering, dressing, using the toilet, getting in and out of bed, eating,
	Number of difficulties in the IADLs	Number of difficulties the respondent has out of the following: difficulties making telephone calls, shopping for groceries, preparing a hot meal, doing work around the house or garden, taking medication, managing money
Psychological domain		
	Complaints: emotional status	= 1 if the respondent has ever had affective or emotional disorders, 0 otherwise
	Depressed	= 1 if the respondent was sad or depressed last month, 0 otherwise
Emotional status	Lack of interest	= 1 if the respondent is less interested than usual in things the last month, 0 otherwise
	Nervousness	Level of nervousness categorized as follows: never, hardly ever, some of the time and most of the time
	Trouble sleeping	= 1 if the respondent has trouble with sleep, 0 otherwise
	Lack of energy	= 1 if the respondent has little energy to do the things he or she wanted to do last month (fatigue), 0 otherwise
Cognitive status	Time awareness	= 1 if the respondent is time aware (knowledge of year, month, day of the month, day of the week), 0 otherwise
Social domain		
	Marital status	Marital status categorized as follows: widowed, married, single, divorced/separated
Social network	Lives with someone else	= 1 if the respondent lives with someone (household size>1), 0 otherwise
	Has someone to confide with	= 1 if the respondent´s social network>1, 0 otherwise
	Years of education	Number of years of education
Social status	Job type	Type of current or last job categorized as follows: manager or army official, professional, technician, clerk, service and sales, agriculture and fishing, crafts, blue collar, elementary, armed forces
	Vigorous physical activity	Respondent´s engagement in vigorous physical activity categorized as follows: more than once a week, once a week, 1-3 times a month, (almost) never
Healthy behaviors	Moderate physical activities	Respondent´s engagement in moderate physical activity categorized as follows: more than once a week, once a week, 1-3 times a month, (almost) never
	Smoking status	Smoking status categorized as follows: non-smoker, former smoker, current smoker
Other		
	Sarcopenia$_i$	= 1 if grip strength<20 kg (female) or <30 kg (male), 0 otherwise, $i \in \{male, female\}$

Construction of the Active Ageing Index:

$$AAI = 0.35D1 + 0.35D2 + 0.1D2 + 0.2D4 \quad (4)$$

[49] ADLs: Activities of daily living. IADLs: Instrumental activities of daily living

Table V: Variables and Weights for Construction of the Active Ageing Index

Domain	Domain weight	Indicators	Indicator weight	Variable and variable description
D1. (Ref: Almeida and Barros) Employment and active retirement	35%	Currently working	50%	*Employed* = 1 if the respondent is employed, 0 otherwise
		Retired	50%	*Retired*socialparticipation* = 1 if the respondent is retired, 0 otherwise
D1.(Ref: Zaidi et al.) Employment	35%	Currently working	100%	*Employed* = 1 if the respondent is employed, 0 otherwise
D2. Participation in society	35%	Participation in recreational or social activities	100%	*Socialparticipation* = 1 if the respondent did activities last year (sport, social or other kind of club), 0 otherwise
D3. Independent, healthy and secure living	10%	Income	25%	*hhincome*[50] Monthly household income divided into intervals (in euros): [1] 1.Until 245, 246-489, 490-734, 735-1223, 1224-2445, above 2445
		Autonomy in DLA	40%	*50%* *no_daily_diff* = 1 if the respondent has no limitations of activities of daily living (ADLs), 0 otherwise
				50% *no_daily_instdiff* = 1 if the respondent has no limitations with instrumental activities of daily living (IADLs), 0 otherwise
		Independent	25%	*Independent* = 1 if the respondent lives alone or with only one other person, 0 otherwise
		Not physically inactive	10%	*Not_phinactive* =1 if the respondent is not physically inactive, 0 otherwise[51]
D4. Capacity and enabling environment for active ageing	20%	Cognitive difficulties	45%	*Cogn_diff* The completion score of cognitive difficulties test (remembering test, orientation to date, mathematical performance) divided into the following intervals: until 25%, 26-50%, 51-75%, 76-100%
		Current health status	55%	*Self_health* =1 if the respondent reports at least good self-assessed health, 0 otherwise

Table VI. Variables for Regression of the Active Ageing Index

	Variable name	Description
SD:Socio-demographic	*Female*	= 1 if the respondent is female, 0 otherwise
	Age, Age^2	Normalized age and age squared
	BMI	Normalized body mass index
	Low education	= 1 if the respondent has low education (primary or lower secondary education), 0 otherwise[52]

[50] Income was subject to normalization using $f(x_i)_N = \frac{f(x_i) - \min(f(x_i))}{\max(f(x_i)) - \min(f(x_i))}$.

