Education and wealth inequalities in healthy ageing in eight harmonised cohorts in the ATHLOS consortium: a population-based study

Yu-Tzu Wu, Christina Daskalopoulou, Graciela Muniz Terrera, Albert Sanchez Niubo, Fernando Rodríguez-Artalejo, Jose Luis Ayuso-Mateos, Martin Bobak, Francisco Félix Caballero, Javier de la Fuente, Alejandro de la Torre-Luque, Esther García-Esquinas, Jose Maria Haro, Seppo Koskinen, Ilona Koupil, Matilde Leonardi, Andrzej Pajak, Demosthenes Panagiotakos, Denes Stefler, Beata Tobias-Adamczyk, Martin Prince, A Matthew Prina, on behalf of the ATHLOS consortium

Summary

Background The rapid growth of the size of the older population is having a substantial effect 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 was to investigate trajectories of healthy ageing in older men and women (aged ≥45 years) and the effect of education and wealth on these trajectories.

Methods This population-based study is based on eight longitudinal cohorts from Australia, the USA, Japan, South Korea, Mexico, and Europe harmonised by the EU Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) consortium. We selected these studies from the repository of 17 ageing studies in the ATHLOS consortium because they reported at least three waves of collected data. We used multilevel modelling to investigate the effect 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), after adjustment for age, sex, and cohort study.

Findings We used data from 141 214 participants, with a mean age of 62·9 years (SD 10·1) and an age range of 45–106 years, of whom 76 484 (54·2%) were women. The earliest year of baseline data was 1992 and the most recent last follow-up year was 2015. Education and wealth affected baseline scores of healthy ageing but had little effect on the rate of decrease in healthy ageing score thereafter. Compared with those with primary education or less, participants with tertiary education had higher baseline scores (adjusted difference in score of 10·54 points, 95% CI 10·31–10·77). The adjusted difference in healthy ageing score 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 for both education and wealth was found in the Health Retirement Study from the USA.

Interpretation The apparent difference in baseline healthy ageing scores between those with high versus low education levels and wealth 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, but no further increase in ageing disparity after age 70 years. Future research should adopt a lifecourse approach to investigate mechanisms of health inequalities across education and wealth in different societies.

Funding European Union Horizon 2020 Research and Innovation Programme.

Lancet Public Health 2020; 5: e386–94

See **Comment** page e364

Social Epidemiology Research Group, Health Service and Population Research Department, Institute of Psychiatry, Psychology and Neuroscience (Y-T Wu PhD, C Daskalopoulou PhD, A M Prina PhD) **and Global Health Institute** (Prof M Prince MD, Prof A M Prina), **King's College London, London, UK; Centre for Clinical Brain Sciences, University of Edinburgh, Edinburgh, UK** (G Muniz Terrera PhD); **Parc Sanitari Sant Joan de Déu, Barcelona, Spain** (A Sanchez Niubo PhD, Prof J M Haro PhD); **Centro de Investigación Biomédica en Red de Salud Mental, CIBERSAM, Madrid, Spain** (A Sanchez Niubo, Prof J M Haro); **Department of Preventive Medicine and Public Health, Universidad Autónoma de Madrid/Idipaz, Madrid, Spain** (Prof F Rodríguez-Artalejo MD, Prof F F Caballero PhD, E García-Esquinas PhD); **Centro de Investigación Biomédica en Red de Epidemiología y Salud Pública, Madrid, Spain** (Prof F Rodríguez-Artalejo, Prof F F Caballero, E García-Esquinas); **IMDEA-Food Institute, Campus of International Excellence, Universidad Autónoma de Madrid, Consejo Superior de Investigaciones Científicas, Madrid, Spain** (Prof F Rodríguez-Artalejo); **Centro de Investigación Biomédica en Red de Salud Mental, Madrid, Spain** (Prof J L Ayuso-Mateos PhD, J de la Fuente MSc, A de la Torre-Luque PhD); **Department of Psychiatry, Universidad Autónoma de Madrid, Madrid, Spain**

