Education and wealth inequalities in healthy ageing: a population-based study of eight harmonised cohorts in the Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) consortium

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Abstract

Background

The rapid growth of the older population is having a substantial impact on health and social care services in many societies across the world. Maintaining health and functioning in older age is a key public health issue but few studies have examined factors associated with inequalities in trajectories of health and functioning across countries. The aim of this study is to investigate trajectories of healthy ageing in older men and women and the impact of education and wealth on the trajectories.

Methods

This analysis was based on eight longitudinal cohorts from Australia, USA, Japan, South Korea, Mexico and Europe (N=141,214) harmonised by the EU Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) consortium. Multilevel modelling was used to investigate the impact of education and wealth on trajectories of healthy ageing scores, which incorporated 41 items of physical and cognitive functioning with a range between 0 (poor) and 100 (good).

Findings

Education and wealth affected baseline scores of healthy ageing but had minimal impacts on decline rates. Compared to those with primary or less education, participants with tertiary education had higher baseline scores (10·54; 95% confidence interval (CI): 10·31, 10·77) adjusting for age, sex and cohort studies. The adjusted difference between lowest and highest quintiles of wealth was 8·98 points (95% CI: 8·74, 9·22). Among the eight cohorts, the strongest inequality gradient was found in the Health Retirement Study from the USA.

Interpretation

The apparent difference in baseline scores suggests that cumulative disadvantage due to low education and wealth might have largely deteriorated health conditions in early life stages, leading to persistent differences throughout older age. Future research should adopt a lifecourse approach to investigate mechanisms of health inequalities across education and wealth in different societies.

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Introduction

Due to a decline in health status, increase of non-communicable diseases, disability and care dependence in later life, the rapid growth of the older population will lead to an increased burden on the already stretched health and social care services.[1] To address the potential impact of population ageing, the concept of 'healthy ageing', which is defined by World Health Organization (WHO) as 'the process of developing and maintaining the functional ability that enables wellbeing in older age',[2] has become a key topic in policy planning and health research. Functional ability focuses on having the capabilities that enable all people to meet their basic needs; to learn, grow and make decisions; to be mobile; to build and maintain relationships; and to contribute to society. This is made up of the interaction between intrinsic capacity, which combines all the individual's physical and mental, psychosocial capacities, and environmental characteristics, which form the context of an individual's life. This latest concept highlights the need to focus on positive aspects of ageing and the importance of considering both individual and contextual factors that may support health and functioning in later life. Whereas, traditional concepts in medical research, such as frailty, accumulated deficits or multimorbidity, have generally focused on negative aspects of health and on the identification of underlying biological and pathological abnormalities in older people.[3,4]

Previous research on health inequalities has focused on a wide range of outcomes such as specific chronic diseases, multimorbidity, frailty and disability, mortality and life expectancy,[5-7] where consistent socioeconomic inequalities according to factors such as education, occupational class and income have been reported. To provide a nuanced understanding of healthy ageing, it is important to investigate how the process of maintaining health and functioning differs across socioeconomic groups. A recent systematic review has summarised risk and protective factors related to healthy ageing.[8] Several studies were identified that reported a positive impact of education and income on ageing outcomes, suggesting the existence of health inequalities in later life across different socioeconomic positions.[8] However, existing studies have used diverse measures and analytical methods, leading to problems in study comparability. This has also hindered the assessment of factors that could be responsible for variations across countries.

To provide a better understanding of healthy ageing, the Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) Project harmonised a wide range of sociodemographic, lifestyle, health and functioning factors from 17 ageing cohorts across the globe.[9] The research team also developed a measure which incorporated multiple domains of physical and cognitive functioning and provided an indicator for healthy ageing across time and cohorts.[10] Built on the ATHLOS work of data harmonisation and methodology development, the aim of this study is to investigate the impact of education and wealth on trajectories of healthy ageing and to examine whether health inequalities across education and wealth vary in diverse older populations.

Methods

Study population

The ATHLOS Project[9] brought together 17 ageing studies across the world and harmonised a wide range of lifestyle, social environment, physical and psychological health factors across different studies. Documentation of the harmonisation process can be accessed at: https://github.com/athlosproject/athlos-project.github.io. To estimate longitudinal changes in health status, the present analysis excluded cohorts with one- or two-wave investigations due to study design (N=192,114) and focused on the eight cohorts with at least three waves of data (N=141,214). This included the Australian Longitudinal Study of Ageing (ALSA),[11] the English Longitudinal Study of Ageing (ELSA),[12] the Study on Nutrition and Cardiovascular Health in Older Adults in Spain (Seniors-ENRICA),[13] the Health and Retirement Study (HRS),[14] the Japanese Study of Ageing and Retirement (JSTAR),[15] the Korean Longitudinal Study of Ageing (KLOSA),[16] the Mexican Health and Ageing Study (MHAS)[17] and the Survey of Health Ageing and Retirement in Europe (SHARE).[18]

Healthy ageing score

Based on the WHO healthy ageing framework, researchers from the ATHLOS consortium reviewed measures of functional ability in the ageing cohorts and identified 41 items related to health, physical and cognitive functioning. These 41 items were harmonised into binary variables and item-response theory modelling was employed to generate a common measure for healthy ageing across cohorts.[10] Using the baseline data of all individuals, a two parameter logistic model was fitted to incorporate all the items and estimate a latent trait score reflecting individual health and functioning level. The estimated parameters from baseline data were applied to follow-up waves and used to generate the scores at different time points. The scores were rescaled into a range between 0 and 100 and a higher score indicated better healthy ageing. More detailed information is provided in Supporting Information S2.

Sociodemographic factors

This analysis focused on five key factors: age, sex, cohort study, education and wealth. To align different baseline age across cohort studies, age was centred to 70 years old (age–70) as one of the cohort studies, ALSA, did not have participants aged 70 years or below. The ATHLOS harmonised dataset provided four levels of education qualification: less than primary education, primary, secondary and tertiary. Since some cohort studies had very few or no participants with less than primary education, the first two levels were combined and the three levels of education were: low (up to primary education), middle (secondary) and high (tertiary). Wealth was a harmonised variable indicating relative position of individuals within specific cohorts. Appropriate measures for personal or household income and finance (such as property, pension or insurance) were identified and divided into quintiles within cohorts (Q1: most deprived; Q5: most affluent). Comparable information was not available in Seniors-ENRICA and therefore this specific analysis only included seven cohort studies. More detailed information on harmonisation is provided in Supporting Information S3.

Analytical strategy

Since multilevel modelling (MLM) can be more flexible when incorporating time variation in follow-up waves across different cohort studies,[19] random-effect model using the MLM framework was conducted to investigate trajectories of health metric scores and examine the effect of sociodemographic factors accounting for non-independence of repeated measures over time. The model was fitted to estimate fixed and random effects of intercept (baseline scores) and slope (change per year) by years of follow-up, allowing an unstructured covariance matrix of intercept and slope. To examine the impact of sociodemographic factors on the trajectories, the analysis first focused on baseline age and sex and included linear and quadratic terms of age, and the interaction between age and sex in different models. Based on the descriptive information in Supporting Information S1, the gaps of healthy ageing scores became greater in older age groups (Figure S2) and varied across men and women (Figure

S3). Thus, a quadratic term of age and interaction between age and sex were fitted to fully account for their impacts on the trajectories. A variable indicating cohort studies was added to the model including age and sex to investigate potential variations across the eight cohort studies adjusting for the two basic demographic factors. Two socioeconomic factors, education and wealth, were further added to the adjusted model including age, sex and study and we examined their effects on intercept and slope estimates. To investigate whether education and wealth might have different impacts on healthy ageing across different cohorts and sex, the analysis further included their interaction terms regressing on intercept and slope. To examine whether specific chronic conditions might explain health inequalities, five types of harmonised chronic diseases, including cardiovascular diseases, hypertension, diabetes, chronic respiratory diseases and joint disorders, were identified at baseline and added to the best model including demographic and socioeconomic factors. To investigate whether the effect of education varied across birth cohorts, interaction terms between birth cohort and education were included in modelling. Model fitness was assessed using Bayesian information criterion (BIC)[20] with lower values indicating better model fit. To contextualise the inequality findings, country-level Gini coefficients for population aged 65 or above (https://data.oecd.org/) were obtained to compare with the score differences across education and relative wealth levels.

Several sensitivity analyses were conducted. Quadratic terms of years of follow up were further added in the mixed models to investigate potential non-linear trajectories. Maximum likelihood estimation should provide unbiased estimates given the assumption of missing at random (MAR) mechanism.[21] Since the percentages of missing data on education (N=2789, 2·0%) and wealth (N=4519, 3·3%) were small in relation to the whole study population, results reported here are based on those with complete information on education or wealth. Loss of statistical power was unlikely to be an issue given the large number of study population. The distributions of education and wealth levels were also found to similar across follow-up waves (Table S3, Supporting Information). To account for potential missing not at random (MNAR) due to mortality, a joint model of longitudinal data on healthy ageing scores and survival data on all-cause mortality was fitted combining multilevel modelling and parametric Weibull survival regression.[22] All analyses were based on the ATHLOS harmonised dataset version 1.7 and conducted using Stata 15.1.

Role of the funding source

The funders had no roles in study design, collection, analysis, interpretation of data, the writing of the report and the decision to submit the study for publication. The corresponding author had full access to all of the data and the final responsibility to submit for publication.

Results

Among the eight cohorts, the earliest studies started from 1992 (Table 1). Two larger cohorts, SHARE and HRS, recruited over 30,000 participants while ALSA and Seniors-ENRICA had less than 3,000. The length and frequency of follow-ups varied across studies. Most studies had follow-up every two years for a period of 10 years. The median follow-up period was six years with an interquartile range of nine years. ALSA had 13 waves over two decades while JSTAR only had 3 waves over four years.

Among the 141,214 participants, the percentage of women was 54% (N=76,484) with a range from 47% (N=908) in ALSA and 57% (N=5,791) in KLOSA. The mean age at baseline was 62·9 years (SD=10·1) and the range was between 45 and 106 years. MHAS had 78% of participants with primary or no formal education (N=10,627) while HRS (N=9,359), SHARE (N=15,170) and JSTAR (N=1,515) had less than 30% participants with low education. The mean healthy ageing score was 67·5 (SD=17·8) across all data and decreased from 69·5 (SD=17·0) at baseline, 64·1 (SD=18·4) at year 10, to 62·6 (SD=18·2) at year 20. The distributions of healthy ageing scores by cohorts are provided in Table 1.

Table 2 reports the associations between trajectories of healthy ageing scores, age and sex. For participants aged 70 years, the baseline score was estimated to be 68·25 (95% CI: 68·13, 68·37) and the decline rate was -1·11 (95% CI: -1·13, -1·09) per year (Figure 1A). Older age was associated with a lower intercept in linear (-0·66; 95% CI: -0·68, -0·65) and quadratic terms of age (-0·02; 95% CI: -0·02, -0·01). Men had higher scores than women (4·36; 95% CI: 4·18, 4·54) and this difference increased with baseline age (0·05; 95% CI: 0·04, 0·07) (Figure 1B). The decline rate was slightly greater in men than women (-0·02; 95% CI: -0·04, 0·00) but the effect size was small. After adjusting for age and sex, variation in intercept and slope was found across cohort studies (Figure 1C; Table S2, Supporting Information). Compared to HRS, a higher baseline score was found in JSTAR (8·38; 95% CI: 7·92, 8·83) and a lower baseline in MHAS (-2·85; 95% CI: -3·15, -2·56). Decline rates were generally greater in HRS and MHAS than other cohort studies.