[51] Physically inactive refers to never (or almost never) being in vigorous or moderate activity.

[52] Following Zaidi (2015).

H: Health Care Characteristics	*Married*	= 1 if the respondent is married or in a registered partnership, 0 otherwise
	Health limitation	= 1 if the respondent has limitation in activities because of health, 0 otherwise
	Mental health	= 1 if the respondent is feeling nervous, depressed or is with lack of interest, 0 otherwise
Soc: Social Activity and Access	*Receive help*[53]	= 1 if the respondent has received help from others (outside household), 0 otherwise
	Give help	= 1 if the respondent has given help the last twelve months, 0 otherwise
Sarc: Sarcopenia	$Sarcopenia_i$	= 1 if grip strength <20 kg (female) or <30 kg (male), 0 otherwise, $i \in \{male, female\}$

Table VII: Selfie Aging Index Estimation Results from the Ordered Probit Model

VARIABLES	**Model 1**		**Model 2**[54]	
$Sarcopenia_{male}$	-0.236***	(0.048)	-0.231***	(0.047)
$Sarcopenia_{female}$	-0.245***	(0.039)	-0.253***	(0.038)
Gender: female	0.140***	(0.018)	0.132***	(0.017)
Age	-0.087***	(0.011)	-0.085***	(0.011)
Age^2	0.001***	(0.000)	0.001***	(0.000)
Complaints: general	-0.251***	(0.016)	-0.254***	(0.016)
Complaints: digestive system	-0.235***	(0.025)	-0.230***	(0.024)
Complaints: eyesight	-0.211***	(0.017)	-0.214***	(0.016)
Complaints: hearing	-0.308***	(0.022)	-0.311***	(0.021)
Complaints: circulatory system	-0.428***	(0.022)	-0.430***	(0.021)
Complaints: musculoskeletal system	-0.327***	(0.015)	-0.337***	(0.015)
Complaints: nervous system	-0.250***	(0.033)	-0.266***	(0.032)
Complaints: respiratory system	-0.364***	(0.025)	-0.363***	(0.024)
Complaints: urinary system	-0.057	(0.045)		
BMI (ref: normal weight)				
Undernourished	-0.176**	(0.074)	-0.165**	(0.071)
Overweight	-0.100***	(0.017)	-0.115***	(0.016)
Obese	-0.262***	(0.021)	-0.275***	(0.021)
Difficulties moving around	0.217	(0.133)		
Number of difficulties in the ADLs	-0.156***	(0.032)	-0.159***	(0.032)
Number of difficulties in the IADLs	-0.122***	(0.021)	-0.106***	(0.019)
Complaints: emotional system	-0.154***	(0.029)	-0.160***	(0.028)
Depressed	-0.153***	(0.017)	-0.148***	(0.017)
Lack of interest	-0.071**	(0.033)	-0.085***	(0.032)
Nervousness (ref: never)				
Seldom	-0.004	(0.019)	-0.008	(0.019)
Sometimes	-0.067***	(0.019)	-0.073***	(0.019)
Often	-0.158***	(0.039)	-0.173***	(0.037)
Trouble sleeping	-0.185***	(0.017)	-0.184***	(0.017)
Lack of energy	0.068***	(0.004)	0.068***	(0.004)
Time awareness	0.003	(0.025)		
Marital status (ref: widowed)				
Married	-0.066**	(0.032)	-0.045*	(0.026)
Single	-0.102**	(0.040)	-0.089**	(0.038)
Divorced/separated	0.021	(0.034)	0.036	(0.033)
Lives with someone else[55]	0.021	(0.028)		

[53] Due to the nature of the data (many variables with many missing values), the indicators *Give help* and *Receive help* were chosen as proxies for social activity.

[54] Model 2 excludes variables that do not contribute to the overall fit of the model. In some aspects the SAI of Gonçalves et al. (2017) differentiates from this SAI. In particular, *Number of difficulties in the IADLs*, *Complaints: emotional status*, *Time awareness, BMI* and *Smoking status* were not significant in the original SAI, but significant in this version. On the other hand, *Difficulties moving around*, *Has someone to confide with* and *Years of education* were not significant in this model, but significant in the original version. All variables except for *Lack of energy* has the expected association with self-assessed health.