Introduction

Due to a decrease in health status and an increase in non-communicable diseases, disability, and care dependence in later life, the rapid growth of the size of the older population is at present set to increase the burden on already stretched health and social care services.[1] To address the potential effect of population ageing, the concept of healthy ageing, defined by 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; learn, grow, and make decisions; be mobile; build and maintain relationships; and contribute to society. This concept is made up of the interaction between intrinsic capacity, which combines all of an individual's physical, mental, and 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 might support health and functioning in later life. By contrast, traditional concepts in medical research (such as frailty, accumulated deficits,

(Prof J L Ayuso-Mateos, J de la Fuente, A de la Torre-Luque); **Hospital Universitario de La Princesa, Instituto de Investigación Sanitaria Princesa (IIS Princesa), Madrid, Spain** (Prof J L Ayuso-Mateos, J de la Fuente, A de la Torre-Luque); **Department of Epidemiology and Public Health, University College London, London, UK** (Prof M Bobak PhD, D Stefler PhD); **National Institute for Health and Welfare (THL), Helsinki, Finland** (Prof S Koskinen PhD); **Centre for Health Equity Studies, Department of Public Health Sciences, Stockholm University, Stockholm, Sweden** (Prof I Koupil MD); **Department of Global Public Health, Karolinska Institutet, Stockholm, Sweden** (Prof I Koupil); **Fondazione IRCCS Istituto Neurologico Carlo Besta, Milan, Italy** (Prof M Leonardi MD); **Department of Epidemiology and Population Studies, Faculty of Health Sciences Jagienllonian University Medical College, Krakow, Poland** (Prof A Pajak PhD); **Harokopio University, Kallithea, Athens, Greece** (Prof D Panagiotakos PhD); **and Department of Medical Sociology, Chair of Epidemiology and Preventive Medicine, Jagiellonian University Medical College, Krakow, Poland** (B Tobias-Adamczyk PhD)

Correspondence to: Dr A Matthew Prina, Social Epidemiology Research Group, Health Service and Population Research Department, Institute of Psychiatry, Psychology & Neuroscience, King's College London, London SE5 8AF, UK
matthew.prina@kcl.ac.uk

For **documentation of ATHLOS project processes** see https://github.com/athlosproject/athlos-project.github.io

Research in context

Evidence before this study

To summarise evidence on determinants of healthy ageing, the Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) consortium has done a systematic review and a comprehensive report was released on the project website in 2018. They searched MEDLINE, Embase, PsycInfo, and Cochrane Central from database inception to Aug 15, 2016, with no restrictions on language, time frame, setting, or characteristics of participants, using terms including "healthy ageing" and other relevant terms such as "successful ageing", "positive ageing", "productive ageing", "optimising ageing", "unimpaired ageing", "robust ageing", and "effective ageing", and their review included all longitudinal cohort studies that used "healthy ageing" as a main outcome measure. Because 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 wellbeing alone) was used. They assessed risk of bias using the Quality in Prognosis Studies tool. The initial search identified 89 905 publications after removal of duplicates and 65 longitudinal cohort studies met the inclusion criteria. Among the 65 included studies, 25 investigated associations between education and healthy ageing and 14 focused on associations between healthy ageing and income and economic status. The risk of bias was low in these studies. Despite the heterogeneity of measurement methods, high levels of education and income were found to be beneficial to healthy ageing. Although previous studies have suggested these positive associations, the strength of association reported from different cohorts might not be comparable due to variation in measurement methods.

Added value of this study

Here we used a harmonised dataset of eight longitudinal cohorts from Australia, the USA, Japan, South Korea, Mexico, and Europe. We found low levels of education and wealth to be associated with poorer health at baseline relative to higher levels of education and wealth, but with little effect on the rate of decrease in healthy ageing scores. The gradient of health inequalities at baseline differed across populations and the steepest gradient was found in the study from the USA.