The associations between trajectories of health status, education and relative wealth are reported in Table 3. Both education and relative wealth had a strong influence on the baseline scores but a limited impact on decline rates after adjusting for age, sex and cohort study. Participants with secondary (5·66; 95% CI: 5·49, 5·83) and tertiary education (10·54; 95% CI: 10·31, 10·77) had higher baseline scores than those with primary education or less. Higher level of wealth was associated with higher baseline scores and the difference between the least and most affluent quintiles was 8·98 points (95% CI: 8·74, 9·22). The effect of education and relative wealth on baseline scores varied across cohort studies. ELSA, HRS, MHAS and

SHARE had larger variation across education levels (Figure 2A). In these cohort studies, participants with secondary education had higher baseline scores by approximate 6 points and the difference increased to nearly 10 points for those with tertiary education. In JSTAR, Seniors-ENRICA, ALSA and KLOSA, the difference between high and low education was less than 6 points. Although most studies showed increasing baseline scores from the least to the most affluent quintiles, ELSA, HRS and SHARE had stronger gradients compared to other cohort studies (Figure 2B). Due to small numbers of ALSA participants in the third and fourth quintiles, the confidence intervals were very wide. When including both education and relative wealth in one model, the effect sizes remained similar across all cohort studies (Table S4, Supporting Information S4). Education and relative wealth had similar impacts on trajectories of healthy ageing scores in both men and women with very clear gradients from lowest to highest levels of education and relative wealth (Table S5, Supporting Information S4). Further adding chronic conditions did not reduce the gaps across education and wealth levels (Table S6-7, Supporting Information S4) and the effect of education did not vary across birth cohorts (Table S9, Supporting Information S4). The scatter plot of Gini coefficients and effect sizes of inequalities across education and wealth (Figure S6, Supporting Information S4) did not show clear patterns.

The results of sensitivity analyses are provided in Supporting Information S5. Although the quadratic model showed better goodness of fit, the effect sizes of quadratic terms were small (Table S10, Supporting Information S5). The results of joint modelling showed a slightly greater decline rate (-1·24; 95% CI: -1·25, -1·22) when including mortality data in the longitudinal analysis (Table S11, Supporting Information S5). A higher baseline score (Hazard ratio (HR): 0·96; 95% CI: 0·95, 0·96) and slower decline rate (HR: 0·57; 95% CI: 0·55, 0·58) were associated with lower risk of mortality after adjusting for age and sex.

Discussion

Using a harmonised dataset of eight ageing cohorts from USA, UK, Spain, Europe, Australia, Japan, Korea and Mexico, this study investigated changes in health and functioning over the ageing process and the potential impact of demographic and socioeconomic factors on the trajectories. Baselines scores and decline rates of healthy ageing scores varied across different age groups, sex and cohort studies. Education and wealth had a strong impact on baseline scores but almost no influence on the decline rates. Participants with lower levels of education and wealth generally had lower baseline healthy ageing scores but the effect sizes were different across cohort studies. Among the eight cohorts, the inequality gradients were found to be strongest in the HRS.

The ATHLOS consortium harmonised data from different ageing cohorts across the globe and provides a large sample size for longitudinal analysis. This study focused on eight population-based cohorts and included participants from different settings. Compared to harmonised datasets in the Gateway to Global Aging Data platform,[23] this study incorporated additional cohort studies from Australia and Spain and an indicator for healthy ageing was generated comprising multiple domains of health and functioning measures across cohorts and follow-up waves. The healthy ageing concept highlights ‘what a person can do in older age’ rather than ‘what kinds of symptoms and pathological abnormalities in an older patient’, which has been the focus of other relevant but distinct concepts such as frailty.[4] While cognitive/motor reserve also focuses on functioning processes and neural network, reserve is mainly determined by factors in earlier life stages.[24] On the other hand, healthy ageing is considered to be a process of maintaining functional ability and interactions between individual and environmental factors that can modify this process in later life.

This study had some limitations. Most studies from low- and middle-income countries only had one or two waves of data and could not be included in this longitudinal analysis. Despite the process of data harmonisation, variation in methods of data collection or management across cohort studies might not be completely omitted and has to be considered when interpreting the findings. Variation in follow-up waves was accounted in multilevel modelling but only two studies (HRS and ALSA) had 20 years of follow-up and informed trajectories after 10 years of follow-up. The linear models might not sufficiently capture changes in decline rates particularly in the latter 10-year follow up period. However, decline rates seemed to be similar in the first 10-year period across cohorts and sensitivity analyses showed similar results. Another modelling approach could be using country as multilevel factor. Yet only SHARE included multiple countries and it would be difficult to generate specific estimates for each cohort study. Measures from different studies might collect slightly different information. Using the example of wealth quintiles, some studies only included a single question of household income while some used a series of questions to collect detailed income and financial information. Given such variation, we were not able to obtain a harmonised variable for absolute wealth and only focused on relative levels. The same issue might also affect items of the healthy ageing score. Variation in measurements might affect the associations between education, wealth and trajectories of healthy ageing. However, we adjusted for the study in the analysis and these two socioeconomic factors still had important impacts on baseline health scores. Although multiple imputation could be used to address missing or unavailable data on education and relative wealth,[25] it was too challenging and computationally intensive to impute such large dataset while taking into account multilevel data structure. However, the effect sizes were unlikely to be over-estimated and statistical power should not be affected given the large study population. Some societal and historical factors such as health systems, welfare policies or economic crisis in different societies may affect health throughout the lifetime and explain health inequalities in later life. However, these measures were not available in the harmonised dataset. We attempted to include country-level Gini coefficients yet no apparaent relationships with health inequalities across education and relative wealth were observed.

Education and wealth were found to have limited impacts on decline rates of healthy ageing scores in older people across different cohorts. This corresponds to an earlier SHARE analysis, which identified several indicators for early-life socioeconomic circumstances (such as number of books at home, housing quality and overcrowding) and reported their consistent associations with baseline levels of physical, cognitive and emotional functioning but not decline rates.[26] Given lack of effect on decline rates, cumulative disadvantage due to low socioeconomic status might have largely deteriorated health conditions in early life stages and lead to persistent differences throughout older age.

Inequalities in healthy ageing across education and wealth were apparent but the scale of the gradient varied across cohort studies. A wider gap was found in HRS, ELSA, MHAS and SHARE while the effect sizes were nearly half of the magnitude in other cohorts. This might be related to contextual factors in different societies, such as different absolute levels of income and material resources, variation in how education affects income or job opportunities, and also systematic differences in the distribution of education groups across sex, birth cohorts and time. Based on the theory of health inequality,[27] education is widely used as a proxy measure for social position or status while wealth indicates a relative position in the income ladder. The subtle variation between these two measures might imply different pathways via material factors or behavioural and psychosocial factors. Wealth is likely to be related to material factors, such as financial difficulties, poor housing tenure, limited access to health care and insurance, which may have direct impacts on poor health across the lifetime and affect functional ability in older age.[28,29] Education is likely to be related to behavioural and psychological factors such as smoking, diet and social support.[27] These factors may also influence physical and mental health and capability to maintain functional ability in later life.[8] In this study, both education and relative wealth had independent effects on trajectories of healthy ageing scores across cohort studies and the effect sizes remained similar when further including chronic conditions. Pathways via material, behavioural and psychological factors might all be important and the role of environmental factors in supporting healthy ageing should be explored.

The findings of this study highlight health inequalities in later life across education and wealth and their impacts may vary across different contexts. To identify potential mechanisms that explain the differential impact of education and wealth, a lifecourse approach is needed to understand how risk of poor health can accumulate since early life stages and investigate key material, behavioural and psychological factors that generate health inequalities in different societieis.[27,30] More longitudinal studies need to be carried out in low- and middle-income countries in order to compare trajectories of healthy ageing across older populations living in various cultural, social and environmental contexts. This will inform policy planning on addressing determinants of healthy ageing across the world and reducing health inequalities in later life.

Research in context

Evidence before this study

To summarise evidence on determinants of healthy ageing, the ATHLOS consortium has carried out a systematic review and a comprehensive report has been released on the project website in 2018. The search terms included 'healthy ageing' and other relevant terms such as 'successful/ positive/ productive/ optimising/ unimpaired/ robust/ effective ageing'. The literature search was conducted in MEDLINE, EMBASE, Psychinfo and Cochrane Central from inception up to August 2016. The review included all longitudinal cohort studies using 'healthy ageing' as a main outcome measure. Since healthy ageing is considered a construct incorporating multiple domains of health, studies were excluded if a single component of healthy ageing (such as cognitive function, quality of life, or well-being alone) was used. There were no restrictions for language, time frame, setting, or characteristics of participants. Risk of bias was assessed using the Quality in Prognosis Studies (QUIPS) tool. The initial search identified 89905 publications after duplicates removal and 65 longitudinal cohort studies met the inclusion criteria. Among the 65 included studies, 25 investigated the associations between education and healthy ageing and 14 focused on the associations with income and economic status. The risk of bias were low in these studies. Despite the heterogeneity of measurement methods, high levels of education and income were found to be beneficial to healthy ageing.

Added value of this study

Although previous studies have suggested positive associations between education, income and healthy ageing, the strength of association reported from different cohorts may not be comparable due to variation in measurement methods. This study was based on a harmonised dataset of eight longitudinal cohorts from Australia, USA, Japan, South Korea, Mexico and Europe. Low levels of education and wealth was associated with poor health at baseline but had limited impacts on decline rates. The gradient of health inequalities at baseline differed across populations and the strongest gradient was found in the Health Retirement Study from the USA.

Implications of all the available evidence

Education and wealth appear to be important determinants of healthy ageing. To support maintenance of functional ability and reduce health inequalities in older age, public health policies should incorporate a lifecourse approach and address key determinants and risk factors from early life stages. Future research needs to understand how risk of poor health can accumulate over the lifecourse and investigate how variation in life experience, social, environmental and cultural factors can impact healthy ageing across different societies.

Declaration of interests

None.

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Role of the funding source

The funders had no roles in study design, collection, analysis, interpretation of data, the writing of the report and the decision to submit the study for publication. The corresponding author had full access to all of the data and the final responsibility to submit for publication.

Data availability statement

Documentation and metadata of the ATHLOS harmonisation process can be accessed at: https://github.com/athlosproject/athlos-project.github.io; https://athlos.pssjd.org. The original cohort data are publicly available (HRS, ELSA, KLOSA, MHAS, SHARE) or can be accessed via contacting the study management teams on reasonable request.

Contributors

YTW, CD and AMP developed the original idea and designed the approach. ASN organised data harmonisation and management. YTW conducted the data analysis. GMT supervised the analyses. All authors contributed to report writing and approved the final manuscript.

Ethics committee approval

This is a secondary data analysis project. All cohort studies have been approved by the relevant local research ethics committees.