[55] As already addressed in Gonçalves et al. (2017) there is a risk of multicollinearity affecting the efficiency of the model, in particular between *Living with someone* and *Marital status*. Multicollinearity could cause unexpected estimates. The risk of multicollinearity was assessed by looking at the correlation matrix of covariates. *Marital status* and *Living with someone* were the only variables with high correlation (<0.6). In Model 2, *Living with someone* was excluded due to a non-significant coefficient, which automatically reduces the issue of multicollinearity.

Has someone to confide with	-0.032	(0.042)		
Years of education	0.007	(0.008)		
Years of education^2	0.001**	(0.000)		
Type of job (ref: manager, army official)				
Professional	-0.069*	(0.038)	-0.051	(0.036)
Technician	-0.145***	(0.035)	-0.183***	(0.034)
Clerk	-0.158***	(0.035)	-0.216***	(0.033)
Services and sales	-0.229***	(0.034)	-0.317***	(0.032)
Agriculture and fishing	-0.380***	(0.045)	-0.513***	(0.043)
Crafts	-0.303***	(0.036)	-0.404***	(0.034)
Blue collar	-0.378***	(0.042)	-0.488***	(0.040)
Elementary	-0.359***	(0.037)	-0.487***	(0.034)
Armed forces	-0.143	(0.097)	-0.213**	(0.095)
Vigorous physical activities (ref: more than once a week)				
Once a week	-0.140***	(0.023)	-0.142***	(0.022)
1-3 times a week	-0.166***	(0.027)	-0.165***	(0.026)
(Almost) never	-0.369***	(0.019)	-0.373***	(0.019)
Moderate physical activities (ref: more than once a week)				
Once a week	-0.020	(0.022)	-0.011	(0.022)
1-3 times a week	-0.133***	(0.034)	-0.132***	(0.033)
(Almost) never	-0.203***	(0.034)	-0.219***	(0.033)
Smoking status (ref: non-smoker)				
Former smoker	0,071***		-0.073	(0.015)
Current smoker	-0.051***		-0.054***	(0.049)
Constant cut1	-4.798***	(0.364)	-4.943***	(0.350)
Constant cut2	-3.431***	(0.363)	-3.581***	(0.349)
Observations	28 375		30 105	
Pseudo R^2	0.272		0.270	
Country dummies	YES		YES	
Year dummies	YES		YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Equivalent Age Effect of Sarcopenia for the SAI and the AAI Domains[56]

$$SAI = ME_1 age + ME_2\, age^2 + ME_3\, sarcopenia + k \quad (5)$$

where k denotes all the other factors of the index and ME is the marginal effect. When $dSAI = 0$, and sarcopenia moves from 0 to 1,

$$\frac{dSAI}{dage} = ME_1 dage + ME_2 * 2 * dage + ME_3 = 0$$

$$dage = -\frac{ME_3}{(ME_1 + 2 * ME_2 * age)} \text{ for each observation.}$$

Equivalent Age Effect for the AAI (*age*^{2} is not significant)

$$-\frac{\beta_3}{\beta_1} \quad (6)$$

$$\text{when } AAI = \beta_1 age + \beta_3 sarcopenia_i + k$$

k denotes all the other factors of the AAI.

[56] Equation (5) uses the SAI for illustration. The impact on the AAI is obtained in the same manner as the SAI. The impact is found by taking the average of the effect for all ages weighted by the number of people at each age. As the AAI uses a linear regression, the coefficients are equal to the marginal effects, simplifying the comparison.

SUPPLEMENTARY APPENDIX

TO

MEASURING AGEING BY A HANDSHAKE

THE IMPACT OF SARCOPENIA ON HEALTHY AGEING

INGRID KNUDSEN AAS, 3105

Figures I: Proportions of Individuals with Sarcopenia per Wave and Country

The prevalence of sarcopenia is higher in the southern parts of Europe. In particular, Spain, Portugal and Israel have high proportions of individuals with sarcopenia, while Germany, Netherlands, Denmark and Sweden have low proportions of individuals with sarcopenia. This confirms the findings of Andersen-Ranberg et al. (2009) that grip strength in northern and continental Europe is higher than in southern Europe.