Implications of all the available evidence

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 concentrate on how risk of poor health can accumulate over the lifecourse and investigate how variation in life experience and social, environmental, and cultural factors can affect healthy ageing across different societies.

or multimorbidity) have generally focused on negative aspects of health and the identification of underlying biological and pathological abnormalities in older people.[3,4]

Previous research on health inequalities has investigated a wide range of outcomes such as specific chronic diseases, multimorbidity, frailty and disability, mortality, and life expectancy,[5–7] and has consistently shown socioeconomic inequalities in these health outcomes associated with factors such as education, occupational class, and income reported. To provide a nuanced understanding of healthy ageing, an assessment of how the process of maintaining health and functioning differs across socioeconomic groups is important. A systematic review has summarised risk and protective factors related to healthy ageing,[8] and several studies were identified that reported a positive effect of education and income on ageing outcomes, suggesting the existence of health inequalities in later life across different socioeconomic positions. However, existing studies have used diverse measures and analytical methods, leading to problems in study comparability and the assessment of factors that could be responsible for variations across countries.

To improve understanding of healthy ageing, the Ageing Trajectories of Health: Longitudinal Opportunities and Synergies (ATHLOS) consortium harmonised a wide range of sociodemographic, lifestyle, health, and functioning factors from 17 ageing cohorts across the world.[9] The research team also developed a measure of healthy ageing that incorporated multiple domains of physical and cognitive functioning and provided an indicator for healthy ageing across time and cohorts.[10] Building on the ATHLOS work of data harmonisation and method development, the aim of this study was to investigate the effect 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 design and population

In this population-based study, we used data from the ATHLOS project.[9] This project gathered 17 ageing studies across the world and harmonised a wide range of lifestyle, social, environmental, physical, and psychological health factors across the different studies. Documentation of the harmonisation process is available online. To estimate longitudinal changes in health status, for the present analysis we excluded cohorts with only one or two survey waves (nine studies, n=192 114) and focused on the remaining eight cohorts with at least three waves of data (n=141 214). This selection comprised 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]

All cohort studies have been approved by the relevant local research ethics committees. This is a secondary data analysis project and so specific ethical approval was not needed.

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. The consortium harmonised these 41 items into binary variables and used item-response theory modelling 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 timepoints. The scores were rescaled into a range between 0 and 100; with a higher score indicating better healthy ageing. More detailed information on these scores is in the appendix (pp 4–9).

Sociodemographic factors

In our analysis we focused on five key factors: age, sex, cohort study, education, and wealth. To align different baseline ages across cohort studies, we centred age to 70 years (ie, calculated as age−70) because one of the cohort studies (ALSA) did not have participants aged 70 years or younger. The datasets harmonised by the ATHLOS consortium provide four levels of education qualification: less than primary education and primary, secondary, and tertiary education. Since some cohort studies had very few or no participants with less than primary education, for our study we combined the first two levels and so the three levels of education we used were low (primary education or less), middle (secondary education), and high (tertiary education). In the ATHLOS harmonised dataset, 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 (quintile 1 [Q1] being the most deprived; quintile 5 [Q5] being the most affluent). In the ATHLOS harmonised dataset, comparable information on wealth was not available in Seniors-ENRICA and therefore for this specific analysis we only included the other seven cohort studies. More detailed information on harmonisation is in the appendix (pp 10–11).

Analytical strategy

Since multilevel modelling can be more flexible when incorporating time variation in follow-up waves across different cohort studies,[19] we used a random-effect model that used a multilevel modelling framework to investigate trajectories of healthy ageing 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 effect of baseline age and sex on the trajectories, we included linear and quadratic terms of age and the interaction between age and sex in different models. In the first model (model 1), we investigated the effect of age on baseline score and rate of decrease in score, in the second model we assessed the effect of sex on baseline score accounting for age (model 2A), and the effect of sex on rate of decrease in score accounting for age (model 2B). According to the descriptive information of healthy ageing scores, the gaps in healthy ageing scores increased in older age groups and varied between men and women (appendix p 8). Thus, we fitted a quadratic term of age and interaction between age and sex to fully account for their effects on the trajectories. We added a variable indicating cohort studies to the model, including age and sex to investigate potential variations across the eight cohort studies adjusting for these two basic demographic factors (model 3A and 3B; appendix p 12). We also added two socioeconomic factors, education and wealth, to the adjusted model including age, sex, and study, and we examined their effects on intercept (model 4A for education, model 5A for wealth) and slope estimates (model 4B for education and model 5B for wealth). To investigate whether education and wealth might have different effects on healthy ageing across different cohorts and sexes, we further include their interaction terms regressing on intercept and slope. We also included both education and wealth in one model to test whether their effects on trajectories of healthy ageing scores were independent. To examine whether specific chronic conditions might explain health inequalities, we identified five types of harmonised chronic diseases (including cardiovascular diseases, hypertension, diabetes, chronic respiratory diseases, and joint disorders) at baseline and added them to the best model including demographic and socioeconomic factors. To investigate whether the effect of education varied across birth cohorts, we included interaction terms between birth cohort and education in the modelling.

