Quantifying ‘Self-perceived Age’ among Europeans and Americans

Draft Version

EPC 2020

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A B S T R A C T

Chronological Age is widely used for estimating future survival. However, quantities such as ‘Subjective survival probabilities’ or ‘Biological Age’ predict mortality better than Chronological Age. The aims of the study are to estimate ‘Self-perceived age’ by reference to life tables and to evaluate its validity in comparison with ‘Subjective survival probabilities’ and ‘Biological Age’. We use data from the 6th Wave of the Survey of Health, Ageing and Retirement in Europe (SHARE), the 12th Wave of Health and Retirement Study (HRS) and life tables from the Human Mortality Database (HMD). For the statistical analysis we employ multinomial regression models. Our results indicate that health status and frequency of physical activities imply similar patterns of ‘Self-perceived age’, ‘Subjective survival probabilities’ and ‘Biological Age’. However, the impact of memory is different for Americans and Europeans. ‘Self-perceived age’ can be used as a marker to detect early changes in future life expectancy.

Keywords: Self-perceived age, Biological Age, Subjective survival probabilities, SHARE, HRS, HMD

Introduction

The long-term sustainability of pension systems is endangered by increasing life expectancy (Nerlich and Schroth 2018). Reforms, such as increasing retirement age, decreasing benefits, increasing employers' contributions and increasing income tax, have been implemented in order to restore long term sustainability of pension systems. However, the burden of these reforms should be fairly divided between today's taxpayers and contributors as well as current and future pensioners (Whitehouse 2007). Forman and Chen (2008) concluded that poor health is one of the most important factors affecting retirement decisions for Americans. They further suggested that retirement age should be linked to the remaining life expectancy or to the mortality risk of an individual. In other words, setting a risk-based retirement age, could improve the degree of fairness in allocating the financial burden of longevity risk.

Chronological Age, in conjunction with population life tables, is used to estimate an individual's average life expectancy. However, subjective measures, such as self-rated health, have been proved a strong predictor of mortality (Idler and Benyamini 1997; Verropoulou 2014), and affect individuals' life expectancy. Therefore, a more personalised definition of 'age' could improve fairness in allocating the financial burden of increasing life expectancy. In the literature, there are two individual-specific quantities that might predict mortality better than Chronological Age, namely 'Subjective survival probabilities' and 'Biological Age'.

Subjective survival probabilities

'Subjective survival probabilities' reflect the views of individuals regarding their future survival. Prior studies noted that experiences, history and environmental factors are taken into account when forming subjective survival expectations (Griffin et al. 2013). Moreover, this individual-specific judgment can explain the considerable variability of subjective survival probabilities (Hamermesh 1985). Physical health status, functional limitations and cognitive function are factors affecting subjective survival probabilities. There is an agreement in the literature that poorer health is associated with lower survival expectations (Van Solinge and Henkens 2018; Rappange et al. 2016; Liu et al. 2007; Hurd and McGarry 1995). In addition, past analyses estimated significant associations between cognitive skills and subjective survival probabilities (Griffin et al. 2013; Elder 2007; Rappange et al. 2016). Finally, it has been shown that subjective survival probabilities predict mortality (Van Solinge et al. 2018; Elder 2007; Kutlu-Koc and Kalwij 2013; Hurd and McGarry 2002).

Biological Age

'Biological Age' is estimated from a set of biomarkers and can be used as a proxy of an individual's accumulated ageing (Belsky et al. 2015). Prior studies noted that individuals with the same Chronological Age might exhibit a different functional organic state and thus different 'Biological Age' (Nakamura et al. 1989). For example, impaired mobility as well as other health problems (e.g. diabetes) may result in higher 'Biological Age' compared to Chronological Age (Mitnitski et al. 2002). Furthermore, Jylhävä et al. (2017) concluded that

'Biological Age' is associated with morbidity and mortality. Hence, extensive efforts have been made to identify a set of biomarkers that will better predict functional capability as well as mortality, compared to Chronological Age (Baker and Sprott 1988; Goggins et al. 2005; Mitnitski et al. 2002).

Self-perceived age

'Self-perceived age' is the age that captures survival information from general population life tables as well as from subjective survival probabilities. Self-reported subjective survival probabilities provide information about the chances of future survival for an individual. Probabilities, expressed in percentages, are a more difficult concept to understand, compare and communicate than an individual's age, expressed in years. On the other hand, the estimation of Biological Age requires a comprehensive dataset of biomarkers (Klemera and Doubal 2006). Taking these complexities into account, we introduce the new concept of 'Self-perceived age'. 'Self-perceived age' is the age which results in identical objective and subjective survival probabilities. In other words, 'Self-perceived age' is implied by self-reported subjective survival probabilities, but it takes into account general population mortality.

Self-perceived age has a number of advantages compared to both Subjective survival probabilities and Biological Age. The first advantage is that, as it is expressed in years, it is easier to understand and communicate compared to subjective survival probabilities. Moreover, it is a quantity (age) linked to a population life table, thus facilitating comparisons. Another advantage is that the calculation of 'Self-perceived age' is less complicated and it requires less data compared to 'Biological Age'.

Objectives of the study

The first objective is to develop an algorithm for the estimation of 'Self-perceived age', by reference to life tables by country and sex, for a large sample of American and European longitudinal survey respondents. The second objective is to evaluate the validity of 'Self-perceived age', by examining associations with physical health, cognitive function as well as lifestyle and behavioral risk factors. We validate further 'Self-perceived age' by comparing it with 'Subjective survival probabilities' and 'Biological Age'. The first comparison would reveal whether individuals who report lower subjective survival probabilities have older 'Self-perceived age' and vice versa. The second comparison would reveal whether individuals with older 'Biological Age' have also older 'Self-perceived age' and vice versa. For example, we would expect individuals with better self-rated health to have younger 'Self-perceived age', younger 'Biological Age', to report higher subjective survival probabilities and to actually live longer. This may allow us to detect future longevity early. To the best of our knowledge this is the first attempt to address the aforementioned research questions.

Methods

Data

We used data from the 6th Wave of the Survey of Health, Ageing and Retirement in Europe (SHARE) and from the 12th Wave of the Health and Retirement Study. The HRS (Health and Retirement Study) is sponsored by the National Institute on Aging (grant number NIA U01AG009740) and is conducted by the University of Michigan. It is an age-cohort-based longitudinal panel survey of persons aged 50 and older in the USA. The data collection of the 12th Wave was completed in 2014.

SHARE (Börsch-Supan et al. 2013) is a cross-national database with information on health, socio-economic status, and social networks. Its format is similar to the US Health and Retirement Study (HRS) and the English Longitudinal Study of Ageing (ELSA). The data collection of the 6th Wave was completed in November 2015 (Börsch-Supan 2017) and the sampling was carried out in 18 countries (Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, France, Germany, Greece, Israel, Italy, Luxembourg, Poland, Portugal, Spain, Sweden, Switzerland and Slovenia). More documentation and information on SHARE can be found at http://www.share-project.org.

The harmonised version of the longitudinal studies, RAND HRS and RAND SHARE, provided by the Gateway to Global Aging Data, was used in order to produce a consistent combined dataset. The original combined sample covered 76252 individuals aged 50 or higher. Due to SHARE rules, information about future life expectancy was not collected for 2906 individuals, for whom proxy interviews were conducted. In addition, there were 1967 individuals with missing values in the variables of interest. Hence, the combined sample used in the analysis includes 71379 individuals.

The objective survival probabilities were obtained from the Human Mortality Database (HMD). HMD provides both period and cohort life tables. However, cohort life tables are incomplete for individuals aged 50 or above and have to be forecasted (Peracchi and Perotti 2010). While this approach clearly incorporates cohort effects into the overall analysis, refining the estimated 'Self-perceived Age', it is subject to estimation errors. Peracchi and Perotti (2010) note that the forecasted cohort life tables may underestimate actual mortality for certain countries. In this study we used period life tables by country and sex which refer to the 5-year period 2010-2014. As SHARE Wave 6 was undertaken in 2015 and HRS Wave 12 in 2014, we consider these life tables relevant to our study (Post and Hanewald 2010; Balia 2011).