Figures II: Intensity of Sarcopenia for Men and Women, Respectively

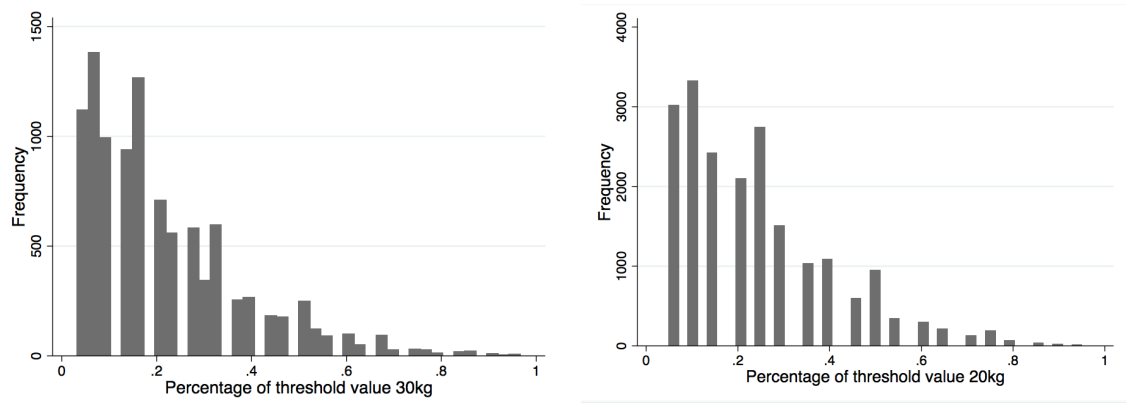

Figure II illustrates the grip strength of individuals with sarcopenia as a percentage of the cut-off value (20 kg for women and 30 kg for men). Observations close to one means the individuals have very low levels of grip strength, while observations with values close to zero means the individuals have grip strength values close to the cut-off value, in other words they have a less "severe" version of sarcopenia. Men and women follow an equal pattern of an exponentially declining number of individuals when approaching "severe" sarcopenia. Having noted that sarcopenia is a condition defined by an exceptionally low handgrip strength, most of the sample have the less "severe" version of sarcopenia.

Figure III: Distribution of the Selfie Aging Index

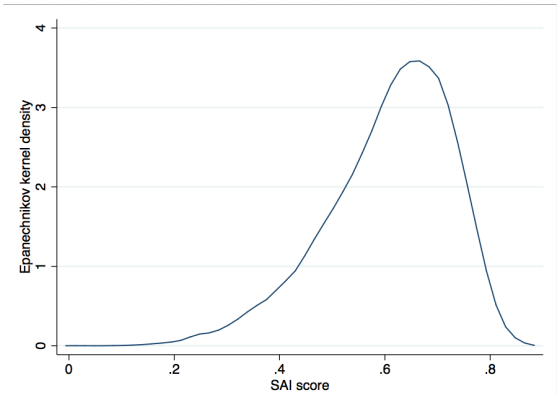

Figure IV: The SAI in Practice

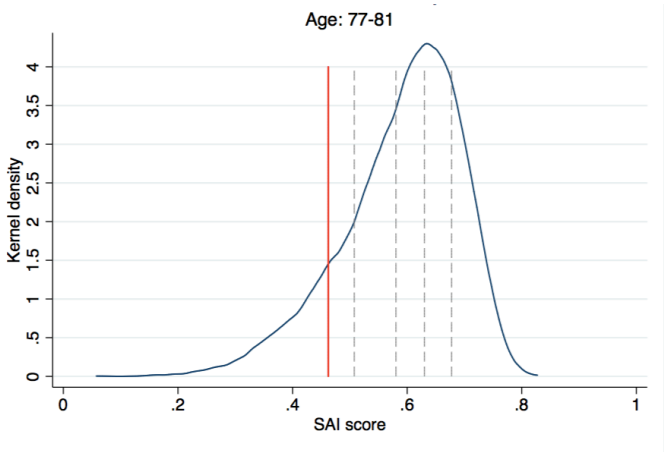

Figure IV presents a hypothetical individual´s SAI score, presented along with the distribution of the SAI score of its peers (people aged plus/minus two years in the sample) with respective quintiles. The SAI score is obtained by inserting the individual´s characteristics into the model.

The hypothetical individual is a female widow, aged 79 years from Estonia. She is a former smoker with sarcopenia has general complaints, complaints about the circularly system, the muscular system, the nervous system, the emotional system, has difficulties moving, is depressed and nervous, has trouble sleeping, has no loss of interest and is lacking energy, worked in service or sales, does moderate and vigorous activities more than once a week, is undernourished and has no difficulties in the ADLs or IADLs.