See Online for appendix

We used descriptive statistics to present baseline demographic information of the participants. For results of multilevel modelling, we present estimated intercept (baseline scores) and regression coefficients with 95% CIs. To visualise the modelling results, we estimated healthy ageing scores given specific age, sex,

	ALSA (n=1947)	ELSA (n=15 010)	Seniors-ENRICA (n=2519)	HRS (n=33 580)	JSTAR (n=5144)	KLOSA (n=10 254)	MHAS (n=13 601)	SHARE (n=59 159)	Total (n=141 214)
Location	Australia	UK	Spain	USA	Japan	South Korea	Mexico	Europe	..
Baseline age, years									
Mean	77·5 (5·9)	62·8 (9·6)	68·7 (6·4)	61·2 (9·8)	62·9 (7·1)	61·5 (11·0)	62·5 (9·6)	64·2 (9·9)	62·9 (10·1)
Range	70–103	50–94	60–93	50–103	50–77	45–105	50–106	50–103	45–106
Sex									
Female	908 (46·6%)	7977 (53·1%)	1338 (53·1%)	18 044 (53·7%)	2616 (50·8%)	5791 (56·5%)	7310 (53·8%)	32 500 (54·9%)	76 484 (54·2%)
Male	1039 (53·4%)	7033 (46·9%)	1181 (46·9%)	15 536 (46·3%)	2528 (49·2%)	4463 (43·5%)	6291 (46·2%)	26 659 (45·1%)	64 730 (45·8%)
Year of study									
Baseline year	1992	2002	2008	1992	2007	2006	2001	2004	..
Last follow-up year	2014	2015	2015	2012	2011	2012	2012	2013	..
Number of waves	13	7	3	11	3	4	3	5	..
Low education (≤primary)*	602 (36·7%)	5516 (39·4%)	1373 (54·5%)	9359 (27·9%)	1515 (29·6%)	4651 (45·4%)	10 627 (78·3%)	15 170 (26·3%)	48 813 (35·3%)
Least wealthy (least affluent quintile)†	701 (37·3%)	2600 (18·6%)	NA	6974 (20·8%)	677 (25·2%)	2097 (20·9%)	3128 (24·0%)	11 463 (19·5%)	27 640 (20·6%)
Overall healthy ageing score	56·8 (14·0)	66·4 (16·8)	67·3 (14·8)	65·6 (18·9)	76·9 (13·5)	68·9 (15·6)	63·9 (16·5)	71·1 (17·1)	67·5 (17·8)

Data are n (%) or mean (SD), unless otherwise stated. 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. JSTAR=Japanese Study of Ageing and Retirement. KLOSA=Korean Longitudinal Study of Ageing. MHAS=Mexican Health and Ageing Study. NA=not applicable. SHARE=Survey of Health Ageing and Retirement in Europe. *Data missing for 2789 (2·0%) of individuals across all studies. †Data missing for 4519 (3·3%) individuals.