Construction of the dependent variable

Subjective survival probabilities (SSPs) are based on Section I of the 'Retirement Plans, Expectations' module of the RAND HRS dataset and in Section I of the 'Retirement and Expectations' module of the RAND SHARE

dataset, where respondents were asked to state their chances (from 0 to 100) to live up to a specified age T (75, 80, 85, etc.), which depended on the age of the respondent at the interview. The cumulative Objective survival probabilities (OSPs), calculated from the HMD life tables, are compared subsequently to the SSPs.

The reported SSPs correspond to a specific prediction interval, starting from current age up to the target age. Therefore, the OSPs should cover the same time horizon (Peracchi and Perotti 2010). Hence,

$$OSP_{x,N} = \prod_{t=1}^{N} OSP_{x+t}$$

where 'x' is the Chronological Age ('CA') of the respondent and 'N' is the prediction interval.

'Self-perceived age' ('SPA') is defined as the age which minimises the difference between SSPs and OSPs. An appropriate algorithm has been developed to estimate 'Self-perceived age'. The code of the algorithm, written in Visual Basic for Applications (VBA), is presented in Figure 1. Two cases had to be considered explicitly: if SSP = 100% then 'Self-perceived age' is set to 0 years; in contrast, if SSP = 0% then 'Self-perceived age' is set to 110 (the oldest age in the life tables) and the associated OSP is 0%.

(Figure 1)

For example, let us suppose that an American female aged 68 reported a Subjective Survival Probability of 90% to be alive over the next 12 years.

i. The first step is to calculate the Objective Survival Probabilities (OSP) by reference to period life tables by country and sex. OSP is 73%, which differs from the self-reported Subjective Survival Probability (SSP). The fact that OSP < SSP means that she thinks that she will live more than the average American female. In other words, she considers that her true Chronological Age is younger than 68 years old.
ii. The second step is to calculate how many years younger she thinks she is, based on the SSP and the life table. More specifically, we reduce her Chronological Age until the calculated OSP is close to 90%. The result is 56.87 years old.
iii. Hence, we conclude that her 'Self-perceived age' is 56.87 years whereas her Chronological Age is 68 years old.

The dependent variable for the statistical modeling was constructed based on the 'SPA - CA' gap. This difference was compared to a tolerance level, in order to capture different levels of closeness between 'Self-perceived' and Chronological Age. The tolerance level - set to 3, 5 and 7 years - represents the accuracy of prediction; hence, lower tolerance reflects a greater degree of accuracy. Thus, the interpretation of the dependent variable is: 1 indicates that 'Self-perceived age' is close to Chronological Age; 2 implies that 'Self-perceived age' is younger than Chronological Age, while 3 means that 'Self-perceived age' is older.

Explanatory variables

Physical Health

This group of variables includes the number of limitations in Activities of Daily Living (out of a list of 5 basic, everyday tasks) and self-rated health (ranging from 1=excellent to 5=poor). In addition, a mobility index (ranging from 0 to 5) shows in how many of the following activities the respondent experiences difficulties: walking one block, walking several blocks, walking across a room, climbing one flight of stairs, and climbing several flights of stairs.

Cognitive function

Cognitive function is represented by the respondents' scores in two relevant tests. In the first test the respondent is asked to subtract 7 from a prior number; the score provides the number of correct subtractions, taking values from 0 to 5. The second test score, total word recall, is the sum of the immediate and of the delayed word recall scores and ranges from 0 to 20. More specifically, the immediate word recall score counts the number of words recalled immediately while the delayed word recall score counts the number of words recalled correctly after a delay of about 5 minutes.

Lifestyle & Behavioral risk factors

This group of variables includes the frequency of vigorous physical activities within a week (1 = every day to 5 = never) and whether the respondent ever smoked daily.

Control variables

Demographic characteristics of the respondent include Chronological Age (in years), Chronological Age squared /100, gender, marital status (widowed, divorced, never married, married), the number of children of the respondent, the number of parents of the respondent still alive at the time of the survey as well as country of residence. Socio-economic factors include total household income in quartiles, total wealth in quartiles and educational level in 3 categories (lower than Upper Secondary, Upper Secondary and Tertiary). Finally, Body Mass Index (BMI) and prediction interval (in years) are included as control variables.

Statistical modeling

The analysis was conducted in two stages. First, we use four multinomial regression models with a tolerance level of 5 years, in order to investigate the impact of explanatory variables on the age gap between 'Self-perceived' and Chronological Age. A different model has been estimated for every combination of region and gender (i.e. European males, European females, American males and American females). Second, we assess the sensitivity of Relative Risk Ratios to different levels of tolerance. In particular, we estimated four models with a tolerance level of 3 years and four additional models with a tolerance level of 7 years.

Results

Sample

The sample characteristics are presented in Table 1. The average 'Self-perceived age' for European males is 55.9 years, more than 10 years lower compared to their average Chronological Age (around 67 years); the respective difference for European women is narrower, around 7 years. By contrast, the difference between 'Self-Perceived' and Chronological Age for American males and females is less than one year.

Despite that, proportions of respondents whose difference between 'Self-perceived' and Chronological Age is below five years are fairly similar across genders and place of origin (around 32%); only American males exhibit a slightly greater degree of convergence (34%). Nevertheless, European males also exhibit the greatest tendency towards having a 'Self-perceived' age more than 5 years younger than their Chronological Age (47%) compared to all other groups (32%-34%).

Regarding health, Europeans report on average fewer ADL limitations and mobility difficulties compared to their American counterparts; however, self-rated health is on average marginally better for Americans. In addition, those in excellent health have younger 'Self-perceived age' (4%) whereas those in poor health have older 'Self-perceived age' (5%) (Figure 2). Individuals in good health and those who do not report any mobility difficulties have a younger 'Self-perceived' age (Figures 3 & 4). It is worth noting that, regarding self-rated health, 'Self-perceived age' is less than Chronological Age for persons younger than 70 years old (Figure 3); thereafter, as self-rated health deteriorates, the opposite holds. Moreover, regarding mobility difficulties, 'Self-perceived age' is less than Chronological Age for persons aged less than 73 but, as the number of difficulties increases, the opposite is the case (Figure 4). Similarly, as the number of ADLs increases, 'Self-perceived age' becomes greater than Chronological Age for persons aged 72 or higher (see Appendix, Figure A1).

(Figures 2, 3 & 4)

Cognitive function seems slightly better for Europeans regarding the subtraction test (Serial 7s) whereas both European and American females exhibit slightly better recall compared to males. Higher subtraction score implies a smaller standard deviation of the difference between 'Self-perceived age' and Chronological Age as well as a smaller standard deviation of Subjective survival probabilities. In other words, predictions become more stable as subtraction scores increase (see Appendix, Figure A2).

On average, European males do vigorous activities more frequently compared to European females and to the Americans. Finally, American males and females ever smoked daily in higher proportions compared to their European counterparts, the difference being more substantial for women (about 14 percentage points). Further, males exhibit substantially higher proportions compared to females in both regions. The standard deviation of 'Self-perceived age' and Chronological Age gap is higher for American and European smokers compared to non-smokers. Hence, predictions are more stable for non-smokers (see Appendix, Figure A3).

(Table 1)

Finally, the imperfect positive correlation between 'Self-perceived' and Chronological Age implies that 'Self-perceived age' might have differential predictive ability for future survival (see Appendix, Table A1).

Multivariable analyses

Physical Health

European males and females who report more ADLs tend to have a 'Self-perceived' age older than their Chronological Age (Table 3 & Figure A1); the Relative Risk Ratios (RRRs) indicate that an additional limitation increases chances by 10%. The association of ADLs with 'Self-perceived' age is less clear for Americans. The RRRs indicate that for American females an additional limitation increases chances of having younger 'Self-perceived' age by 9.4% and older by 3.3% while for American males the findings are non-significant but indicate higher chances of having a younger 'Self-perceived' age.