Figures V: Distribution of the AAI (ref: Zaidi et al.) and the AAI (ref: Almeida and Barros)

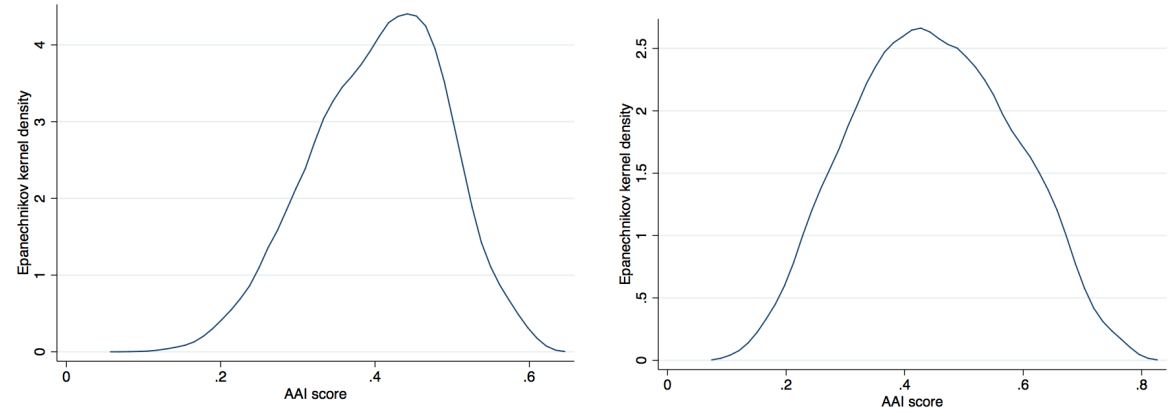

Table I: Factors Associated with the Active Ageing Index, Second Approach (ref: Zaidi)

VARIABLES	**Model 1**		**Model 2**	
$Sarcopenia_{male}$	-0.046***	(0.004)	-0.046***	(0.004)
$Sarcopenia_{female}$	-0.027***	(0.003)	-0.027***	(0.003)
Gender: female	-0.031***	(0.002)	-0.031***	(0.002)
Age	-0.969***	(0.016)	-0.969***	(0.016)
Age^2	0.792***	(0.023)	0.792***	(0.022)
BMI	-0.131***	(0.018)	-0.118***	(0.017)
Low education	-0.065***	(0.002)	-0.065***	(0.002)
Married	0.0003	(0.002)		
Health limitations	-0.036***	(0.002)	-0.036***	(0.002)
Mental health	-0.010***	(0.002)	-0.010***	(0.002)
Receive help	-0.009***	(0.002)	-0.009***	(0.002)
Give help	0.023***	(0.002)	0.023***	(0.002)
Constant	0.674***	(0.009)	0.674***	(0.009)
Observations	45 748		45 768	
R^2	0.316		0.316	
Country dummies	YES		YES	
Year dummies	YES		YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table II: Conversion of Age to Normalized Values[57]

Age	Normalized	Age	Normalized	Age	Normalized
50	0	**68**	0.346	**86**	0.692
51	0.019	**69**	0.365	**87**	0.712
52	0.038	**70**	0.385	**88**	0.731
53	0.058	**71**	0.404	**89**	0.750
54	0.077	**72**	0.423	**90**	0.769
55	0.096	**73**	0.442	**91**	0.788
56	0.115	**74**	0.462	**92**	0.808
57	0.135	**75**	0.481	**93**	0.827
58	0.154	**76**	0.500	**94**	0.846
59	0.173	**77**	0.519	**95**	0.865
60	0.192	**78**	0.538	**96**	0.885
61	0.212	**79**	0.558	**97**	0.904
62	0.231	**80**	0.577	**98**	0.923
63	0.250	**81**	0.596	**99**	0.942
64	0.269	**82**	0.615	**100**	0.962
65	0.288	**83**	0.635	**101**	0.981
66	0.308	**84**	0.654	**102**	1
67	0.327	**85**	0.673		

Table III: Estimation Results of the Different Domains of the Active Ageing Index