Table 1: **Characteristics of study population in eight cohort studies and overall**

	Model 1	Model 2A	Model 2B
Baseline score	68·25 (68·13 to 68·37)	66·21 (66·07 to 66·36)	66·19 (66·05 to 66·34)
Linear age (years, at baseline)	−0·65 (−0·66 to −0·64)	−0·66 (−0·68 to −0·65)	−0·66 (−0·67 to −0·65)
Quadratic age	−0·02 (−0·02 to −0·02)	−0·02 (−0·02 to −0·01)	−0·02 (−0·02 to −0·01)
Sex (male *vs* female)	..	4·36 (4·18 to 4·54)	4·41 (4·22 to 4·59)
Interaction between age and sex	..	0·05 (0·04 to 0·07)	0·05 (0·04 to 0·07)
Rate of decrease in score (by year of follow-up)	−1·11 (−1·13 to −1·09)	−1·11 (−1·12 to −1·09)	−1·10 (−1·12 to −1·08)
Linear age, years (at baseline)	−0·06 (−0·06 to −0·06)	−0·06 (−0·06 to −0·06)	−0·06 (−0·06 to −0·06)
Quadratic age	0·00 (0·00 to 0·00)	0·00 (0·00 to 0·00)	0·00 (0·00 to 0·00)
Sex (men *vs* women)	..	..	−0·02 (−0·04 to 0·00)
Variance			
Intercept	180·53 (178·81 to 182·27)	176·33 (174·63 to 178·04)	176·32 (174·63 to 178·03)
Slope	0·79 (0·77 to 0·81)	0·79 (0·77 to 0·81)	0·79 (0·77 to 0·81)
Covariance	−2·08 (−2·24 to −1·92)	−2·08 (−2·24 to −1·91)	−2·07 (−2·23 to −1·91)
Residual	83·46 (83·02 to 83·90)	83·48 (83·04 to 83·93)	83·48 (83·04 to 83·92)
Goodness of fit			
BIC	3 854 387	3 851 659	3 851 668

Data are estimated intercept and regression coefficients from multilevel modelling, with 95% CI in parentheses, unless otherwise stated. Model 1 modelled the effect of age on baseline score and rate of decrease in score; model 2A modelled the effect of sex on baseline score accounting for age; and model 2B modelled the effect of sex on baseline score and rate of decrease in score accounting for age. BIC=Bayesian information criterion.

Table 2: **The association between trajectories of healthy ageing score, age, and sex**

or cohort study and present scores by age or years of follow-up.

We assessed model fitness using the Bayesian information criterion,[20] with lower values indicating a better model fit. To contextualise the inequality findings, we obtained country-level Gini coefficients for populations aged 65 years or older from the Organisation for Economic Co-operation and Development to compare with the score differences across education and relative wealth levels and present the data in scatter plots.

For **country-level coefficients** see https://data.oecd.org/

We did several sensitivity analyses. We added quadratic terms of years of follow-up to the mixed models to investigate potential non-linear trajectories. Maximum likelihood estimation should provide unbiased estimates given the assumption of a missing-at-random mechanism.[21] Since the proportions of missing data on education (n=2789 [2·0%]) and wealth (n=4519 [3·3%]) were small in relation to the whole study population, here we report results of analyses related to education or wealth based on participants with complete information on education or

wealth. Loss of statistical power was unlikely to be an issue given the large size of the study sample. We also found the distributions of education and wealth levels to be similar across follow-up waves (appendix p 13). To account for potential missing-not-at-random data due to mortality, we fitted a joint model of longitudinal data on healthy ageing scores and survival data on all-cause mortality combining multilevel modelling and parametric Weibull survival regression.[22] We present the results of joint models as hazard ratios (HRs) with 95% CIs.

We did all analysis using Stata (version 15.1) and all analyses were based on the ATHLOS harmonised dataset (version 1.7).

Role of the funding source

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

Results

Among the eight cohorts (n=141 214), the earliest studies started from 1992 (table 1). The two larger cohorts, SHARE and HRS, recruited over 30 000 participants while ALSA and Seniors-ENRICA had less than 3000. The length and frequency of follow-up varied across studies. Most studies had follow-up every 2 years for a period of 10 years. The median follow-up period was 6 years (IQR 2–11). ALSA has the most waves of data collection, with 13 waves over two decades, whereas JSTAR only had three waves over 4 years.