As the number of mobility difficulties increases, individuals tend to have a 'Self-perceived' age older than their Chronological Age. The RRRs indicate that for European males an additional mobility difficulty increases chances of having a 'Self-perceived' age older than their Chronological Age by 10.7% while for American males relative chances increase by 11.7%. Mobility difficulties affect European females the most (RRR 1.138) and American females the least (RRR 1.077).

Poor self-rated health implies an older 'Self-perceived' age compared to Chronological Age. Associations are strong and significant in all instances. The RRRs indicate that for European males, a one-point deterioration in the 5-point scale of self-rated health increases chances of having older 'Self-perceived age' by 42.0% while the relative increase for American males is 49.3%. For females, relative increases are somewhat less, 37.7% and 40.2%, respectively.

Cognitive function

Better cognitive skills, based on the subtraction test, imply for both Europeans and Americans a 'Self-perceived age' closer to Chronological Age (Figure A2). The RRRs indicate that, for European males, a one-point improvement in the serial 7s test score reduces the chances of having younger 'Self-perceived age' by 3.8% and the chances of having older 'Self-perceived age' by 2.2%. The impact of cognitive skills is more significant for Americans. The RRRs indicate that for American males, a one-point improvement in the serial 7s test score reduces the chances of having younger 'Self-perceived age' by 8.4% while it reduces the chances of having older 'Self-perceived age' by 1.4%. Better memory also implies that 'Self-perceived age' is closer to Chronological Age for Americans while for Europeans it indicates a younger 'Self-perceived age'.

Lifestyle & Behavioural Risk Factors

Individuals who do vigorous activities frequently have a 'Self-perceived age' younger than their Chronological Age; this holds for both genders and irrespectively of place of origin. For instance, the RRRs indicate that, for European males, as frequency of vigorous activities decreases, chances of having a 'Self-perceived age' older than their Chronological Age increase by 4.4% while chances of having a younger 'Self-perceived Age' declines by 4.3%. Similarly, American females, who do vigorous activities less frequently, tend to have a 'Self-perceived age' older than Chronological Age; relative chances increase by 7.9%.

Male nonsmokers have a 'Self-perceived age' younger than their Chronological Age, compared to male smokers. The RRRs indicate that American male nonsmokers exhibit 11% higher chances of having younger 'Self-perceived age'. Similarly, chances for European males are 3.0% higher. However, the results for females are contradictory. On the one hand, the RRRs indicate that European female nonsmokers have a 'Self-perceived age' younger than their Chronological Age. On the other hand, American female nonsmokers have a 'Self-perceived age' more than 5 years different (either younger or older) from Chronological Age (Figure A3).

(Table 2)

Sensitivity analysis

To assess the robustness of our results we run two additional sets of models varying the tolerance level in the dependent variable. The first set of results is estimated using a tolerance level of 3 years and the second set using a tolerance level of 7 years (see Appendix, Tables A2 and A3). Overall, the results are fairly consistent with those of the base model. Factors exhibiting the most consistent associations are mobility limitations, self-perceived health, cognitive function and frequency of vigorous activities. However, this does not hold regarding the association of smoking with 'Self-perceived age' for American and European females. For example, European female nonsmokers have a 'Self-perceived age' close to their Chronological Age – compared to European female smokers - if a tolerance level of 3 years is used, but this does not hold for a tolerance level of 7 years. Furthermore, American female nonsmokers have a 'Self-perceived age' more than 5 years different from their Chronological Age if a tolerance level of 3 years is used, but this does not hold for a tolerance level of 7 years. These inconclusive findings require further investigation.

Discussion

'Self-perceived age' versus 'Subjective survival probabilities'

Our findings show that poor self-rated health, more ADLs and more mobility difficulties imply a 'Self-perceived age' older than Chronological Age as well as survival underestimation compared to the general population for both Europeans and Americans. Poor self-rated health and more limitations in Activities of Daily Living are also associated with lower survival expectations (Van Solinge and Henkens 2018; Rarrange et al. 2016; Liu et al. 2007; Hurd and McGarry 1995). It is worth mentioning that self-rated health as well as ADLs are strong predictors of actual mortality (Idler and Benyamini 1997; Verropoulou 2014; Scott et al. 1997). Overall, we

conclude that poor self-rated health, more ADLs and more mobility difficulties imply lower self-reported subjective survival probabilities and older 'Self-perceived age'; therefore, the patterns are consistent.

Our results show that persons who do vigorous activities frequently tend to have a 'Self-perceived age' younger than their Chronological Age and they tend to report higher subjective survival probabilities; this holds for both Europeans and Americans. Prior research noted that physically active individuals over-estimate subjective life expectancy (Griffin et al. 2013; Rarrange et al. 2016; Liu et al. 2007). Furthermore, higher levels of physical activity are related to lower mortality (Gregg et al. 2003). We conclude that greater frequency of vigorous activities implies consistency between 'Self-perceived age' and subjective survival probabilities.

According to our findings European and American male nonsmokers tend to have a 'Self-perceived age' younger than their Chronological Age. The effect of smoking on 'Self-perceived age' is less clear for females. The literature on the association of subjective survival probabilities with smoking is inconclusive. Past analyses noted that current smokers report lower subjective survival probabilities (Hurd & McGarry 1995; Rarrange et al. 2016) whereas other researchers suggest that current smokers over-estimate survival (Liu et al. 2007; Balia 2011). Furthermore, it is well known that smoking increases mortality (Ezzati & Lopez 2003). Overall, we conclude that for males, smoking implies consistency between 'Self-perceived age' and subjective survival probabilities but not for females.

'Self-perceived Age' versus 'Biological Age'

Our results indicate that those with poor self-rated health, more limitations in Activities of Daily Living and more mobility difficulties have a 'Self-perceived age' older than their Chronological Age. Belsky et al. (2015) suggested that persons with older 'Biological Age' perceived themselves to be in poorer health. In addition, individuals with older 'Biological Age' have poorer physical function; worse balance, less strength and more mobility difficulties. Furthermore, Jylhä et al. (2006) show that self-rated health is associated with frequently used biomarkers. Hence, because of the link between self-rated health and biomarkers, we conclude that 'Self-perceived' age is likely to be consistent with 'Biological Age'.

Our results indicate that individuals who do vigorous activities frequently tend to have a 'Self-perceived age' younger than their Chronological Age. Prior studies noted that individuals who do physical activity regularly, have a 'Biological Age' younger than their Chronological Age. (Nakamura et al. 1989). We, therefore, conclude that 'Self-perceived' and 'Biological Age' are consistent with respect to the frequency of vigorous activities.

According to our findings, male nonsmokers tend to have 'Self-perceived age' younger than their Chronological Age. Smoking reduces life expectancy (Doll et al. 1994) and is associated with accelerated biological aging (Beach et al. 2015). Therefore, we conclude that for males 'Self-perceived' and 'Biological Age' are consistent with respect to smoking status.

Americans versus Europeans

The impact of worse self-rated health on 'Self-perceived age' is more significant for Americans than for Europeans. Our results also indicate that the impact of self-rated health on 'Self-perceived age' is more significant for males compared to females. In contrast, several analyses concluded that women are frailer than men in older ages (Puts et al. 2005, Goggins et al. 2005). On the other hand, the impact of mobility difficulties on 'Self-perceived age' is more significant for Europeans than for Americans.

According to our findings, Europeans with better memory tend to have a 'Self-perceived age' younger than Chronological Age. Shipley et al. (2006) showed that British adults with better memory skills face lower mortality risks. Belsky et al. (2015) concluded that individuals with older 'Biological Age' had poorer cognitive function. We therefore conclude that better memory for Europeans implies younger 'Self-perceived' and 'Biological Age' as well as lower actual mortality.