VARIABLES	**D1**		**D2**		**D3**		**D4**	
$Sarcopenia_{male}$	-0.050***	(0.004)	-0.068***	(0.005)	-0.083***	(0.003)	0.004	(0.003)
$Sarcopenia_{female}$	-0.027***	(0.003)	-0.040***	(0.004)	-0.107***	(0.002)	-0.001	(0.002)
Gender: female	-0.035***	(0.001)	-0.019***	(0.003)	0.007***	(0.001)	-0.002	(0.002)
Age	-0.974***	(0.011)	0.207***	(0.030)	0.651***	(0.010)	0.256***	(0.013)
Age^2	0.771***	(0.001)	-0.362***	(0.030)	-0.899***	(0.014)	-0.340***	(0.018)
BMI	-0.168***	(0.011)	-0.281***	(0.021)	-0.363***	(0.011)	0.364***	(0.013)
Low education	-0.062***	(0.001)	-0.092***	(0.003)	-0.020***	(0.001)	-0.004***	(0.002)
Married	0.001	(0.001)	0.018***	(0.003)	-0.029***	(0.001)	0.004**	(0.002)
Health limitations	-0.054***	(0.001)	-0.057***	(0.003)	-0.093***	(0.001)	0.141***	(0.001)
Mental health	-0.016***	(0.001)	-0.018***	(0.003)	-0.035***	(0.001)	0.036***	(0.001)
Receive help	-0.004***	(0.002)	0.005	(0.003)	-0.059***	(0.001)	0.007***	(0.002)
Give help	0.021***	(0.001)	0.068***	(0.003)	0.023***	(0.001)	-0.007***	(0.002)
Constant	0.504***	(0.008)	0.401***	(0.014)	0.997***	(0.003)	0.552***	(0.005)
Observations	132 053		132 084		187 337		103 243	
R^2	0.253		0.117		0.195		0.161	
Country dummies	YES		YES		YES		YES	
Year dummies	YES		YES		YES		YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

[57] The equivalent age effect is obtained by converting the normalized value to the real age using $f(x_i)_N = \frac{f(x_i) - \min(f(x_i))}{\max(f(x_i)) - \min(f(x_i))}$, and subtracting the minimum age of the distribution (50).

Table IV: Estimation Results of the Ordered Probit of Self-Assessed Health (no controls)

VARIABLES	Model 1	
$Sarcopenia_{male}$	-0.553***	(0.013)
$Sarcopenia_{female}$	-0.676***	(0.010)
Age	-0.063***	(0.003)
$(Age^2)/100$	0.030***	(0.002)
Constant cut1	-3.575***	(0.109)
Constant cut2	-2.461***	(0.109)
Observations	230 686	
Pseudo R^2	0.0901	
Country dummies	YES	
Year dummies	YES	

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table V: Marginal Effects of Sarcopenia and Age on Self-Assessed Health[58]

	Poor or fair	Good	Very good or excellent
$Sarcopenia_{male}$	0.180*** (0,004)	-0.017*** (0,000)	-0.163*** (0,004)
$Sarcopeia_{female}$	0.220*** (0,003)	-0.021*** (0,000)	-0.129*** (0,003)
Age	0.021*** (0,001)	-0.002*** (0,000)	-0.019*** (0,001)
$(Age^2)/100$	-0.009*** (0,001)	0.001*** (0,000)	0.009*** (0,001)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table VI: Estimation Results from the Production Function of Sarcopenia

VARIABLES	Male (1)	Male (2)	Female (1)	Female (2)
Age	0.038***	0.039***	0.024***	0.016***
	(0.001)	(0.002)	(0.001)	(0.002)
Moderate physical activity (ref: More than once a week)				
Once a week	-0.013		0.044*	
	(0.032)		(0.024)	
Once to three times a month	0.018		0.062*	
	(0.043)		(0.034)	
Hardly ever, or never	0.063**		0.116***	
	(0.031)		(0.026)	
Lagged moderate physical activity (ref: More than once a week)				
Once a week		0.139*		0.217***
		(0.081)		(0.052)
Once to three times a month		0.238***		0.421***
		(0.091)		(0.061)
Hardly ever, or never		0.295***		0.602***
		(0.100)		(0.069)
Vigorous physical activity (ref: More than once a week)				
Once a week	0.005		0.112***	
	(0.038)		(0.029)	
Once to three times a month	0.040		0.077**	
	(0.043)		(0.034)	
Hardly ever, or never	0.183***		0.238***	
	(0.028)		(0.022)	
Lagged vigorous physical activity (ref: More than once a week)				
Once a week		0.068		0.120**

[58] The marginal effects are derived from Table IV.