Among the 141 214 participants, 76 484 (54·2%) were women, with the proportion of women in each study ranged from 46·6% (n=908) in ALSA to 56·5% (n=5791) in KLOSA (table 1). The mean age at baseline was 62·9 years (SD 10·1) and with a range of 45–106 years. 10 627 (78·3%) participants in MHAS had low level education, whereas HRS, SHARE, and JSTAR had fewer than 30% of participants with low level education. Over the whole study period, the mean healthy ageing score was 67·5 points (SD 17·8) across all studies, decreasing from an overall mean at baseline of 69·5 points (SD 17·0), to 64·1 points (18·4) at year 10, and 62·6 points (18·2) at year 20. The distribution of healthy ageing scores by cohort are shown in table 1.

The associations between trajectories of healthy ageing scores, age, and sex are shown in table 2. For participants aged 70 years (model 1), the baseline score was estimated to be 68·25 points (95% CI 68·13 to 68·37) and the rate of decrease in score was –1·11 (95% CI –1·13 to –1·09) per year (figure 1, table 2). Older age (model 1) was associated with a lower intercept in linear (–0·65, 95% CI –0·66 to –0·64) and quadratic (–0·02, –0·02 to –0·02) terms of age than was younger age. Men had higher scores than women (model 2A; estimated difference in score between men and women of 4·36, 4·18 to 4·54)