Our results indicate that the impact of memory function on Americans is different from that for Europeans. In particular, better memory for Americans implies a 'Self-perceived age' close to their Chronological Age. Furthermore, better subtraction score implies a 'Self-perceived age' closer to Chronological Age for both Americans and Europeans while the associated standard deviation decreases. Prior research also noted that those with better cognitive functioning might form more accurate subjective survival probability assessments (Elder 2007).

Our results suggest also that the frequency of vigorous activities has a greater effect among Americans rather than Europeans.

(Figure 4)

Summary of main findings

The main findings of the analysis are summarized below:

- Persons with poor self-rated health and more mobility limitations have older Biological Age, older 'Self-perceived age' and lower subjective survival probabilities. Self-rated health is also associated with frequently used biomarkers. Overall, the results can be considered similar and consistent.
- Persons who do vigorous exercise frequently have younger Biological Age, younger 'Self-perceived age' and they higher subjective survival probabilities. Vigorous activities are also associated with lower mortality. Therefore, results can be considered similar and consistent.
- Male nonsmokers have younger Biological Age, younger 'Self-perceived age' but the literature is inconclusive on the impact of smoking status on subjective survival. Therefore, only the results of 'Biological Age' and 'Self-perceived age' are similar.
- Europeans with better memory have younger Biological Age, younger 'Self-perceived age' but the literature is not conclusive on the impact of cognitive function on subjective survival. The results of 'Biological Age' and 'Self-perceived age' can be considered similar and consistent.

- Americans with better memory have a younger 'Biological Age'. However, better memory implies a 'Self-perceived age' closer to Chronological Age and more accurate subjective survival predictions. Therefore, only the results of 'Subjective survival probabilities' and 'Self-perceived age' are similar. Furthermore, European public health policies are more generous (Navaro et al. 2006) and primary care, which helps to prevent illnesses, is more widespread compared to the United States (Starfield and Macinko 2005). In other words, the differential impact of memory function on Europeans and Americans could be partly explained by the differences in health care systems.
- Europeans and Americans with better subtraction score have a younger 'Biological Age'. Better subtraction score implies a 'Self-perceived age' closer to Chronological Age and better cognitive function implies more accurate subjective survival probabilities (d'Uva et al. 2017). Therefore, only the results of 'Subjective survival probabilities' and 'Self-perceived age' can be considered similar.

Policy implications

A range of policy implications can be considered. First, retirement age can be linked indirectly to self-rated health using 'Self-perceived age' as a proxy. For example, retirement age could be deferred only for individuals in good health, who have a younger 'Self-perceived' and 'Biological Age'. The extent of retirement deferral could be based on the difference between population average 'Self-perceived' age, which is dependent on health status, and the Chronological Age of the individual. In this way, the financial burden of increasing life expectancy may be shared more fairly across individuals based on their contribution. Furthermore, governments could organize campaigns for promoting the benefits of physical activity for older persons. For example, an increase in the retirement age could be considered fair for a society, if the majority of individuals aged 50 or above, do vigorous activities frequently. The extent of retirement age increase could be based on the difference between the population average 'Self-perceived' and Chronological Age, which can be used as a proxy for future life expectancy.

Limitations

Some limitations of this study should be taken into account when considering the findings. First the analysis is based on cross-sectional data and therefore cohort effects have not been accounted for. Second, 'Biological Age' was not calculated for respondents in this sample, due to the lack of data. Therefore, all comparisons are based only on the findings of the relevant literature. Furthermore, all measures used in the analysis are self-reported; as such they may be subject to measurement errors due to misreporting. Nevertheless, we checked the robustness of our results by running two additional sets of models.

The calculation of 'Self-perceived age' requires using a life table as input; thus, we cannot use the actual mortality of the respondents. Instead we use HMD period life tables by country and sex, which are estimated based on the general population. These life tables reflect average population mortality and do not vary by health status. To address this limitation, we compared the consistency of 'Self-perceived age' with 'Biological Age'

and ‘Subjective survival probabilities. Further, period life tables include several cohorts and reflect the average mortality across these cohorts. Goldstein and Wachter (2006) noted that for populations whose mortality patterns change, period life expectancy is a lagged measure of cohort life expectancy, the lag depending on the pace of mortality improvement. Overall, we would expect cohort-based ‘Self-perceived age’ to be marginally younger compared to period-based ‘Self-perceived age’.

Conclusion

This study presents a methodology for estimating individual ‘Self-perceived age’ by reference to life tables. The findings of the analysis show that ‘Self-perceived age’ is a robust concept, since health status and frequency of physical activities exhibit the expected associations across genders and countries. These results can be useful for improving the long-term sustainability of pension systems. The next steps include investigating ‘Self-perceived age’ variations across sociodemographic factors and estimating ‘Self-perceived age’ loadings for life tables by sex and health status.

Acknowledgements

This paper uses data from SHARE Wave 6 (DOI: 10.6103/SHARE.w6.600), see Börsch-Supan et al. (2013) for methodological details. The SHARE data collection has been primarily funded by the European Commission through FP5 (QLK6-CT-2001-00360), FP6 (SHARE-I3: RII-CT-2006-062193, COMPARE: CIT5-CT-2005-028857, SHARELIFE: CIT4-CT-2006-028812) and FP7 (SHARE-PREP: N°211909, SHARE-LEAP: N°227822, SHARE M4: N°261982). Additional funding from the German Ministry of Education and Research, the Max Planck Society for the Advancement of Science, the U.S. National Institute on Aging (U01_AG09740-13S2, P01_AG005842, P01_AG08291, P30_AG12815, R21_AG025169, Y1-AG-4553-01, IAG_BSR06-11, OGHA_04-064, HHSN271201300071C) and from various national funding sources is gratefully acknowledged (see www.share-project.org)

This analysis uses data or information from the Harmonized HRS dataset and Codebook, Version A as of February 2018 developed by the Gateway to Global Aging Data. The development of the Harmonized HRS was funded by the National Institute on Aging (R01 AG030153, RC2 AG036619, 1R03AG043052). For more information, please refer to www.g2aging.org.

References

Baker III, G. T., & Sprott, R. L. (1988). Biomarkers of aging. Experimental gerontology, 23(4-5), 223-239.

Beach, S. R., Dogan, M. V., Lei, M. K., Cutrona, C. E., Gerrard, M., Gibbons, F. X., ... & Philibert, R. A. (2015). Methylomic aging as a window onto the influence of lifestyle: Tobacco and alcohol use alter the rate of biological aging. Journal of the American Geriatrics Society, 63(12), 2519-2525.

Belsky, D.W., Caspi, A., Houts, R., Cohen, H.J., Corcoran, D.L., Danese, A., Harrington, H., Israel, S., Levine, M.E., Schaefer, J.D., Sugden, K., Williams, B., Yashin, A.I., Poulton, R., Moffitt, T.E., (2015). Quantification of biological aging in young adults. Proceedings of the National Academy of Sciences, 112(30), E4104-E4110.

Börsch-Supan A. (2017) Survey of Health, Ageing and Retirement in Europe (SHARE) Wave 6. Release version: 6.0.0. SHARE-ERIC. Data set. DOI: 10.6103/SHARE.w6.600

Börsch-Supan A., Brandt M., Hunkler C., Kneip T., Korbmacher J., Malter F., Schaan B., Stuck S. & Zuber S. (2013) Data resource profile: the Survey of Health, Ageing and Retirement in Europe (SHARE). International journal of epidemiology, 42(4), 992-1001. DOI: 10.1093/ije/dyt088

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

d'Uva, T. B., O'Donnell, O., & van Doorslaer, E. (2017). Who can predict their own demise? Heterogeneity in the accuracy and value of longevity expectations☆. The Journal of the Economics of Ageing.