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Figure legends

Figure 1. Estimated healthy ageing scores by baseline age, sex and cohort study

Figure 2. Differences in baseline healthy ageing scores across education levels and wealth quintiles by cohort studies (adjusted for age and sex)

Tables

Table 1. Characteristics of study population by eight cohort studies

Cohort	Location	Baseline age (years) Mean (SD)	[range]	Sex Women: N (%)	Baseline/last follow up year	Number of wave	Low education (<primary): N (%) *Missing=2789 (2·0%)*	Wealth (least affluent quintile): N (%) *Missing=4519 (3·3%)*	Number of participants	Health status scores: Mean (SD)
ALSA	Australia	77·5 (5·9)	[70, 103]	908 (46·6)	1992/2014	13	602 (36·7)	701 (37·3)	1947	56·8 (14·0)
ELSA	UK	62·8 (9·6)	[50, 94]	7977 (53·1)	2002/2015	7	5516 (39·4)	2600 (18·6)	15010	66·4 (16·8)
ENRICA	Spain	68·7 (6·4)	[60, 93]	1338 (53·1)	2008/2015	3	1373 (54·5)	N/A	2519	67·3 (14·8)
HRS	US	61·2 (9·8)	[50, 103]	18044 (53·7)	1992/2012	11	9359 (27·9)	6974 (20·8)	33580	65·6 (18·9)
JSTAR	Japan	62·9 (7·1)	[50, 77]	2616 (50·8)	2007/2011	3	1515 (29·6)	677 (25·2)	5144	76·9 (13·5)
KLOSA	S. Korea	61·5 (11·0)	[45, 105]	5791 (56·5)	2006/2012	4	4651 (45·4)	2097 (20·9)	10254	68·9 (15·6)
MHAS	Mexico	62·5 (9·6)	[50, 106]	7310 (53·8)	2001/2012	3	10627 (78·3)	3128 (24·0)	13601	63·9 (16·5)
SHARE	Europe	64·2 (9·9)	[50, 103]	32500 (54·9)	2004/2013	5	15170 (26·3)	11463 (19·5)	59159	71·1 (17·1)
Total		62·9 (10·1)	[45, 106]	76484 (54·2)			48813 (35·3)	27640 (20·6)	141214	67·5 (17·8)

ALSA: Australian Longitudinal Study of Ageing; ELSA: English Longitudinal Study of Ageing; Seniors-ENRICA: Study on Nutrition and Cardiovascular Health in Older Adults in Spain; HRS: Health and Retirement Study (HRS); JSTAR: Japanese Study of Ageing and Retirement; KLOSA; Korean Longitudinal Study of Ageing; MHAS: Mexican Health and Ageing Study; SHARE: Survey of Health Ageing and Retirement in Europe

Table 2. The association between trajectories of health metrics, age and sex

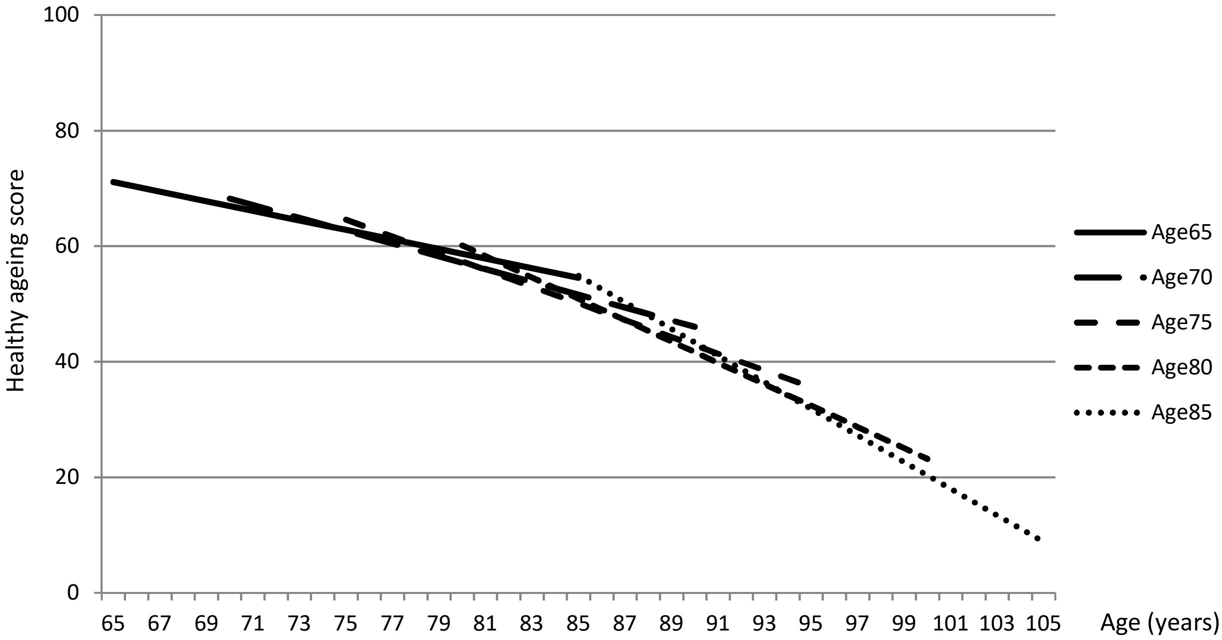
	Model 1	Model 2	Model 3
	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)
Baseline score	68·25 (68·13, 68·37)	66·21 (66·07, 66·36)	66·19 (66·05, 66·34)
Age (years, at baseline)	-0·65 (-0·66, -0·64)	-0·66 (-0·68, -0·65)	-0·66 (-0·67, -0·65)
Age^2	-0·02 (-0.02, -0.02)	-0·02 (-0·02, -0·01)	-0·02 (-0·02, -0·01)
Sex (men vs women)		4·36 (4·18, 4·54)	4·41 (4·22, 4·59)
Age*sex		0·05 (0·04, 0·07)	0·05 (0·04, 0·07)
Decline rate (by year of follow-up)	-1·11 (-1.13, -1.09)	-1.11 (-1·12, -1·09)	-1·10 (-1·12, -1·08)
Age (years, at baseline)	-0·06 (-0·06, -0·06)	-0·06 (-0·06, -0·06)	-0·06 (-0·06, -0·06)
Age^2	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)
Sex (men vs women)			-0·02 (-0·04, 0·00)
Variance			
Intercept	180·53 (178·81, 182·27)	176·33 (174·63, 178·04)	176·32 (174·63, 178·03)
Slope	0·79 (0·77, 0·81)	0·79 (0·77, 0·81)	0·79 (0·77, 0·81)
Covariance	-2·08 (-2·24, -1·92)	-2·08 (-2·24, -1·91)	-2·07 (-2·23, -1·91)
Residual	83·46 (83·02, 83·90)	83·48 (83·04, 83·93)	83·48 (83·04, 83·92)
Goodness of fit			
BIC	3854387	3851659	3851668

Table 3. The association between education, wealth and trajectories of health metrics (adjusted for age, sex and cohort study)

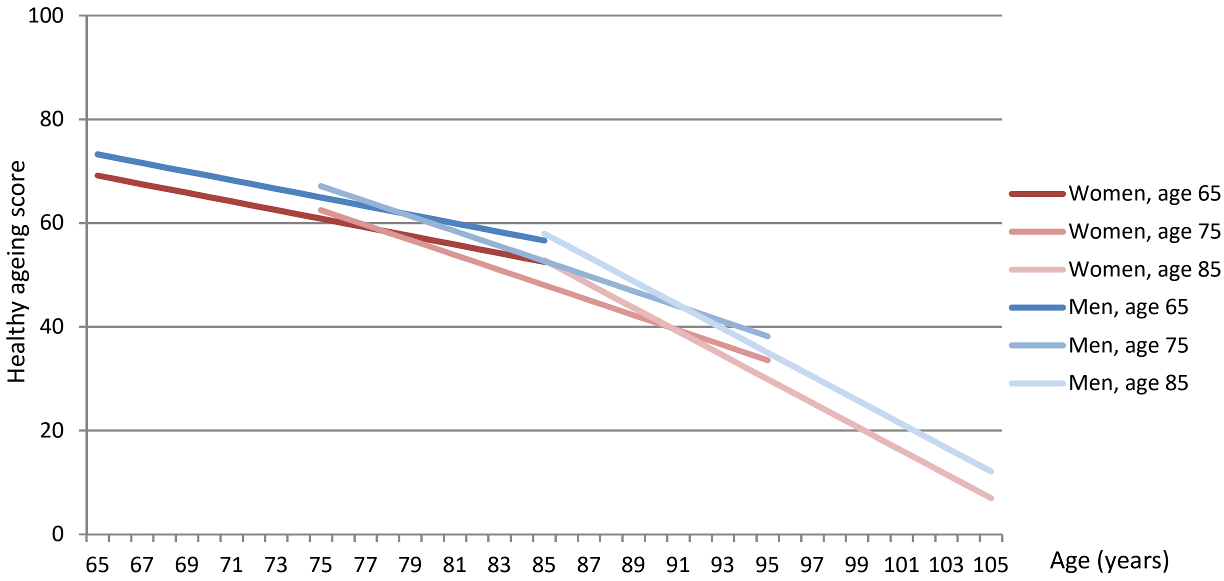
	Education		Wealth	
	Model 1	Model 2	Model 1	Model 2
	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)
Baseline score	60·18 (59·96, 60·41)	58·97 (58·85, 59·48)	60·53 (60·28, 60·77)	55·74 (55·38, 56·10)
Education				
Middle vs Low	5·66 (5·49, 5·83)	6·80 (6·44, 7·15)		
High vs Low	10·54 (10·31, 10·77)	13·48 (13·02, 13·94)		
Relative wealth				
Q2 vs Q1			2·24 (2·00, 2·47)	6·17 (5·70, 6·65)
Q3 vs Q1			4·13 (3·89, 4·36)	9·91 (9·44, 10·39)
Q4 vs Q1			6·55 (6·32, 6·79)	13·14 (12·66, 13·62)
Q5 vs Q1			8·98 (8·74, 9·22)	16·34 (15·86, 16·82)
Decline rate				
(by year of follow-up)	-1·26 (-1·28, -1·24)	-1·28 (-1·31, -1·25)	-1·27 (-1·29, -1·24)	-1·19 (-1·23, -1·16)
Education				
Middle vs Low		0·01 (-0·03, 0·04)		
High vs Low		0·04 (0·00, 0·09)		
Relative wealth				
Q2 vs Q1				-0·08 (-0·13, -0·03)
Q3 vs Q1				-0·13 (-0·18, -0·08)
Q4 vs Q1				-0·11 (-0·16, -0·06)
Q5 vs Q1				-0·08 (-0·13, -0·03)
Goodness of fit				
BIC	3778816	3778487	3703900	3702573