		(0.069)		(0.056)
Once to three times a month		0.052		0.155
		(0.124)		(0.100)
Hardly ever, or never		-0.168		0.088
		(0.173)		(0.142)
BMI (ref: normal weight)				
Undernourished	-0.209**	-0.358***	0.296***	0.229**
	(0.090)	(0.127)	(0.062)	(0.099)
Overweight	-0.073***	-0.023	-0.185***	-0.213***
	(0.022)	(0.034)	(0.019)	(0.027)
Obese	-0.148***	-0.107**	-0.161***	-0.165***
	(0.029)	(0.045)	(0.022)	(0.032)
Nursing home	0.201	0.292	0.340***	0.311*
	(0.127)	(0.188)	(0.112)	(0.159)
Chronic diseases	0.020**	0.019	0.016**	-0.014
	(0.009)	(0.014)	(0.007)	(0.011)
Years of education	0.002	0.003	-0.017***	-0.017***
	(0.003)	(0.004)	(0.002)	(0.003)
Income/10 000	-0.003	-0.0001	-0.0003	0.0005
	(0.004)	(0.002)	(0.002)	(0.002)
Married	0.241***	0.308***	-0.222***	-0.227***
	(0.024)	(0.038)	(0.017)	(0.002)
$L.sarcopenia_{male}$	1.943***	2.017***		
	(0.028)	(0.043)		
$L.sarcopenia_{female}$			1.754***	1.762***
			(0.021)	(0.030)
Self-assessed health	-0.211***	-0.169***	-0.251***	-0.171***
	(0.023)	(0.037)	(0.019)	(0.029)
Number of difficulties in the ADLs	0.037***	0.043	0.063***	0.039*
	(0.010)	(0.027)	(0.008)	(0.023)
Number of difficulties in the IADLs	0.099***	0.127***	0.043***	0.048**
	(0.015)	(0.026)	(0.013)	(0.021)
Constant	-5.080***	-5.428***	-3.167***	-2.770***
	(0.124)	(0.201)	(0.086)	(0.129)
Observations	84 611	38 239	84 611	38 239
Pseudo R^2	0.373	0.391	0.366	0.372
Country dummies	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table VII: Estimation Results from the Production Function of Sarcopenia for Men

VARIABLES	Model (1)	Model (2)	Model (3)	Model (4)
Age	-0.040**	0.035**	0.032***	0.034***
	(0.016)	(0.015)	(0.002)	(0.001)
Age^2	0.000493***	2.64e-05		
	(0.0001)	(0.0001)		
Moderate physical activity (ref: More than once a week)				
Once a week	-0.008	-0.013	-0.007	0.011
	(0.032)	(0.032)	(0.032)	(0.032)
Once to three times a month	0.0285	0.0175	0.0308	0.058
	(0.0434)	(0.0433)	(0.0433)	(0.043)
Hardly ever, or never	0.077**	0.063**	0.082***	0.234***
	(0.031)	(0.031)	(0.031)	(0.029)

Vigorous physical activity (ref: More than once a week)				
Once a week	0.001	0.005	-0.001	-0.0009
	(0.038)	(0.038)	(0.038)	(0.038)
Once to three times a month	0.041	0.040	0.038	0.040
	(0.044)	(0.043)	(0.044)	(0.044)
Hardly ever, or never	0.182***	0.183***	0.183***	0.233***
	(0.028)	(0.028)	(0.028)	(0.027)
BMI (ref: normal weight)				
Undernourished	-0.210**	-0.210**	-0.203**	-0.138
	(0.091)	(0.090)	(0.090)	(0.088)
Overweight	-0.077***	-0.072***	-0.082***	-0.085***
	(0.023)	(0.023)	(0.023)	(0.023)
Obese	-0.151***	-0.147***	-0.158***	-0.134***
	(0.029)	(0.029)	(0.029)	(0.029)
Nursing home	0.203	0.201	0.207	0.329***
	(0.128)	(0.127)	(0.127)	(0.122)
Chronic diseases	0.0189**	0.0205**	0.0156*	0.050***
	(0.009)	(0.009)	(0.009)	(0.008)
Self-assessed health	-0.216***	-0.211***	-0.214***	
	(0.023)	(0.023)	(0.023)	
Number of difficulties in the IADLs	0.039***	0.037***	0.043***	
	(0.010)	(0.010)	(0.010)	
Number of difficulties in the ADLs	0.100***	0.100***	0.100***	
	(0.015)	(0.015)	(0.015)	
Years of education	0.001	0.002	0.002	-0.002
	(0.003)	(0.002)	(0.002)	(0.002)
Income/10 000	-0.003	-0.003	-0.003	-0.004
	(0,004)	(0.004)	(0.004)	(0.005)
Married	0.236***	0.242***	0.226***	0.214***
	(0.025)	(0.024)	(0.024)	(0.024)
Retired	0.354***		0.302***	0.279***
	(0.029)		(0.028)	(0.028)
L.sarcopenia$_{male}$	1.914***	1.942***	1.922***	1.942***
	(0.029)	(0.028)	(0.029)	(0.028)
Constant	-2.316***	-4.945***	-4.881***	-3.628***
	(0.581)	(0.556)	(0.127)	(0.087)
Observations	84 591	84 611	84 591	84 619
Pseudo R^2	0.3778	0.3734	0.3771	0.3684
Country dummies	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Model (1) includes variables for age, age^2 and for being retired.
Model (2) excludes retired from the model.
Model (3) excludes age^2 from the model.
Model (4) excludes the number of difficulties in the IADLs and ADLS and self-assessed health