Elder T. E. 2007. Subjective Survival Probabilities in the Health and Retirement Study: Systematic Biases and Predictive Validity, Michigan Retirement Research Center Research Paper No. WP 2007-159. Available at SSRN: https://ssrn.com/abstract=1083823 or http://dx.doi.org/10.2139/ssrn.1083823

Ezzati, M., & Lopez, A. D. 2003. Estimates of global mortality attributable to smoking in 2000. The Lancet, 362(9387), 847-852.

Forman, J., & Chen, B. Y. P. (2008). Optimal retirement age.

Goldstein, J. R., & Wachter, K. W. (2006). Relationships between period and cohort life expectancy: Gaps and lags. Population Studies, 60(3), 257-269

Hamermesh D. S. (1985) Expectations, life expectancy, and economic behavior. The Quarterly Journal of Economics, 100(2), 389-408.

Health and Retirement Study, RAND HRS Longitudinal File 2014 v2 public use dataset. Produced and distributed by the University of Michigan with funding from the National Institute on Aging (grant number NIA U01AG009740).

Hurd M.D. and McGarry K. 1995. Evaluation of the subjective probabilities of survival in the health and retirement study. The Journal of Human Resources, pp. S268-S292.

Hurd M. D., & McGarry K. (2002) The predictive validity of subjective probabilities of survival. The Economic Journal, 112(482), 966-985.

Human Mortality Database. University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany). Available at www.mortality.org (data downloaded on 26/09/2017).

Gateway to Global Aging Data, Produced by the USC Program on Global Aging, Health & Policy, with funding from the National Institute on Aging (R01 AG030153)

Goggins, W. B., Woo, J., Sham, A., & Ho, S. C. (2005). Frailty index as a measure of biological age in a Chinese population. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 60(8), 1046-1051.

Gregg, Edward W., Jane A. Cauley, Katie Stone, Theodore J. Thompson, Douglas C. Bauer, Steven R. Cummings, Kristine E. Ensrud, and Study of Osteoporotic Fractures Research Group. 2003. Relationship of changes in physical activity and mortality among older women. Jama 289 (18) : 2379-2386.

Griffin, B., Loh, V. and Hesketh, B. 2013. A mental model of factors associated with subjective life expectancy. Social science & medicine, 82, pp. 79-86.

Idler E. L., Benyamini Y. (1997) Self-rated health and mortality: a review of twenty-seven community studies. Journal of health and social behavior, 21-37.

Jylhävä, J., Pedersen, N. L., Hägg, S. (2017). Biological age predictors. EBioMedicine, 21, 29-36.

Jylhä, M., Volpato, S., & Guralnik, J. M. (2006). Self-rated health showed a graded association with frequently used biomarkers in a large population sample. Journal of clinical epidemiology, 59(5), 465-471

Klemera, P., & Doubal, S. (2006). A new approach to the concept and computation of biological age. Mechanisms of ageing and development, 127(3), 240-248.

Kutlu-Koc, V., & Kalwij, A. (2013) Individuals' survival expectations and actual mortality. Discussion Papers, (2013-013).

Mitnitski, A., Song, X., Skoog, I., Broe, G. A., Cox, J. L., Grunfeld, E., & Rockwood, K. (2005). Relative fitness and frailty of elderly men and women in developed countries and their relationship with mortality. Journal of the American Geriatrics Society, 53(12), 2184-2189.

Mitnitski, A. B., Graham, J. E., Mogilner, A. J., & Rockwood, K. (2002). Frailty, fitness and late-life mortality in relation to chronological and biological age. BMC geriatrics, 2(1), 1.

Nakamura, E., Moritani, T., & Kanetaka, A. (1989). Biological age versus physical fitness age. *European journal of applied physiology and occupational physiology*, *58*(7), 778-785.

Navarro, V., Muntaner, C., Borrell, C., Benach, J., Quiroga, Á., Rodríguez-Sanz, M., ... & Pasarín, M. I. (2006). Politics and health outcomes. The Lancet, 368(9540), 1033-1037.

Nerlich C. ,Schroth J. (2018). The economic impact of population ageing and pension reforms. ECB Economic Bulletin, Issue 2.

Peracchi, F., Perotti, V. (2010). Subjective survival probabilities and life tables: evidence from Europe. Einaudi Institute for Economics and Finance (EIEF) Working Paper, 10, 16.

Post, T., Hanewald, K. (2010) Stochastic Mortality, Subjective Survival Expectations, and Individual Saving Behavior (No. SFB649DP2010-040). Humboldt University, Collaborative Research Center 649.

Puts, M. T., Lips, P., & Deeg, D. J. (2005). Sex differences in the risk of frailty for mortality independent of disability and chronic diseases. Journal of the American Geriatrics Society, 53(1), 40-47.

Rappange D. R., Brouwer W. B. and Exel J. 2016. Rational expectations? An explorative study of subjective survival probabilities and lifestyle across Europe. Health Expectations 19(1): 121-137

Liu J. T., Tsou M. W., and Hammitt J. K. 2007. Health information and subjective survival probability: Evidence from Taiwan. Journal of Risk Research 10(2): 149-175.

Scott, W. K., Macera, C. A., Cornman, C. B., & Sharpe, P. A. (1997). Functional health status as a predictor of mortality in men and women over 65. Journal of clinical epidemiology, 50(3), 291-296.

Shipley, B. A., Der, G., Taylor, M. D., & Deary, I. J. (2006). Cognition and all-cause mortality across the entire adult age range: health and lifestyle survey. *Psychosomatic medicine*, *68*(1), 17-24.

Starfield, B., Shi, L., & Macinko, J. (2005). Contribution of primary care to health systems and health. The milbank quarterly, 83(3), 457-502

Van Solinge, H. and Henkens, K. 2018. Subjective life expectancy and actual mortality: results of a 10-year panel study among older workers. European journal of ageing, 15(2), pp.155-164

Verropoulou, G. (2014). Specific versus general self-reported health indicators predicting mortality among older adults in Europe: disparities by gender employing SHARE longitudinal data. International journal of public health, 59(4), 665-678.

Whitehouse, E. (2007). Life-expectancy risk and pensions: who bears the burden?. OECD Social, Employment, and Migration Working Papers, (60), 1.

Tables & Figures

Table 1 Sample characteristics (n = 71 379)

Variable	European males	European females	American males	American females
Number of respondents	24862	31098	6468	8951
Dependent Variables				
'Self-perceived age' (mean [SD])	55.88 [27.3]	59.77 [28.4]	66.41 [26.4]	66.51 [27.7]
'SPA' more than 5 years younger from 'CA'	46.7%	32.3%	33.6%	32.8%
'SPA' up to 5 years different from 'CA'	31.9%	31.8%	34.0%	31.6%
'SPA' more than 5 years older from 'CA'	21.4%	35.9%	32.4%	35.6%
Independent Variables				
Demographic Characteristics				
Chronological Age (mean [SD])	67.53 [9.3]	66.89 [9.8]	67.35 [9.6]	67.17 [9.8]
Physical Health				
Number of ADLs (mean [SD])	0.15 [0.57]	0.18 [0.6]	0.28 [0.8]	0.35 [0.9]
Self-rated health (mean [SD])	3.08 [1.05]	3.16 [1.04]	2.88 [1.05]	2.91 [1.05]
Mobility Index (mean [SD])	0.40 [0.8]	0.56 [0.9]	0.95 [1.39]	1.31 [1.52]
Cognitive function				
Serial 7s test (mean [SD])	4.40 [1.09]	4.19 [1.28]	3.74 [1.52]	3.33 [1.7]
Word Recall score (mean [SD])	9.11 [3.4]	9.80 [3.6]	9.28 [3.3]	10.20 [3.4]
Lifestyle and behavioral risk factors				
Frequency of vigorous activities (mean [SD])	3.46 [1.3]	3.67 [1.31]	3.70 [1.305]	4.07 [1.2]
Ever smoked daily	60%	36.2%	65.6%	49.8%

'SA' is the 'Self-perceived age' and 'CA' is the Chronological Age of the respondent.