Figure 1. Estimated healthy ageing scores by baseline age, sex and cohort study

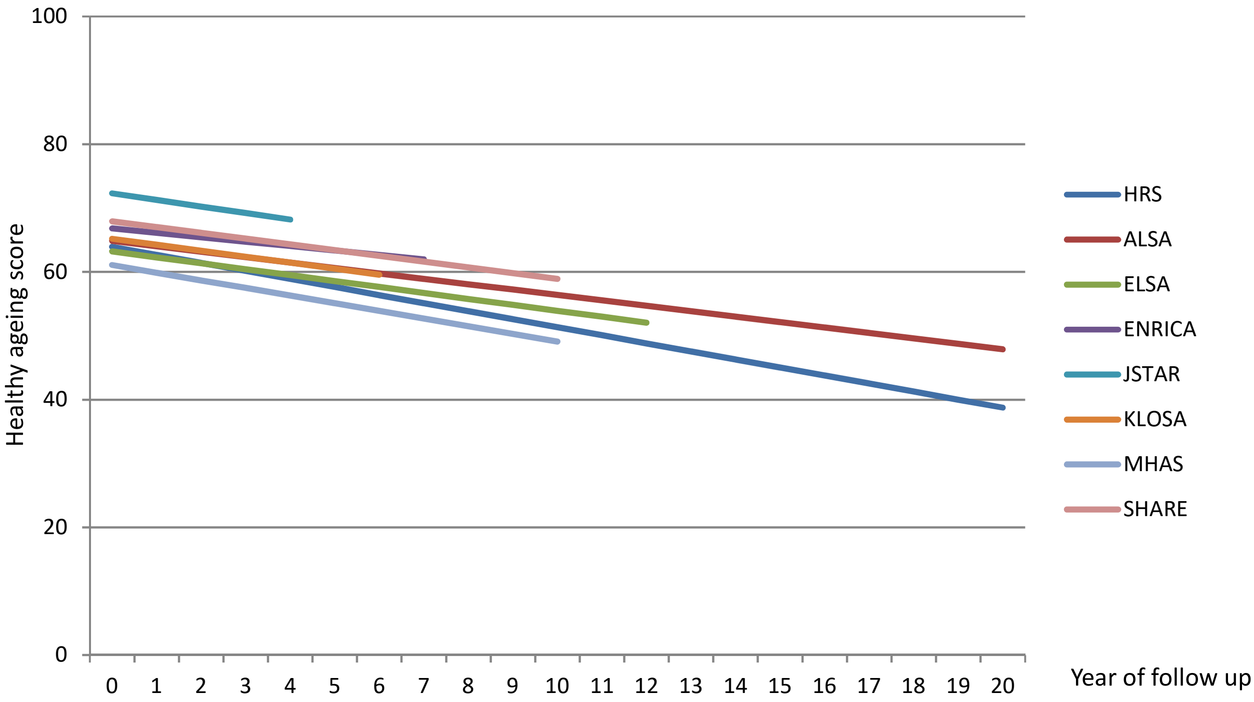
(A) Baseline age



(B) Baseline age and sex



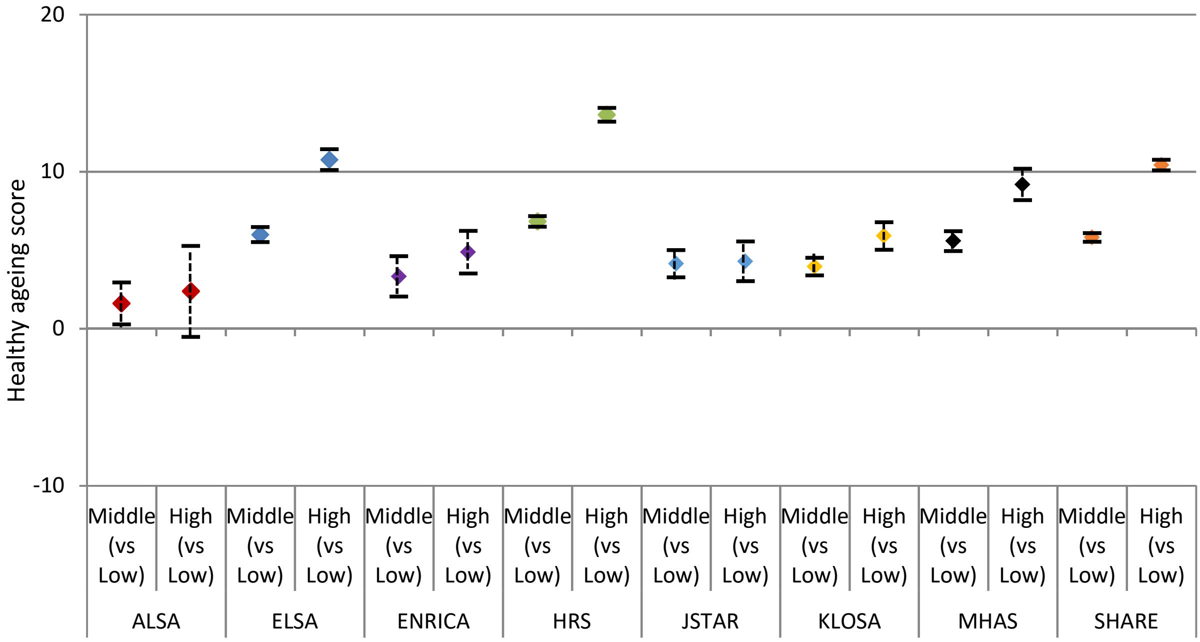
(C) Cohort study (adjusted for age and sex)



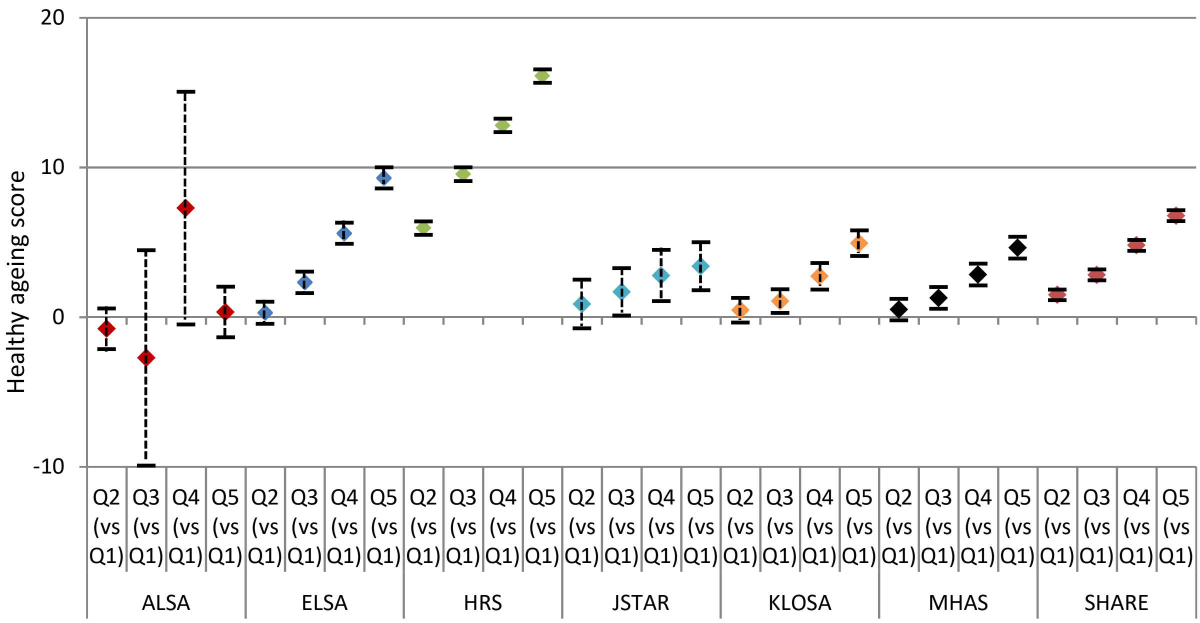
ALSA: Australian Longitudinal Study of Ageing; ELSA: English Longitudinal Study of Ageing; Seniors-ENRICA: Study on Nutrition and Cardiovascular Health in Older Adults in Spain; HRS: Health and Retirement Study (HRS); JSTAR: Japanese Study of Ageing and Retirement; KLOSA; Korean Longitudinal Study of Ageing; MHAS: Mexican Health and Ageing Study; SHARE: Survey of Health Ageing and Retirement in Europe

Figure 2. Differences in baseline healthy ageing scores across education levels and wealth quintiles by cohort studies (adjusted for age and sex)

(A) Education (Low: primary education or less; Middle: secondary education; High: tertiary education)



(B) Wealth (Cohort-specific quintiles; Q1: least affluent; Q5: most affluent)



ALSA: Australian Longitudinal Study of Ageing; ELSA: English Longitudinal Study of Ageing; Seniors-ENRICA: Study on Nutrition and Cardiovascular Health in Older Adults in Spain; HRS: Health and Retirement Study (HRS); JSTAR: Japanese Study of Ageing and Retirement; KLOSA; Korean Longitudinal Study of Ageing; MHAS: Mexican Health and Ageing Study; SHARE: Survey of Health Ageing and Retirement in Europe

Education and wealth inequalities in healthy ageing: a population-based study of eight harmonised cohorts in the Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) consortium

Supporting Information

S1. ATHLOS consortium and funding information

The ATHLOS consortium: Albert Sanchez-Niubo, Laia Egea-Cortés, Ivet Bayes, Blanca Mellor, Iago Giné-Vázquez, Beatriz Olaya, Stefanos Tyrovolas, Javier de la Fuente, Jose L Ayuso-Mateos, Francisco Félix Caballero, Esther García-Esquinas, Esther Lopez-Garcia, Fernando Rodríguez-Artalejo, Christina Daskalopoulou, Hai Nguyen, Yu-Tzu Wu, Matthew Prina, Martin Prince, Denes Stefler, Martin Bobak, Swantje Paulsen, Holger Arndt, Katarzyna Zawisza, Aleksander Galas ,Beata Tobiasz-Adamczyk, Agnieszka Doryńska, Magdalena Kozela, Krystyna Szafraniec, Andrzej Pająk, Matilde Leonardi, Davide Guido, Alberto Raggi, Anna Goodman, Ilona Koupil, Demosthenes Panagiotakos, Abdonas Tamosiunas, Ricardas Radisauskas, Sergei Scherbov, Warren Sanderson, Seppo Koskinen, Päivi Sainio, Jerome Bickenbach, Somnath Chatterji, Josep Maria Haro

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S2. ATHLOS healthy ageing score

(A) Data

Based on the WHO framework,[1] the ATHLOS research team reviewed information in the included cohort studies[2] and identified the items which might indicate underlying concept of healthy ageing, 'the process of developing and maintaining functional ability that enables wellbeing in older age'. The selected items mainly focused on physical and cognitive functioning as they are key to maintain functional ability in daily life. A small number of items related to health such as pain, sleep problems, level of energy were also selected as they were considered to strongly influence functional performance. The selected items were harmonised across the 17 cohorts and dichotomised into binary variables (0 = Presence of difficulties, 1 = Absence of difficulties). The 41 items used to generate healthy ageing scores included:

1. Difficulties with memory.
2. Dizzines problems when walking on a level surface.
3. Difficulties with orientation in time.
4. Walking speed (Low – Lower than the 25th percentile of the distribution; Moderate or high – Higher than the 25th percentile of the distribution).
5. Level of energy experienced at the time of the interview.
6. Sleeping problems.
7. Self-reported pain experienced at the time of the interview.
8. Loss of urine beyond control.
9. Difficulty for hearing.
10. Difficult for hearing what is said in a conversation.
11. Difficulties in eye sight using glasses or corrective lens as usual.
12. Difficulties for seeing things at a distance, using glasses or corrective lens as usual.
13. Difficulties for seeing things up close, using glasses or corrective lens as usual.
14. Difficulty for walking by yourself and without using any special equipment.
15. Difficulty for sitting for long periods.
16. Difficulty for getting up from sitting down.
17. Difficulty for climbing one or several flights of stairs.
18. Difficulty with stooping, kneeling, or crouching.
19. Difficulty for reaching or extending arms.
20. Difficulty pulling or pushing large objects.
21. Difficulty for lifting or carrying weights.
22. Difficulty for picking up things with fingers.
23. Difficulties for using the toilet (limitations in Activities of Daily Living).
24. Difficulties for bathing or showering (limitations in Activities of Daily Living).
25. Difficulty for getting dressed (limitations in Activities of Daily Living).
26. Difficulties for eating (limitations in Activities of Daily Living).
27. Difficulties for getting in or out of bed (limitations in Activities of Daily Living).

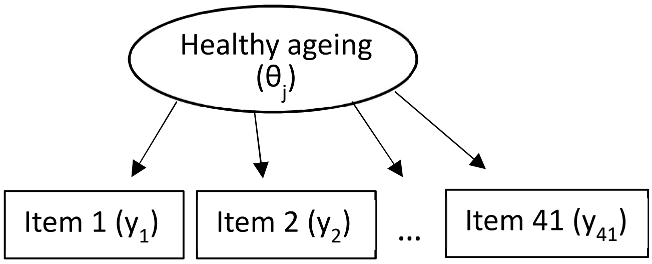
28. Difficulties for moving around the home (limitations in Activities of Daily Living).
29. Difficulties for doing housework (limitations in Instrumental Activities of Daily Living).
30. Difficulties for preparing meals (limitations in Instrumental Activities for Daily Living).
31. Difficulties for using telephone (limitations in Instrumental Activities of Daily Living)
32. Difficulties for taking medications (limitations in Instrumental Activities of Daily Living).
33. Difficulties for managing money (limitations in Instrumental Activities of Daily Living).
34. Difficulties for using a map (limitations in Instrumental Activities of Daily Living).
35. Difficulties for shopping for groceries (limitations in Instrumental Activities of Daily Living).
36. Difficulties for getting out of home (limitations in Instrumental Activities of Daily Living).
37. Immediate recall (Low – Lower than the 25th percentile of the distribution; Moderate or high – Higher than the 25th percentile of the distribution).
38. Verbal fluency (Low – Lower than the 25th percentile of the distribution; Moderate or high – Higher than the 25th percentile of the distribution).
39. Processing speed (Low – Lower than the 25th percentile of the distribution; Moderate or high – Higher than the 25th percentile of the distribution).
40. Delayed recall (Low – Lower than the 25th percentile of the distribution; Moderate or high – Higher than the 25th percentile of the distribution).
41. Numeracy (Low – Lower than the 25th percentile of the distribution; Moderate or high – Higher than the 25th percentile of the distribution).