Table VIII: Estimation Results from the Production Function with Different Specification for Women

VARIABLES	Model (1)	Model (2)	Model (3)	Model (4)
Age	0.055***	0.010	0.029***	0.031***
	(0.013)	(0.012)	(0.001)	(0.001)
Age^2	-0.0002**	0.0001		
	(8.79e-05)	(8.16e-05)		
Moderate physical activity (ref: More than once a week)				
Once a week	0.042*	0.044*	0.041*	0.062***
	(0.024)	(0.024)	(0.024)	(0.024)
Once to three times a month	0.054	0.061*	0.053	0.092***
	(0.035)	(0.035)	(0.035)	(0.034)
Hardly ever, or never	0.107***	0.115***	0.105***	0.236***
	(0.026)	(0.026)	(0.026)	(0.024)
Vigorous physical activity (ref: More than once a week				
Once a week	0.117***	0.113***	0.118***	0.121***
	(0.029)	(0.029)	(0.029)	(0.029)
Once to three times a month	0.0814**	0.0778**	0.0823**	0.088***
	(0.034)	(0.034)	(0.034)	(0.034)
Hardly ever, or never	0.241***	0.238***	0.241***	0.293***
	(0.022)	(0.022)	(0.022)	(0.022)
BMI (ref: normal weight)				
Undernourished	0.302***	0.296***	0.302***	0.339***
	(0.062)	(0.062)	(0.062)	(0.062)
Overweight	-0.183***	-0.184***	-0.181***	-0.178***
	(0.019)	(0.019)	(0.019)	(0.019)
Obese	-0.160***	-0.159***	-0.157***	-0.136***
	(0.022)	(0.022)	(0.022)	(0.022)
Nursing home	0.343***	0.339***	0.342***	0.462***
	(0.111)	(0.112)	(0.112)	(0.110)
Chronic diseases	0.0186***	0.0166**	0.0198***	0.054***
	(0.007)	(0.007)	(0.007)	(0.007)
Self-assessed health	-0.254***	-0.252***	-0.254***	
	(0.019)	(0.019)	(0.019)	
Number of difficulties in the IADLs	0.061***	0.062***	0.059***	
	(0.009)	(0.009)	(0.009)	
Number of difficulties in the ADLs	0.0441***	0.0429***	0.0445***	
	(0.013)	(0.013)	(0.013)	
Years of education	-0.016***	-0.017***	-0.017***	-0.021***
	(0.002)	(0.002)	(0.002)	(0.002)
Married	-0.218***	-0.220***	-0.215***	-0.217***
	(0.017)	(0.017)	(0.017)	(0.017)
Income/10 000	-0.0002	-0.0004	-0.0003	-0.0008
	(0.002)	(0.002)	(0.002)	(0.002)
Retired	-0.218***		-0.204***	-0.209***
	(0.023)		(0.021)	(0.021)
$L.sarcopenia_{female}$	1.740***	1.753***	1.740***	1.774***
	(0.021)	(0.021)	(0.021)	(0.021)
Constant	-4.248***	-2.669***	-3.369***	-3.628***
	(0.457)	(0.416)	(0.089)	(0.087)
Observations	84 591	84 611	84 591	84 619
Pseudo R^2	0.3686	0.3664	0.3685	0.3608
Country dummies	YES	YES	YES	YES
Year dummies	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Model (1) includes variables for age, age^2 and for being retired.
Model (2) excludes retired from the model.
Model (3) excludes age^2 from the model.
Model (4) excludes Number of difficulties in the IADLs and ADLS and self-assessed health