Table 2 Relative Risk Ratios (RRRs) based on Multinomial Logistic regression. Comparison of 'Self-perceived age' and Chronological Age: tolerance level 5 years.

'Self-perceived age' younger than 5 years from Chronological Age vs 'Self-perceived age' up to 5 years different from Chronological Age[a]	**European males**	**European females**	**American males**	**American females**
Physical Health				
ADLs	1.007	1.020	1.051	1.094*
Mobility Index	0.939*	0.931**	1.009	0.988
Self-rated health	0.746**	0.794**	0.685**	0.736**
Cognitive function				
Serial 7s test	0.962*	0.953**	0.916**	0.898**
Word Recall score	1.014**	1.008	0.994	0.994
Lifestyle & Behavioural Risk Factors				
Frequency of Vigorous activities	0.957**	0.944**	0.921**	0.958
Never smoked daily (reference: smoked daily)	1.030	0.984	1.110	1.057
'Self-perceived age' older than 5 years from Chronological Age vs 'Self-perceived age' up to 5 years different from Chronological Age[a]	**European males**	**European females**	**American males**	**American females**
Physical Health				
ADLs	1.105**	1.104**	0.966	1.033
Mobility Index	1.107**	1.138**	1.117**	1.077**
Self-rated health	1.42**	1.377**	1.493**	1.402**
Cognitive function				
Serial 7s test	0.978	0.987	0.986	0.966
Word Recall score	0.975**	0.968**	0.979	0.983
Lifestyle & Behavioural Risk Factors				
Frequency of Vigorous activities	1.044**	1.024	1.007	1.073**
Never smoked daily (reference: smoked daily)	0.884**	0.895**	0.955	1.009

[a] The dependent variable is an unordered categorical variable reflecting the difference in years between 'self-perceived age' and chronological age. * p<5% . ** p<1%. Controlling for: country of residence; chronological age; chronological age-squared/100; number of parents alive; BMI; prediction interval (in years); wealth; income; marital status and education level.

Figure 1 Structure of the algorithms developed to calculate 'Self-perceived age' and the dependent variable 'SPA – CA' gap.

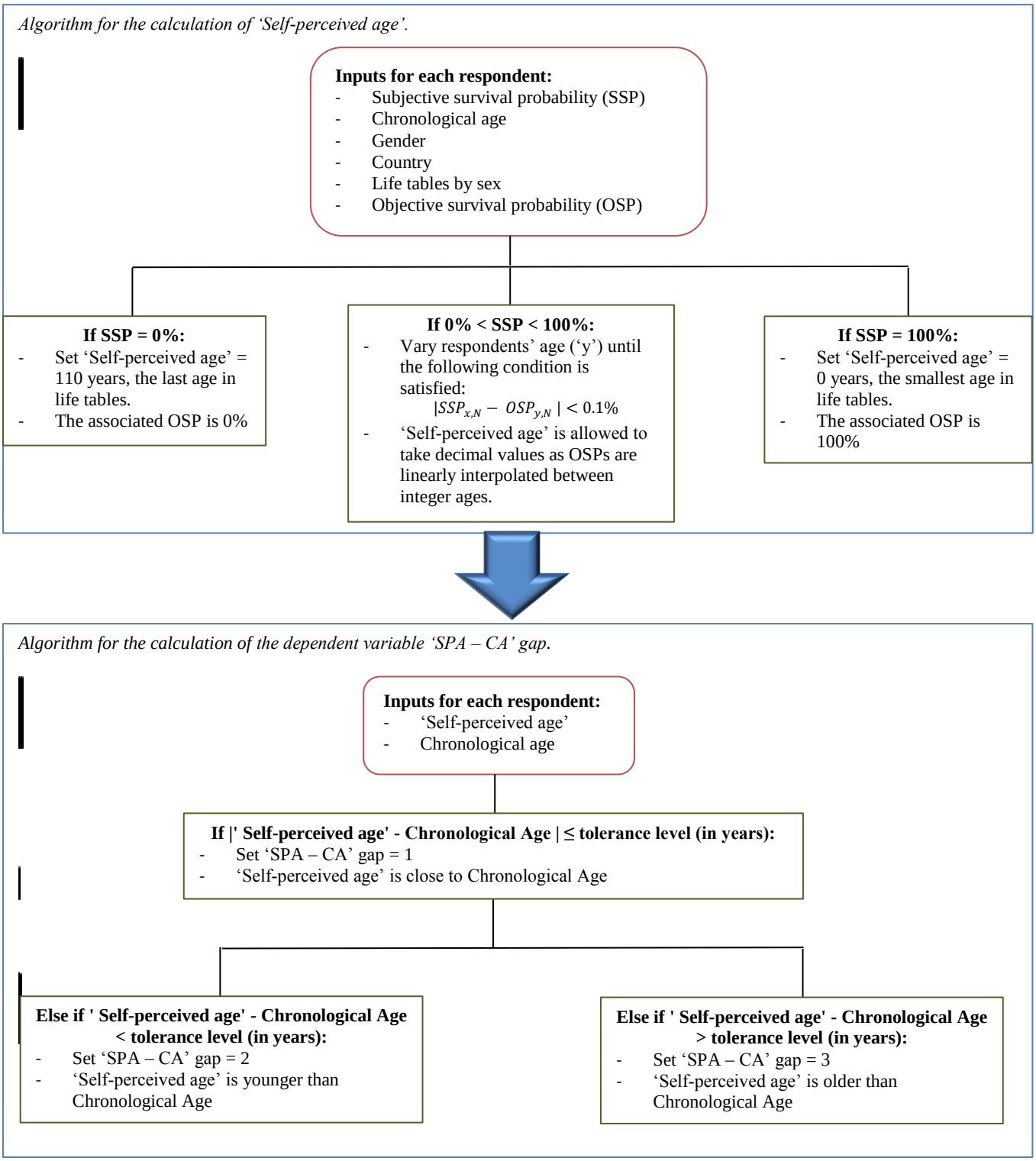

Figure 2 Relationship of 'SPA – CA' gap with self-rated health.

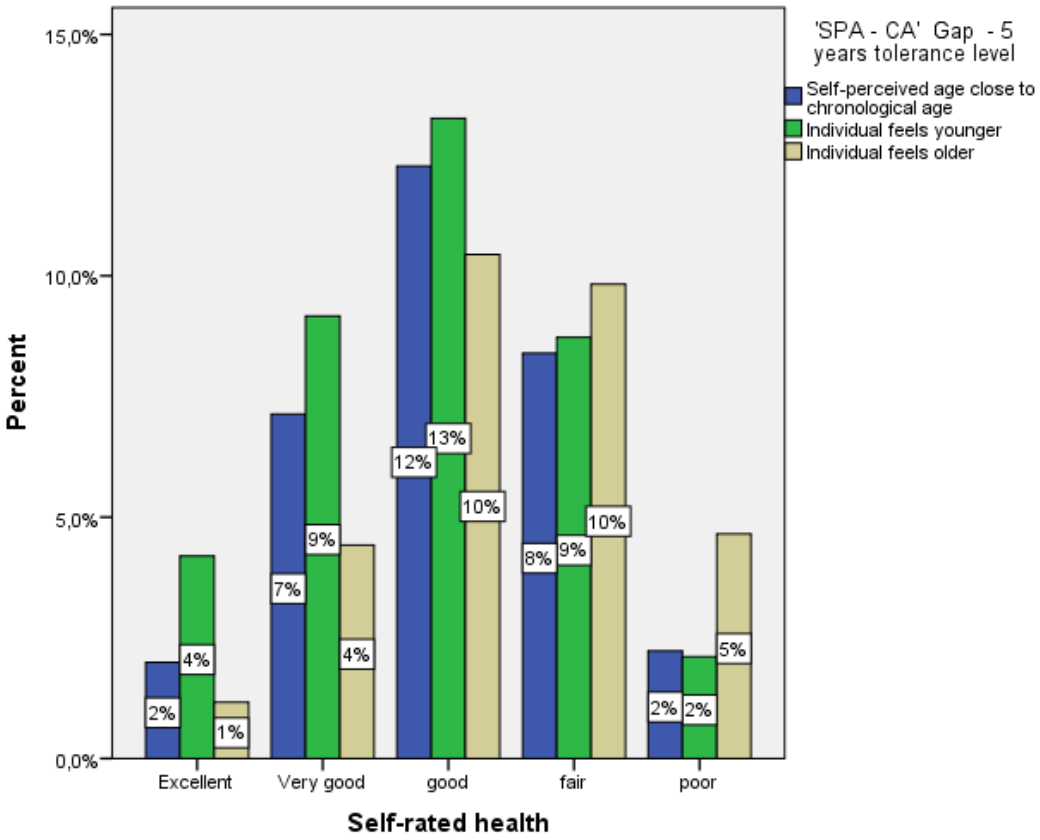

Figure 3 Relationship between average 'Self-perceived age' and average Chronological Age as self-rated health deteriorates.