Documentation of the ATHLOS harmonization can be accessed at: https://github.com/athlosproject/athlos-project.github.io.

(B) Statistical analyses

To generate a common measure for healthy ageing across cohort studies, the analysis focused on baseline data of all participants aged 18 years or above from 16 cohort studies (N=343915). Item response theory (IRT)[3,4] modelling was used to incorporate 41 items related to health, physical and cognitive functioning and estimate latent trait scores for individuals based on the unidimensionality assumption (Figure S1).

Figure S1. IRT modelling structure



Compared to traditional approach of calculating a total score, IRT models can take into account variation in response patterns and generate corresponding latent trait scores to reflect such variation.[5] A two parameter logistic IRT model was fitted to estimate the relationships between the underlying concept of healthy ageing (θ) for individual *j* (θ_j) and items ($y_1 \dots y_{41}$) using the following formula:

$$\text{logit}[\Pr(y_{ij}=1|\theta_j)]=a_i(\theta_j-b_i)$$

Given certain level of *θ*, the probability of absence of specific difficulty *i* was determined by two parameters: *a*, item discrimination, and *b,* item difficulty. The estimated latent trait score (*θ*) followed a normal distribution with a mean of 0 and a variance of 1. The model fitness was assessed using Root Mean Square Error of Approximation (RMSEA<0.06), Comparative Fit Index (CFI>0.95) and Tucker-Lewis index (TLI>0.95).[6]

To test measurement invariance across different cohort studies, a logistic regression framework was used to estimate differential item functioning (DIF)[7] and ensure the relationships between item and latent (*a*, *b*) were similar across cohorts. If DIF were detected, the Stocking-Lord Equating approach was carried out to rescale study-specific parameters so the estimated scores were comparable across cohorts.[8,9] To check validity of the healthy ageing scores, the analysis further investigated the associations between the scores, mortality and healthy life expectancy at the country level. The parameters estimated from the baseline data were applied to follow-up waves with the assumption of measurement invariance over time. Since the longitudinal analysis needs at least three waves of data, this study focused on the scores in the eight longitudinal cohorts. To improve interpretation of the results, the latent trait scores were transferred into a range between 0 and 100.

(C) Descriptive information

Descriptive information on the eight longitudinal cohorts is reported here. The mean score was 67·5 (standard deviation=17·8) and the median was 68·2 (interquartile range=26·5). Since most cohort studies had follow-up every two years, Figure S2 shows histograms of healthy ageing scores by every two years in the eight longitudinal cohorts. The distributions were slightly skewed to left. Most participants in the eight cohorts were generally healthy.

Figure S3 reports mean scores by age group and year of follow-up. The healthy ageing scores decreased with years of follow-up. At baseline (Year 0), the score differences became greater in older age groups and the gap remained apparent across follow-up period. This indicated the effect of age was not linear and a quadratic term should be included in the modelling of trajectories. Figure S4 shows mean scores by age group and sex. Within the same age groups, men generally had higher scores than women and the differences increased with older age. Figure S5 shows baseline mean scores by cohort studies and age group. Within the same age group, the mean score of the Japanese cohort (JSTAR) was higher than other cohort studies and lower scores were found in the Mexican cohort (MHAS).

Figure S2. Histograms of healthy ageing scores by years of follow-up in the eight longitudinal cohorts (Year 0, 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20)

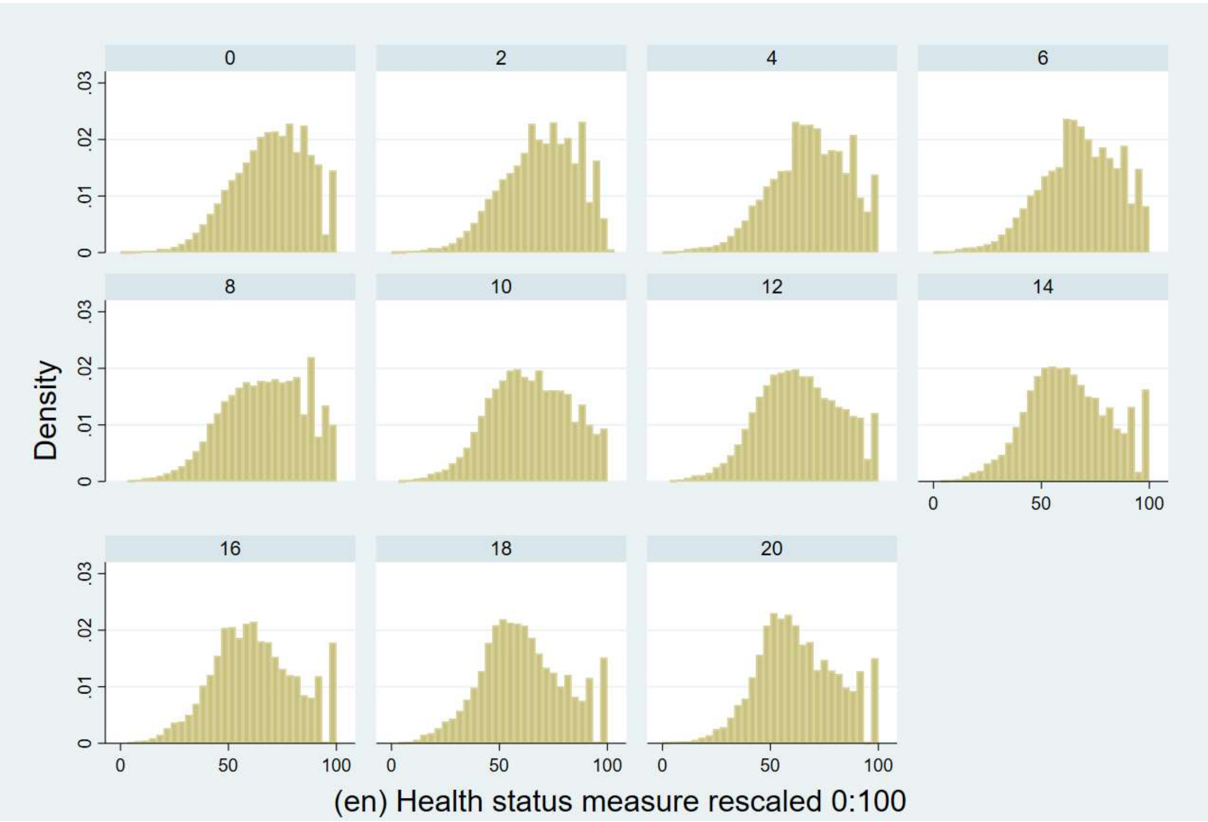


Figure S3. Mean scores by baseline age group over time

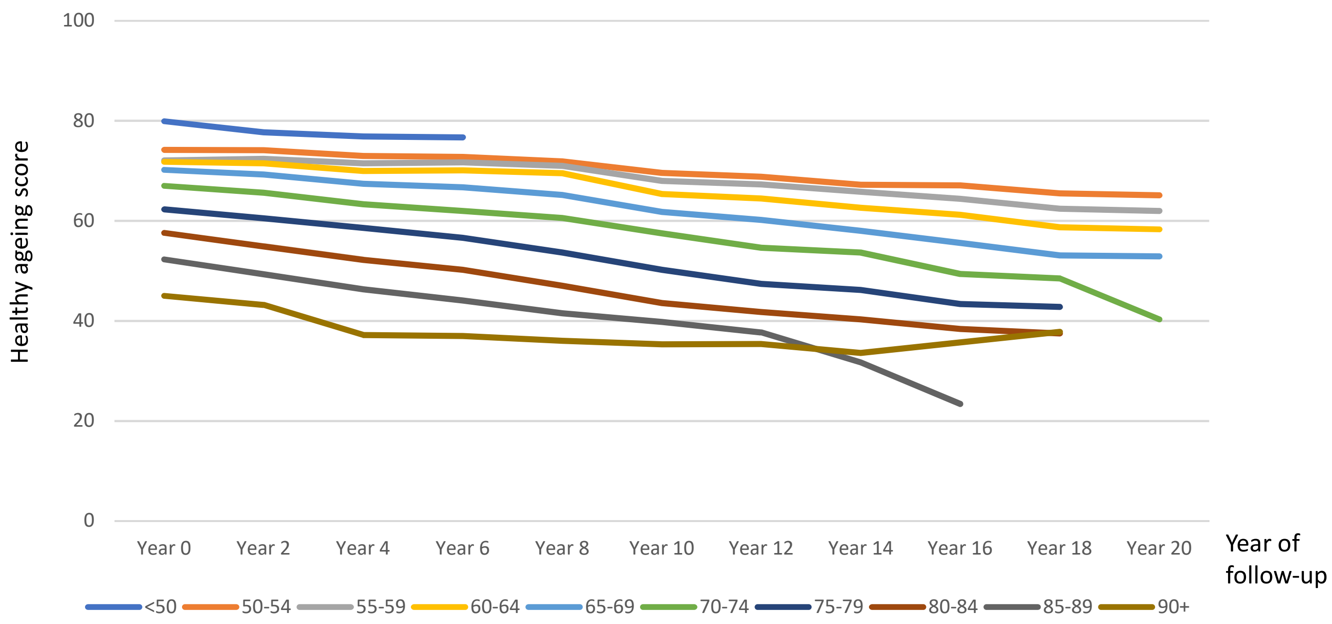


Figure S4. Mean scores by baseline age group and sex over time (m: men; f: women)

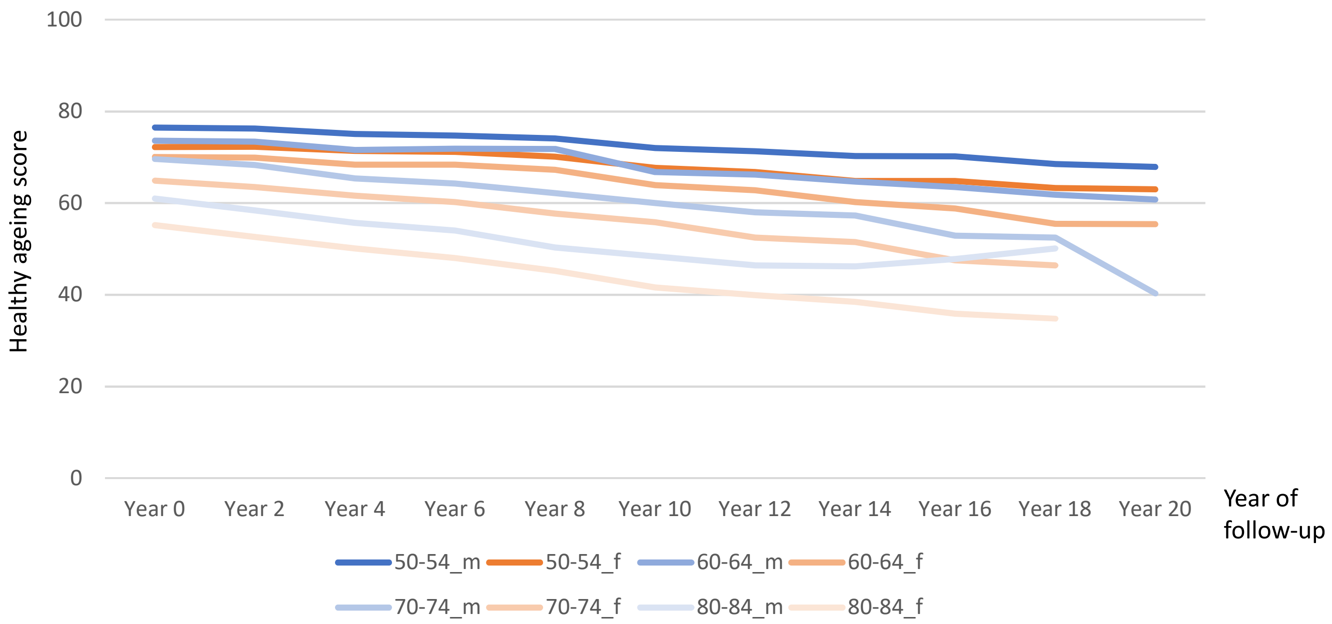
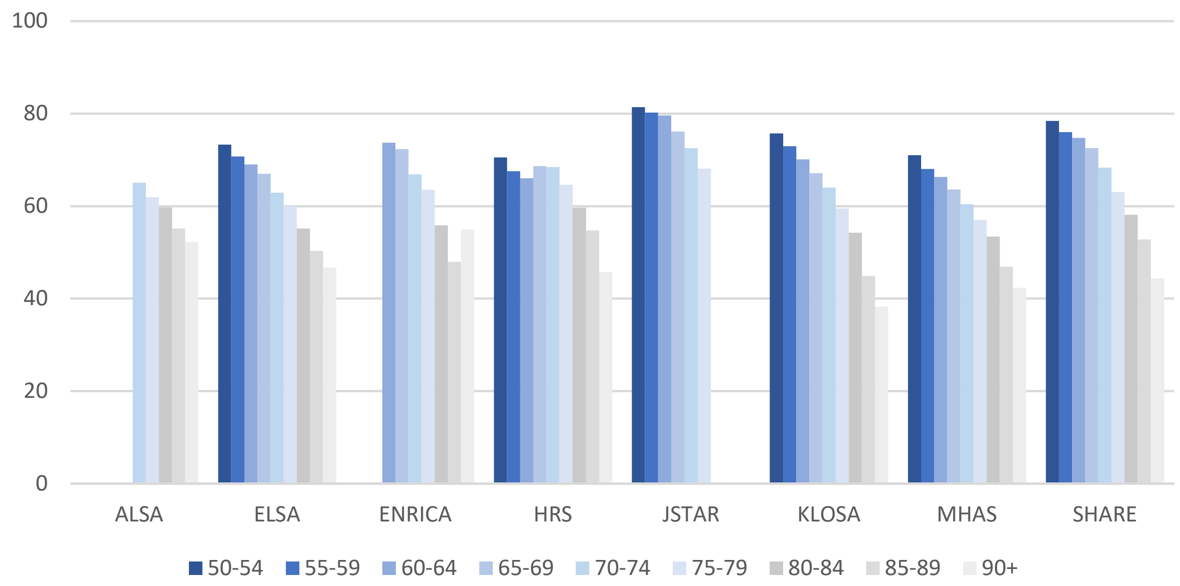


Figure S5. Baseline mean scores by cohort studies and age group (m: men; f: women)



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S3. Harmonisation of education and relative wealth variables

The ATHLOS research team has established a standardised process of harmonisation. Researchers in the collaboration reviewed relevant information from all included cohorts and identified appropriate measures for harmonisation of specific variables such as education and relative wealth. Table S1.1 and S1.2 report the original variables that were used in harmonisation of education and relative wealth in the eight longitudinal cohort studies. The Github links for R codes are also provided.

Table S1.1: Harmonisation of education

	Original variable name and label in the cohort	Link to harmonisation codes
ALSA	*TYPQUAL*: Highest qualification	https://github.com/athlosproject/athlos-project.github.io/blob/master/ALSA/1_Sociodemo_econom/5_education.Rmd
ELSA	*edqual*: Educational qualification	https://github.com/athlosproject/athlos-project.github.io/blob/master/ELSA/1_Sociodemo_econom/5_education.Rmd
ENRICA	*p61*: Maximum level of studies that have you completed	https://github.com/athlosproject/athlos-project.github.io/blob/master/ENRICA/1_Sociodemo_econom/5_education.Rmd
HRS	*RAEDUC*: Respondent education (category)	https://github.com/athlosproject/athlos-project.github.io/blob/master/HRS/1_Sociodemo_econom/5_education.Rmd
JSTAR	*a_002_a*: Highest school	https://github.com/athlosproject/athlos-project.github.io/blob/master/JSTAR/1_Sociodemo_econom/5_education.Rmd
KLOSA	*w01A003*: Education background	https://github.com/athlosproject/athlos-project.github.io/blob/master/KLOSA/1_Sociodemo_econom/5_education.Rmd
MHAS	*a3_1*: Level of education	https://github.com/athlosproject/athlos-project.github.io/blob/master/MHAS/1_Sociodemo_econom/5_education.Rmd
SHARE	*isced_r*: ISCED-97 coding of education	https://github.com/athlosproject/athlos-project.github.io/blob/master/SHARE/1_Sociodemo_econom/5_education.Rmd

Table S1.2: Harmonisation of relative wealth

	Variable name in the original cohort: label	Link to harmonisation codes
ALSA	*TTLINCYR*: Total gross income	https://github.com/athlosproject/athlos-project.github.io/blob/master/ALSA/1_Sociodemo_econom/13_Wealth.Rmd
ELSA	*yq5_bu_s*: Quintiles of benefit unit equivalised income	https://github.com/athlosproject/athlos-project.github.io/blob/master/ELSA/1_Sociodemo_econom/13_Wealth.Rmd
ENRICA		
HRS	*H1ITOT*: Total HHold (respondent and spouse)	https://github.com/athlosproject/athlos-project.github.io/blob/master/HRS/1_Sociodemo_econom/13_Wealth.Rmd
JSTAR	*e_013_1*: Net income bracket	https://github.com/athlosproject/athlos-project.github.io/blob/master/JSTAR/1_Sociodemo_econom/13_Wealth.Rmd
KLOSA	*w01E126*: Total income last year	https://github.com/athlosproject/athlos-project.github.io/blob/master/KLOSA/1_Sociodemo_econom/13_Wealth.Rmd
MHAS	*K8_1, K9A1, K9B1, K9C1, K8_2, K9A2, K9B2, K9C2, K11_1, K12A1, K12B1, K12C1, K11_2, K12A2, K12B2, K12C2, K22_1, K23A1, K23B1, K23C1, K22_2, K23A2, K23B2, K23C2, K31_3, K32A3, K32B3, K32C3, K34_3, K35A3, K35B3, K35C3, K40, K41A, K41B, K41C, K42, K45a_3, K45b_3, K45c_3, K44A_1, K44B1, K44B2, K44B3, K45A_1, K45B1, K45B2, K45B3, K47A_1, K47B1, K47B2, K47B3, K48A_1, K48B1, K48B2, K48B3, K50A_1, K51B1, K51B2, K51B3, K53A_1, K53B1, K53B2, K53B3, K54A_1, K54B1, K54B2, K54B3, K58_1, K59A1, K59B1, K59C1, K58_2, K59A2, K59B2, K59C2, K58_3, K59A3, K59B3, K59C3, K58_4, K59A4, K59B4, K59C4, K64_1, K65A1, K65B1, K65C1, K64_2, K65A2, K65B2, K65C2, K64_3, K65A3, K65B3, K65C3, K64_4, K65A4, K65B4, K65C4, K77_1, K77_2, K80_1, K80_2, K83e, K80c, K25_1, K26A1, K26B1, K26C1, K25_2, K26A2, K26B2, K26C2, K31_1, K32A1, K32B1, K32C1,*	https://github.com/athlosproject/athlos-project.github.io/blob/master/MHAS/1_Sociodemo_econom/13_Wealth.Rmd

	K34_1, K35A1, K35B1, K35C1, K31_2, K32A2, K32B2, K32C2, K34_2, K35A2, K35B2, K35C2, K51A_1, K51B1, K51B2, K51B3	
SHARE	*income_pct_w1*: household income percentiles	https://github.com/athlosproject/athlos-project.github.io/blob/master/SHARE/1_Sociodemo_econom/13_Wealth.Rmd

S4. Additional results

(A) Cohort study

Table S2: Results of models including cohort studies (adjusted for age and gender)

	Model 1	Model 2
	Coeff. (95% CI)	Coeff. (95% CI)
Baseline scores	63·37 (63·17, 63·57)	63·95 (63·74, 64·15)
HRS	Reference	Reference
ALSA	2·02 (1·38, 2·67)	0·95 (0·27, 1·62)
ELSA	0·31 (0·05, 0·58)	-0·72 (-1·00, -0·44)
ENRICA	4·67 (4·11, 5·24)	2·89 (2·26, 3·52)
JSTAR	8·98 (8·55, 9·40)	8·38 (7·92, 8·83)
KLOSA	2·17 (1·87, 2·48)	1·27 (0·94, 1·60)
MHAS	-2·62 (-2·90, -2·34)	-2·85 (-3·15, -2·56)
SHARE	4·88 (4·69, 5·07)	3·99 (3·79, 4·19)
Decline rates	-1·07 (-1·09, -1·05)	-1·26 (-1·28, -1·24)
HRS		Reference
ALSA		0·41 (0·32, 0·49)
ELSA		0·33 (0·30, 0·36)
ENRICA		0·57 (0·48, 0·66)
JSTAR		0·23 (0·11, 0·36)
KLOSA		0·32 (0·27, 0·37)
MHAS		0·06 (0·03, 0·09)
SHARE		0·36 (0·33, 0·39)
Variance		
Intercept	169·33 (167·69, 170·99)	168·73 (167·10, 170·38)
Slope	0·79 (0·76, 0·81)	0·76 (0·74, 0·78)
Covariance	-2·30 (-2·46, -2·14)	-2·14 (-2·29, -1·98)
Residual	83·49 (83·05, 83·94)	83·46 (83·02, 83·90)
Goodness of fit		
BIC	3846028	3845106

ALSA: Australian Longitudinal Study of Ageing; ELSA: English Longitudinal Study of Ageing; HRS: Health and Retirement Study (HRS); JSTAR: Japanese Study of Ageing and Retirement; KLOSA; Korean Longitudinal Study of Ageing; MHAS: Mexican Health and Ageing Study; SHARE: Survey of Health Ageing and Retirement in Europe

(B) Education and relative wealth

Table S3: Numbers and percentage of education and relative wealth levels in follow-up waves