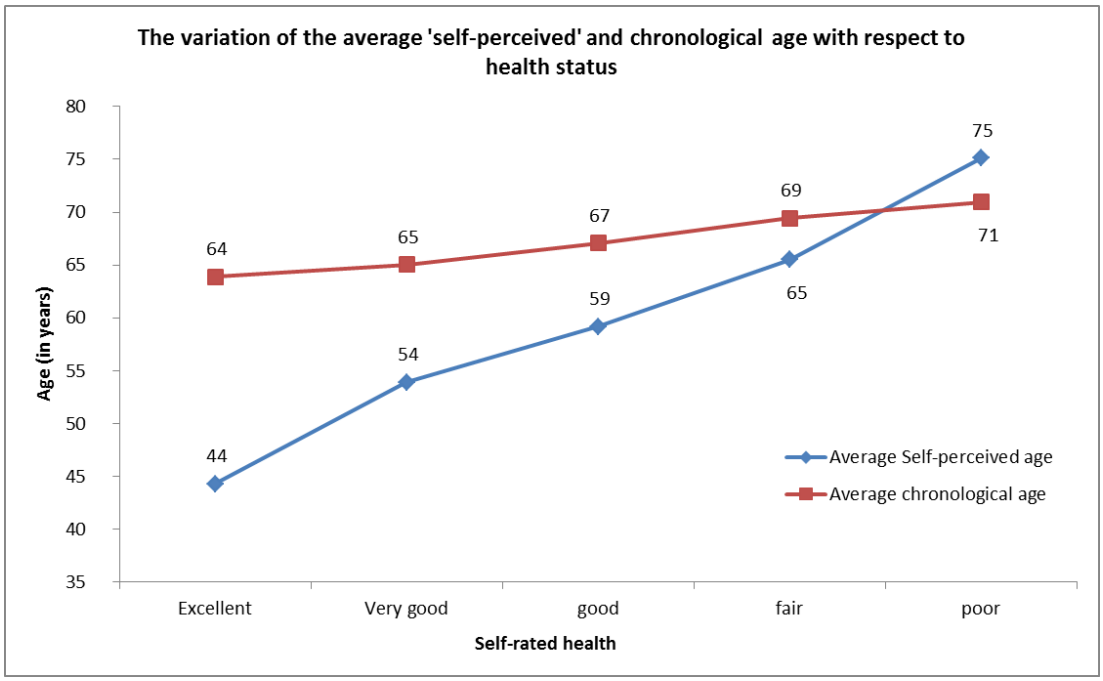

Figure 4 Relationship between average 'Self -perceived age' and average Chronological Age as the number of mobility difficulties increases.

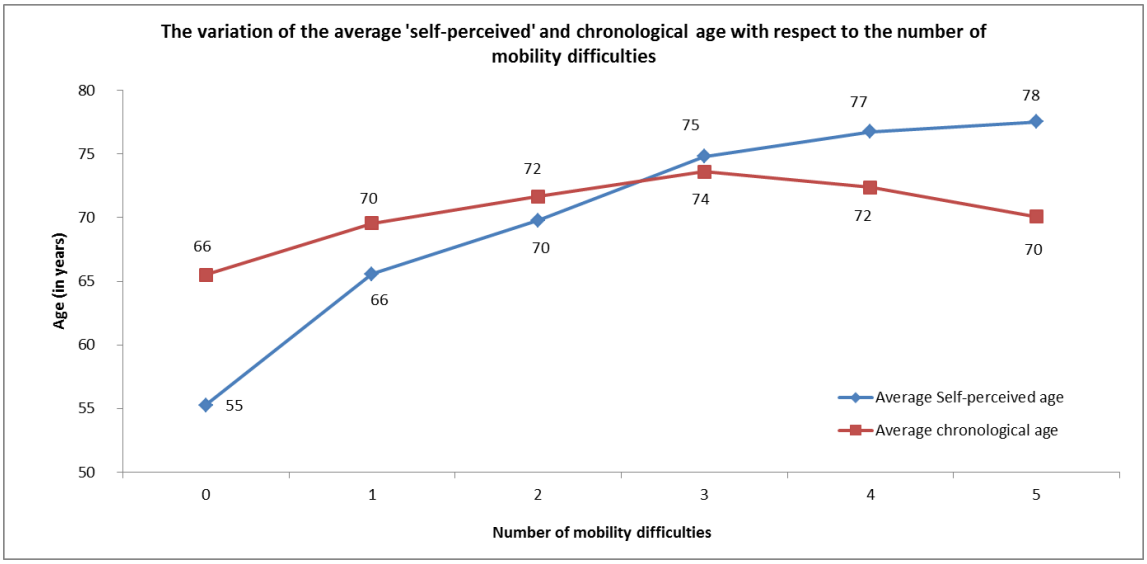

Figure 4 Summary of the main findings for 'Self-perceived age' in comparison to 'Biological Age' and 'Subjective life expectancy'.

Appendix

Table A1 Pearson and Spearman's-rho correlation coefficients for 'Self-perceived age' and Chronological Age.

Correlations of 'Self-perceived age' and Chronological Age	**Pearson**	**Spearman's-rho**
Full sample	33.1%**	47.6 %**
Self-rated health		
Excellent	26.3%**	35.3%**
Very good	29.1%**	45.3%**
Good	30.3%**	46.6%**
Fair	29.9%**	43.6%**
Poor	27.7%	36%**

* p<5% . ** p<1%. 'Self-perceived' and Chronological Age are positively correlated as expected, but not perfectly. This imperfect correlation implies that 'Self-perceived' and Chronological Age might have differential predictive ability for future survival.

Table A2 Relative Risk Ratios (RRRs) based on Multinomial Logistic regressions. Comparison of 'Self-perceived age' and Chronological Age: tolerance level 3 years

'Self-perceived age' younger than 3 years from Chronological Age vs 'Self-perceived age' up to 3 years different from Chronological Age[a]	**European males**	**European females**	**American males**	**American females**
Physical Health				
ADLs	0.992	1.003	1.037	1.074
Mobility Index	0.928*	0.929**	1.022	0.991
Self-rated health	0.755**	0.819**	0.746**	0.758**
Cognitive function				
Serial 7s test	0.943**	0.964*	0.920**	0.922**
Word Recall score	1.009	1.006	0.998	1.001
Lifestyle & Behavioural Risk Factors				
Frequency of Vigorous activities	0.956**	0.967*	0.966	0.956
Never smoked daily (reference: smoked daily)	1.012	1.002	0.970	1.103
'Self-perceived age' older than 3 years from Chronological Age vs 'Self-perceived age' up to 3 years different from Chronological Age[a]	**European males**	**European females**	**American males**	**American females**
Physical Health				
ADLs	1.074	1.087**	0.975	1.011
Mobility Index	1.087**	1.101**	1.111**	1.078**
Self-rated health	1.325**	1.333**	1.480**	1.385**
Cognitive function				
Serial 7s test	0.969	1.000	0.988	0.985
Word Recall score	0.975**	0.972**	0.986	0.994
Lifestyle & Behavioural Risk Factors				
Frequency of Vigorous activities	1.036*	1.041**	1.040	1.050
Never smoked daily (reference: smoked daily)	0.869**	0.949	0.908	1.066

[a] The dependent variable is an unordered categorical variable reflecting the difference in years between the 'self-perceived age' and the chronological age. * p<5% . ** p<1%. Controlling for: country of residence; chronological age; chronological age-squared/100; number of parents alive; BMI; prediction interval (in years); Wealth; Income; marital status and education level.