	Education			Wealth				
wave	Low	Middle	High	Q1	Q2	Q3	Q4	Q5
1	48813	66895	22717	27640	26826	26824	26000	26886
	(35·3)	(48·3)	(16·4)	(20·6)	(20·0)	(20·0)	(19·4)	(20·0)
2	48813	66895	22717	27640	26826	26824	26000	26886
	(35·3)	(48·3)	(16·4)	(20·6)	(20·0)	(20·0)	(19·4)	(20·0)
3	37884	42158	14372	18370	17855	18232	17533	18365
	(40·1)	(44·7)	(15·2)	(20·3)	(19·8)	(20·2)	(19·4)	(20·3)
4	19852	31316	10623	12091	12238	12646	12163	12972
	(32·1)	(50·7)	(17·2)	(19·5)	(19·7)	(20·4)	(19·6)	(20·9)
5	11625	20637	7219	7661	7917	7770	8004	8558
	(29·4)	(52·3)	(18·3)	(19·2)	(19·8)	(19·5)	(20·1)	(21·4)
6	7464	13676	4189	4766	5019	4957	5202	5774
	(29·5)	(54·0)	(16·5)	(18·5)	(19·5)	(19·3)	(20·2)	(22·5)
7	6197	12271	3814	4021	4334	4350	4676	5198
	(27·8)	(55·1)	(17·1)	(17·8)	(19·2)	(19·3)	(20·7)	(23·0)
8	4352	9416	2950	3038	3363	3260	3396	3711
	(26·0)	(56·3)	(17·7)	(18·1)	(20·1)	(19·5)	(20·3)	(22·1)
9	3337	6811	2009	2138	2457	2381	2483	2736
	(27·5)	(56·0)	(16·5)	(17·5)	(20·2)	(19·5)	(20·4)	(22·4)
10	2857	6155	1850	1867	2174	2140	2241	2472
	(26·3)	(56·7)	(17·0)	(17·1)	(20·0)	(19·6)	(20·6)	(22·7)
11+	2191	5184	1536	1636	1995	1669	1708	1968
	(24·6)	(58·2)	(17·2)	(18·2)	(22·2)	(18·6)	(19·0)	(21·9)

Table S4: Results of model including both education and relative wealth (adjusted for age and sex)

	ALSA	ELSA	HRS	JSTAR	KLOSA	MHAS	SHARE
Education							
Low	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Middle	1·51	4·42	4·02	3·94	3·42	4·87	5·27
	(0·15, 2·86)	(3·91, 4·94)	(3·67, 4·37)	(2·73, 5·15)	(2·84, 4·00)	(4·22, 5·53)	(4·99, 5·54)
High	2·17	7·67	8·42	4·15	4·65	7·99	9·22
	(-0·78, 5·12)	(6·93, 8·40)	(7·95, 8·89)	(2·41, 5·90)	(3·72, 5·57)	(6·96, 9·03)	(8·87, 9·57)
Wealth							
Q1 (least affluent)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Q2	-0·54	-0·11	5·23	0·99	0·48	0·31	1·11
	(-1·96, 0·89)	(-0·86, 0·63)	(4·79, 5·68)	(-0·62, 2·59)	(-0·33, 1·30)	(-0·41, 1·02)	(0·75, 1·46)
Q3	-2·49	1·45	8·12	1·69	0·93	0·83	1·96
	(-9·84, 4·85)	(0·71, 2·19)	(7·67, 8·58)	(0·13, 3·24)	(0·15, 1·71)	(0·11, 1·54)	(1·60, 2·32)
Q4	7·31	4·20	10·71	2·42	2·19	1·81	3·43
	(-0·31, 14·93)	(3·46, 4·94)	(10·25, 11·18)	(0·73, 4·12)	(1·31, 3·07)	(1·08, 2·53)	(3·06, 3·79)
Q5 (most affluent)	0·19	6·94	12·79	2·70	3·90	2·54	4·75
	(-1·64, 2·02)	(6·19, 7·70)	(12·31, 13·28)	(1·07, 4·33)	(3·03, 4·78)	(1·78, 3·29)	(4·38, 5·12)

ALSA: Australian Longitudinal Study of Ageing; ELSA: English Longitudinal Study of Ageing; HRS: Health and Retirement Study (HRS); JSTAR: Japanese Study of Ageing and Retirement; KLOSA; Korean Longitudinal Study of Ageing; MHAS: Mexican Health and Ageing Study; SHARE: Survey of Health Ageing and Retirement in Europe

Table S5: The effects of education and relative wealth on women and men (adjusted for age and study)

	Education		Wealth	
	Women	Men	Women	Men
Education				
Low	Reference	Reference		
Middle	6·64 (6·42, 6·86)	5·65 (5·40, 5·90)		
High	11·27 (10·95, 11·59)	10·92 (10·60, 11·23)		
Wealth				
Q1 (least affluent)			Reference	Reference
Q2			2·51 (2·21, 2·81)	2·05 (1·67, 2·43)
Q3			4·13 (3·82, 4·45)	4·40 (4·03, 4·77)
Q4			6·56 (6·24, 6·89)	6·92 (6·56, 7·29)
Q5 (most affluent)			8·91 (8·58, 9·23)	9·51 (9·14, 9·87)

(C) Chronic diseases

This analysis focused on five types of harmonised chronic diseases at baseline: cardiovascular diseases (14.6% participants with the condition), hypertension (36.1%), diabetes (11.9%), chronic respiratory diseases (7.3%) and joint disorders (26.5%). Cardiovascular diseases included any of the following conditions: angina, stroke, myocardial infarction, heart attack, coronary heart disease, congestive heart failure, heart murmur, valve disease or cerebral vascular disease. Chronic respiratory diseases included asthma, emphysema, chronic pulmonary disease, chronic obstructive pulmonary disease or chronic bronchitis. Joint disorders included arthritis, rheumatism or osteoarthritis. The five chronic diseases were added to the models including demographic (age, sex, cohort study) and socioeconomic factors (education or wealth) to investigate whether these chronic diseases could explain the associations between education, relative wealth and healthy ageing scores. The results are reported in Table S6 (education) and Table S7 (relative wealth). Although all chronic diseases were found to be associated with lower healthy ageing scores at baseline, the effect sizes of education and relative wealth remained similar when adding different chronic diseases. This indicated that inequalities across education and relative wealth could not be explained by these chronic diseases.

Table S6: The impact of chronic diseases on health inequalities across education

	Education	*+Cardiovascular diseases*	*+Hypertension*	*+Diabetes*	*+Chronic respiratory diseases*	*+Joint disorders*
	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)
Baseline score	60·18 (59·96, 60·41)	62·61 (62·38, 62·83)	62·75 (62·52, 62·99)	61·58 (61·34, 61·82)	60·89 (60·66, 61·11)	65·18 (64·96, 65·41)
Education						
Middle vs Low	5·66 (5·49, 5·83)	5·55 (5·38, 5·72)	5·59 (5·42, 5·77)	5·62 (5·43, 5·81)	5·52 (5·35, 5·70)	5·03 (4·86, 5·20)
High vs Low	10·54 (10·31, 10·77)	10·17 (9·95, 10·40)	10·31 (10·08, 10·54)	10·45 (10·19, 10·71)	10·35 (10·12, 10·57)	9·62 (9·41, 9·84)
Specific chronic condition						
Yes vs No		-9·69 (-9·91, -9·47)	-4·83 (-4·99, -4·67)	-7·42 (-7·67, -7·17)	-8·60 (-8·89, -8·31)	-10·73 (-10·91, -10·56)
Decline rate (by year of follow-up)	-1·26 (-1·28, -1·24)	-1·29 (-1·32, -1·27)	-1·26 (-1·29, -1·24)	-1·25 (-1·28, -1·23)	-1·27 (-1·29, -1·25)	-1·38 (-1·40, -1·35)
Specific chronic condition						
Yes vs No		0·13 (0.10, 0.16)	0·00 (-0·02, 0·03)	-0·15 (-0·19, -0·12)	0·14 (0·10, 0·18)	0·31 (0·28, 0·33)
Goodness of fit						
BIC	3778816	3673166	3736997	3245326	3738391	3727416

All models were adjusted for age, sex and study. Cardiovascular diseases: angina, stroke, myocardial infarction, heart attack, coronary heart disease, congestive heart failure, heart murmur, valve disease, cerebral vascular disease; Chronic respiratory diseases: asthma, emphysema, chronic pulmonary disease, chronic obstructive pulmonary disease or chronic bronchitis; Joint disorders: arthritis, rheumatism or osteoarthritis

Table S7: The impact of chronic diseases on health inequalities across relative wealth quintiles

	Relative wealth	*+Cardiovascular diseases*	*+Hypertension*	*+Diabetes*	*+Chronic respiratory diseases*	*+Joint disorders*
	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)
Baseline score	60·53 (60·28, 60·77)	63·01 (62·76, 63·26)	63·18 (62·93, 63·44)	61·59 (61·32, 61·86)	61·23 (60·99, 61·48)	65·18 (64·96, 65·41)
Relative wealth						
Q2 vs Q1	2·24 (2·00, 2·47)	2·18 (1·95, 2·41)	2·21 (1·97, 2·44)	2·39 (2.13, 2·66)	2·19 (1·96, 2·43)	2·13 (1·90, 2·35)
Q3 vs Q1	4·13 (3·89, 4·36)	3·95 (3·71, 4·18)	4·08 (3·85, 4·31)	4·55 (4·28, 4·81)	4·04 (3·81, 4·28)	3·82 (3·60, 4·05)
Q4 vs Q1	6·55 (6·32, 6·79)	6·21 (5·97, 6·44)	6·42 (6·19, 6·66)	7.02 (6·75, 7·29)	6·42 (6·18, 6·66)	5·95 (5·72, 6·18)
Q5 vs Q1	8·98 (8·74, 9·22)	8·52 (8·28, 8·75)	8·74 (8·50, 8·98)	9·41 (9·14, 9·68)	8·76 (8·53, 9·00)	8·22 (7·99, 8·44)
Specific chronic condition						
Yes vs No		-9·69 (-9·91, -9·47)	-4·92 (-5.09, -4·76)	-7·44 (-7·69, -7·18)	-8·70 (-8·99, -8·40)	-10·91 (-11·09, -10·74)
Decline rate (by year of follow-up)	-1·27 (-1·29, -1·24)	-1·30 (-1·32, -1·28)	-1·27 (-1·29, -1·25)	-1·26 (-1·28, -1·24)	-1·28 (-1·30, -1·26)	-1·38 (-1·41, -1·36)
Specific chronic condition						
Yes vs No		0·13 (0.10, 0.16)	0·00 (-0·02, 0·03)	-0·16 (-0·20, -0·12)	0·15 (0·11, 0·20)	0·31 (0·29, 0·34)
Goodness of fit						
BIC	3703900	3603596	3736997	3170443	3668617	3657537

All models were adjusted for age, sex and study. Cardiovascular diseases: angina, stroke, myocardial infarction, heart attack, coronary heart disease, congestive heart failure, heart murmur, valve disease, cerebral vascular disease; Chronic respiratory diseases: asthma, emphysema, chronic pulmonary disease, chronic obstructive pulmonary disease or chronic bronchitis; Joint disorders: arthritis, rheumatism or osteoarthritis

(D) Birth cohort

Among all birth cohorts, a greater difference was found between 1940-1949 and 1930-1939 (Table S8). This cut-off also corresponds to World War II and therefore the birth cohort were combined into two groups: post-war (after 1940) and pre-war (before 1939).

The effect of birth cohort on baseline and slope of healthy ageing scores was small when adjusting for age, gender and study (Table S9). Absolute level of education can change over generations while relative wealth should be stable across birth cohorts. Thus, this analysis only focused on education and their interactions with birth cohorts. The interaction terms between education and birth cohort indicate limited difference between post- and pre-war birth cohorts.

Table S8: Mean and standard deviation of the healthy ageing scores by baseline age group and birth cohort

	Birth cohort					
Age group (years)	Post 1950	1940-1949	1930-1939	1920-1929	1910-1919	Pre 1909
45-49	79·9 (13·5)					
50-54	76·0 (15·3)	70·9 (16·1)	67·1 (16·6)			
55-59	73·7 (16·0)	73·1 (15·2)	65·7 (17·0)			
60-64	73·7 (16·2)	73·3 (14·9)	66·7 (16·3)	66·0 (16·7)		
65-69		72·2 (14·9)	69·1 (15·5)	68·4 (17·0)		
70-74		69·5 (16·6)	67·2 (15·8)	66·3 (17·2)	67·0 (16·7)	
75-79			62·6 (16·3)	61·2 (16·4)	64·1 (16·6)	
80-84			60·0 (15·8)	57·0 (16·6)	58·1 (16·6)	57·7 (15·7)
85-89				52·4 (17·2)	50·2 (16·8)	54·7 (15·6)
90+				47·3 (15·6)	44·7 (16·3)	45·0 (16·6)

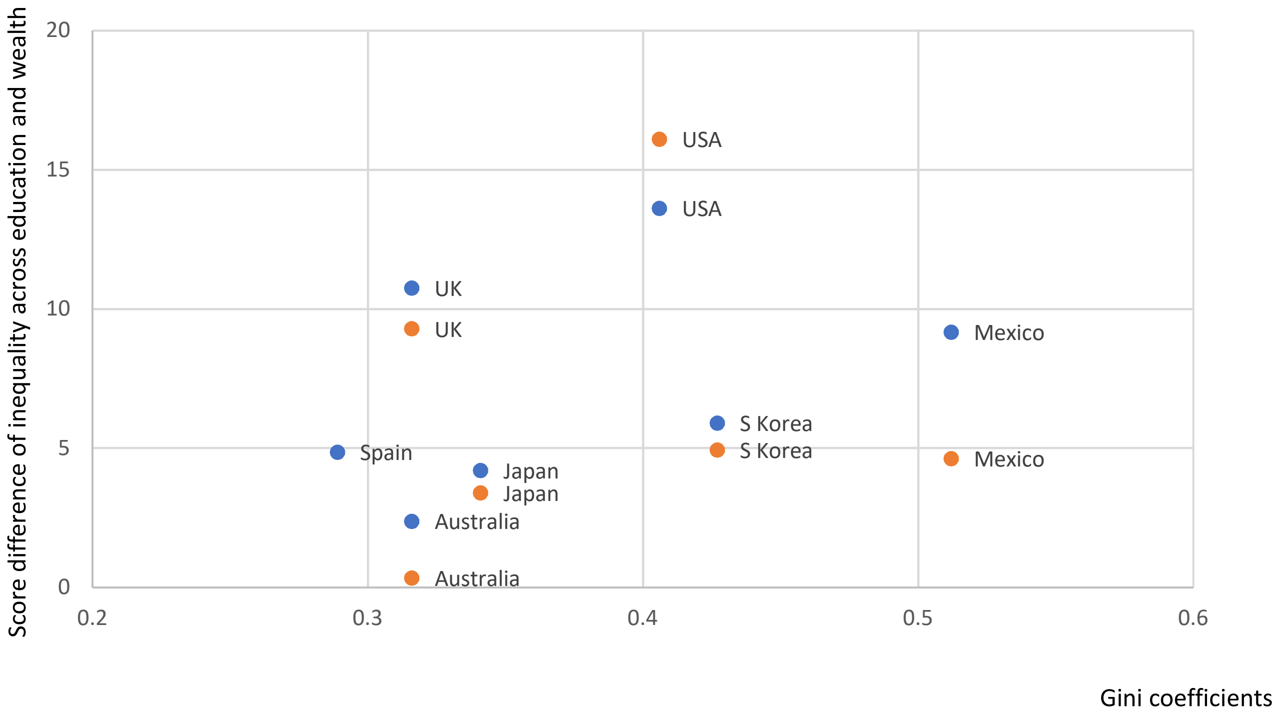
Table S9. The effect of birth cohort and education on trajectories of healthy ageing

	Model 1	Model 2	Model 3
	Coeff. (95% CI)	Coeff. (95% CI)	Coeff. (95% CI)
Baseline score	60·06 (59·74, 60·38)	60·38 (60·04, 60·70)	59·92 (59·58, 60·26)
Education			
Middle vs Low	5·66 (5·49, 5·83)	5·66 (5·49, 5·84)	5·73 (5·49, 5·97)
High vs Low	10·54 (10·31, 10·77)	10·55 (10·32, 10·77)	11·05 (10·75, 11·34)
Birth cohort			
Pre- vs post-war	0·13 (-0·10, 0·36)	-0·16 (-0·41, 0·08)	0·35 (0·05, 0·66)
Interaction terms			
Pre-war*Middle			-0·03 (-0·36, 0·30)
Pre-war*High			-1·36 (-1·82, -0·91)
Decline rate			
(by year of follow-up)	-1·26 (-1·28, -1·24)	-1·28 (-1·31, -1·25)	-1·26 (-1·28, -1·24)
Birth cohort			
Pre- vs post-war		0·12 (0·09, 0·15)	
Goodness of fit			
BIC	3778828	3778791	3778814

(E) Gini coefficient and inequality

To contextualise the inequality findings, Gini coefficients for population aged 65 or above in Australia, UK, Spain, USA, Japan, South Korea and Mexico were obtained from the OECD database (https://data.oecd.org/). Figure S6 shows Gini coefficients by countries in relation to the effect sizes of education (high vs low) and relative wealth (Q5 vs Q1) across the eight cohort studies. No clear patterns were observed.

Figure S6. Scatter plot of Gini coefficients (0: no inequality; 1: high inequality) and effect sizes of inequalities across education (blue; baseline difference between high and low) and wealth (orange; baseline difference between Q5 and Q1)



S5. Sensitivity analyses

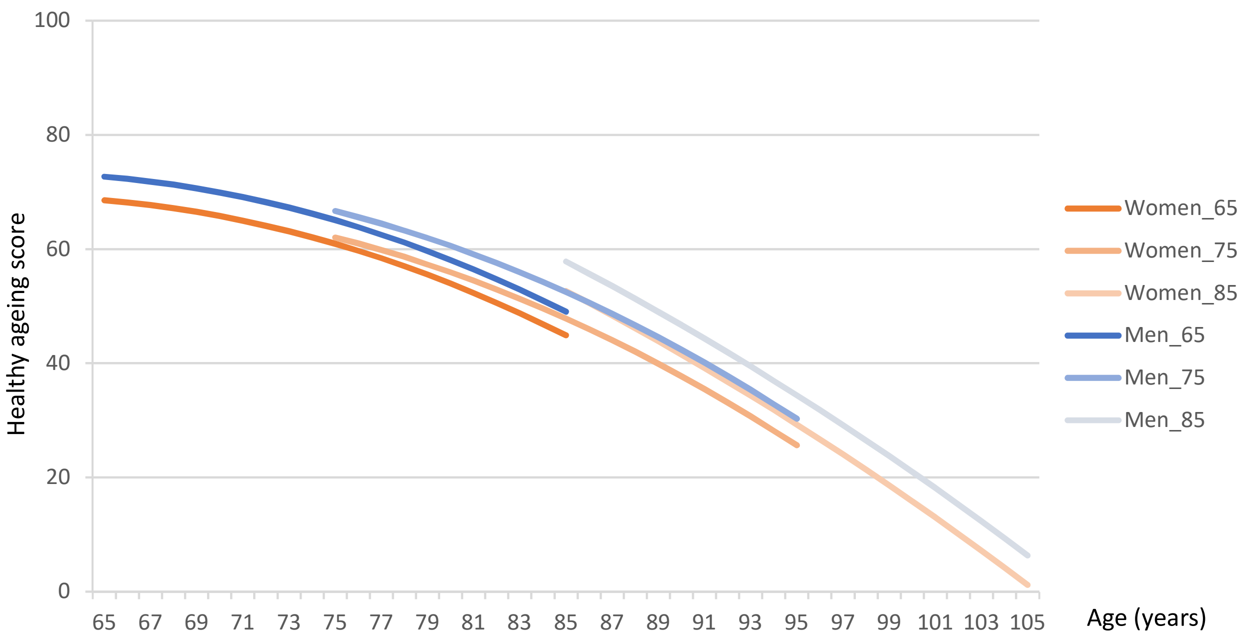
(A) Quadratic model

Table S10: Random effect models including quadratic terms of follow-up years

	Model 1	Model 2	Model 3
	Coeff (95% CI)	Coeff (95% CI)	Coeff (95% CI)
Baseline score	67·68 (67·56, 67·80)	65·64 (65·49, 65·78)	65·58 (65·43, 65·73)
Age (years, at baseline)	-0·64 (-0·65, -0·63)	-0·65 (-0·66, -0·64)	-0·65 (-0·66, -0·64)
Age^2	-0·01 (-0·02, -0·01)	-0·01 (-0·01, -0·01)	-0·01 (-0·01, -0·01)
Sex (men vs women)		4·45 (4·26, 4·63)	4·52 (4·33, 4·70)
Age*sex		0·05 (0·04, 0·07)	0·05 (0·04, 0·07)
Decline rate (by year of follow-up)	-0·63 (-0·65, -0·61)	-0·63 (-0·66, -0·60)	-0·58 (-0·62, -0·55)
Age (years, at baseline)	-0·07 (-0·07, -0·07)	-0·07 (-0·07, -0·06)	-0·07 (-0·07, -0·07)
Age^2	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)
Sex (men vs women)			-0·10 (-0·14, -0·06)
Changes in decline rate over time	-0·04 (-0·05, -0·04)	-0·04 (-0·05, -0·04)	-0·05 (-0·05, -0·04)
Age (years, at baseline)	0·00 (0·00· 0·00)	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)
Age^2	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)
Sex (men vs women)			0·01 (0·00, 0·01)
Variance			
Constant	179·63 (177·83, 181·45)	175·21 (173·44, 176·99)	175·19 (173·42, 176·97)
Slope	2·80 (2·71, 2·90)	2·80 (2·71, 2·90)	2·80 (2·70, 2·90)
Quadratic	0·01 (0·01, 0·01)	0·01 (0·01, 0·01)	0·01 (0·01, 0·01)
Cov (cons, slope)	-2·24 (-2·58, -1·90)	-2·17 (-2·51, -1·83)	-2·15 (-2·49, -1·81)
Cov (cons, Q)	-0·08 (-0·11, -0·06)	-0·09 (-0·11, -0·07)	-0·09 (-0·11, -0·07)
Cov (slope, Q)	-0·12 (-0·12, -0·11)	-0·12 (-0·12, -0·11)	-0·12 (-0·12, -0·11)
Residual	77·34 (76·79, 77·78)	77·36 (76·92, 77·80)	77·36 (76·92, 77·80)
Goodness of fit			
BIC	3847143	3844345	3844348

Figure S7: Estimated healthy ageing scores by baseline age

Figure S8: Estimated healthy ageing scores over time by age and sex



(B) Joint models including longitudinal and mortality data

Table S11: Results of joint models including longitudinal data on healthy ageing scores and mortality

	Model 1	Model 2
Longitudinal	Coeff. (95% CI)	Coeff. (95% CI)
Baseline score	68·26 (68·14, 68·37)	66·22 (66·08, 66·37)
Age (years, at baseline)	-0·65 (-0·65, -0·64)	-0·65 (-0·66, -0·64)
Age^2	-0·02 (-0·02, -0·01)	-0·01 (-0·02, -0·01)
Sex (men vs women)		4·33 (4·14, 4·51)
Age*sex		0·04 (0·02, 0·05)
Decline rate (by year of follow-up)	-1·24 (-1·25, -1·22)	-1·21 (-1·23, -1·19)
Age (years, at baseline)	-0·07 (-0·07, -0·07)	-0·07 (-0·07, -0·07)
Age^2	0·00 (0·00, 0·00)	0·00 (0·00, 0·00)
Sex (men vs women)		-0·05 (-0·07, -0·03)
Survival	HR (95% CI)	HR (95% CI)
Baseline score	0·96 (0·96, 0·96)	0·96 (0·95, 0·96)
Year of follow-up	0·58 (0·56, 0·59)	0·57 (0·55, 0·58)
Baseline age	1·11 (1·11, 1·11)	1·11 (1·11, 1·11)
Sex (men vs women)		1·48 (1·44, 1·52)