Table A3 Relative Risk Ratios (RRRs) based on Multinomial Logistic regressions. Comparison of 'Self-perceived age' and Chronological Age: tolerance level 7 years.

'Self-perceived age' younger than 7 years from Chronological Age vs 'Self-perceived age' up to 7 years different from Chronological Age[a]	**European males**	**European females**	**American males**	**American females**
Physical Health				
ADLs	1.031	0.968	1.086	1.106
Mobility Index	0.929**	0.934**	0.991	0.984
Self-rated health	0.725**	0.787**	0.671**	0.731**
Cognitive function				
Serial 7s test	0.948**	0.957**	0.898**	0.87**
Word Recall score	1.014**	1.012*	0.996	0.994
Lifestyle & Behavioural Risk Factors				
Frequency of Vigorous activities	0.956**	0.955**	0.925**	0.962
Never smoked daily (reference: smoked daily)	1.013	0.971	1.141*	1.007
'Self-perceived age' older than 7 years from Chronological Age vs 'Self-perceived age' up to 7 years different from Chronological Age[a]	**European males**	**European females**	**American males**	**American females**
Physical Health				
ADLs	1.105**	1.050	1.013	1.045
Mobility Index	1.14**	1.164**	1.073*	1.079**
Self-rated health	1.461**	1.413**	1.59**	1.433**
Cognitive function				
Serial 7s test	0.952	0.983	0.971	0.947
Word Recall score	0.974**	0.970**	0.977*	0.981*
Lifestyle & Behavioural Risk Factors				
Frequency of Vigorous activities	1.041*	1.052**	1.027	1.080**
Never smoked daily (reference: smoked daily)	0.837**	0.859**	1.009	0.994

[a] The dependent variable is an unordered categorical variable reflecting the difference in years between the 'self-perceived age' and the chronological age. * p<5% . ** p<1%. Controlling for: country of residence; chronological age; chronological age-squared/100; number of parents alive; BMI; prediction interval (in years); Wealth; Income; marital status and education level.

Figure A1 Relationship between average 'Self-perceived age' and average Chronological Age as the number of ADLs increases.

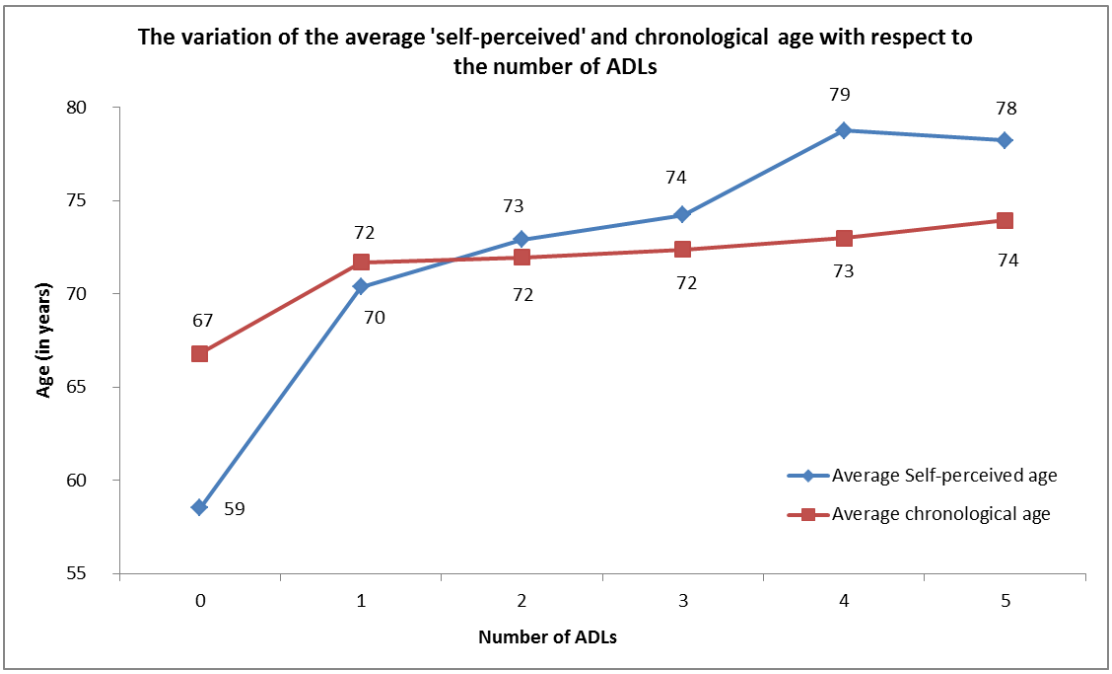

Figure A2 Relationship of the standard deviation of 'Self-perceived age' and Chronological Age gap and the standard deviation of Subjective survival probabilities as the subtraction score increases.

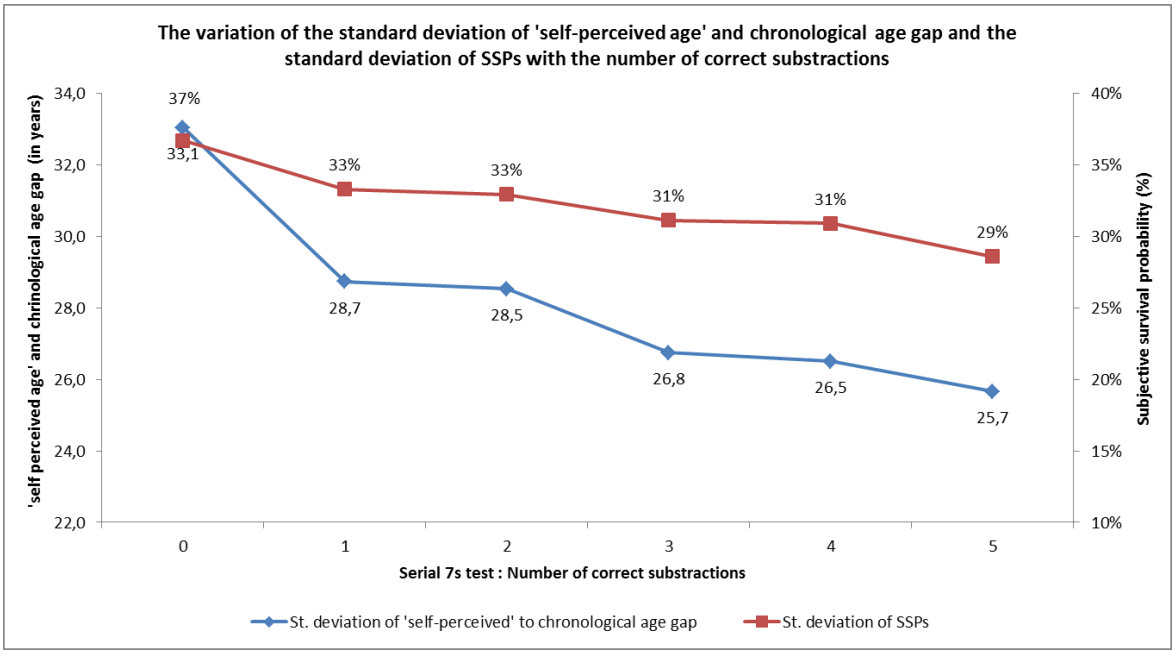

Figure A3 Variation of the standard deviation of 'Self-perceived age' and Chronological Age gap with respect to smoking status