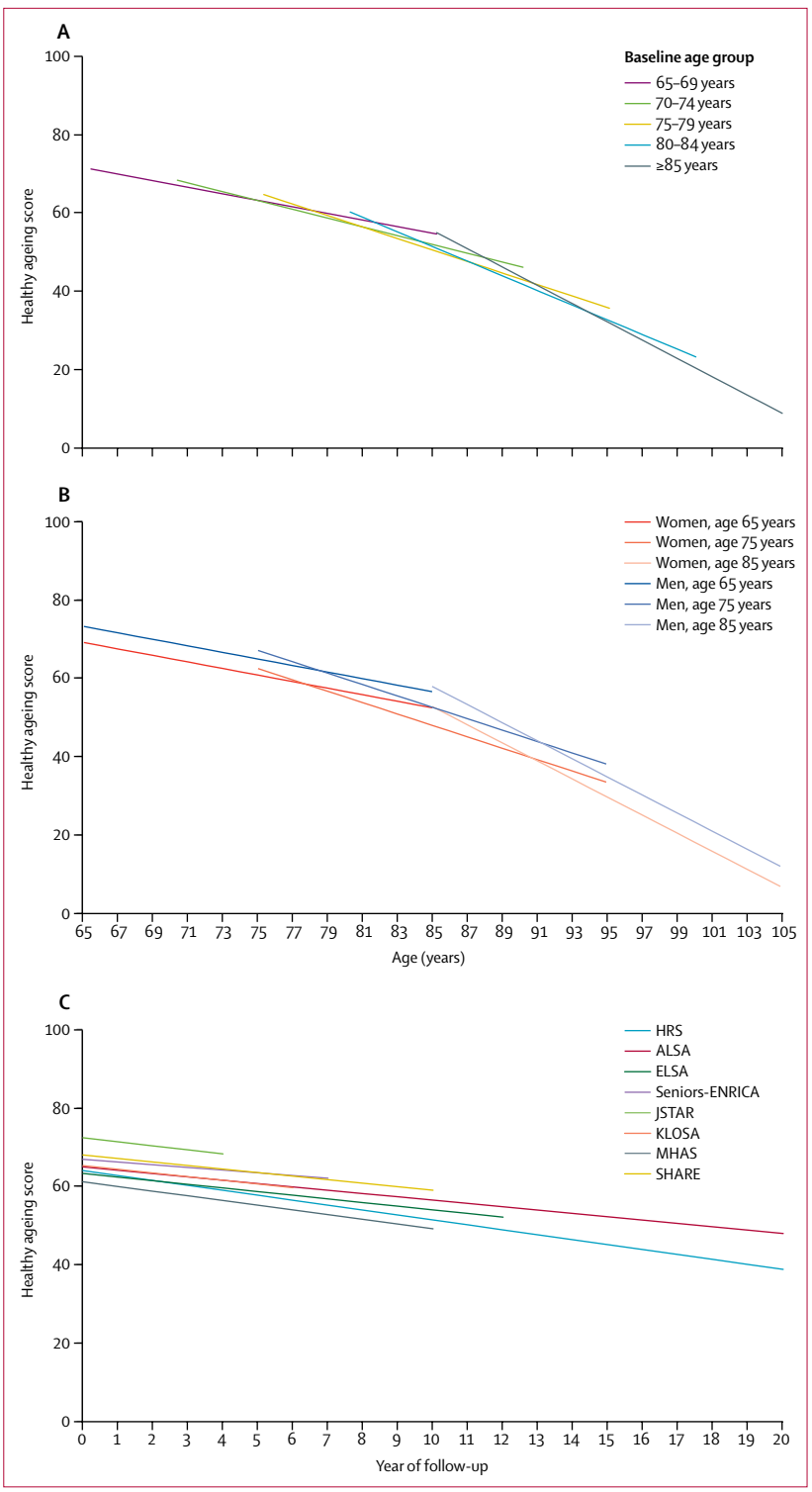

Figure 1: **Estimated healthy ageing scores by baseline age, sex, and cohort study**
(A) Baseline age. (B) Baseline age and sex. (C) Cohort study (adjusted for age and sex). ALSA=Australian Longitudinal Study of Ageing. ELSA=English Longitudinal Study of Ageing. Seniors-ENRICA=Study on Nutrition and Cardiovascular Health in Older Adults in Spain. HRS=Health and Retirement Study. 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		Wealth	
	Model 4A	Model 4B	Model 5A	Model 5B
Baseline score	60·18 (59·96 to 60·41)	58·97 (58·85 to 59·48)	60·53 (60·28 to 60·77)	55·74 (55·38 to 56·10)
Education				
Middle *vs* low	5·66 (5·49 to 5·83)	6·80 (6·44 to 7·15)	..	..
High *vs* low	10·54 (10·31 to 10·77)	13·48 (13·02 to 13·94)	..	..
Relative wealth				
Q2 *vs* Q1	..	..	2·24 (2·00 to 2·47)	6·17 (5·70 to 6·65)
Q3 *vs* Q1	..	..	4·13 (3·89 to 4·36)	9·91 (9·44 to 10·39)
Q4 *vs* Q1	..	..	6·55 (6·32 to 6·79)	13·14 (12·66 to 13·62)
Q5 *vs* Q1	..	..	8·98 (8·74 to 9·22)	16·34 (15·86 to 16·82)
Rate of decrease in score (by year of follow-up)	−1·26 (−1·28 to −1·24)	−1·28 (−1·31 to −1·25)	−1·27 (−1·29 to −1·24)	−1·19 (−1·23 to −1·16)
Education				
Middle *vs* low	..	0·01 (−0·03 to 0·04)	..	..
High *vs* low	..	0·04 (0·00 to 0·09)	..	..
Relative wealth				
Q2 *vs* Q1	..	..	..	−0·08 (−0·13 to −0·03)
Q3 *vs* Q1	..	..	..	−0·13 (−0·18 to −0·08)
Q4 *vs* Q1	..	..	..	−0·11 (−0·16 to −0·06)
Q5 *vs* Q1	..	..	..	−0·08 (−0·13 to −0·03)
Goodness of fit				
BIC	3 778 816	3 778 487	3 703 900	3 702 573

Data are estimated intercept and regression coefficients from multilevel modelling, with 95% CIs in parentheses, unless otherwise stated. For wealth, cohort-specific quintiles range from least affluent (Q1) to most affluent (Q5). Model 4A modelled the effect of education on baseline score; model 4B modelled the effect of education on baseline score and rate of decrease in score; model 5A modelled the effect of wealth on baseline score; and model 5B modelled the effect of wealth on baseline score and rate of decrease in score. BIC=Bayesian information criterion.

Table 3: **Association between education, wealth, and trajectories of healthy ageing score (adjusted for age, sex, and cohort study)**

and this difference increased with 1 year increase in baseline age (0·05, 0·04 to 0·07; figure 1, table 2). The rate of decrease in score was slightly greater in men than in women (–0·02, 95% CI –0·04 to 0·00) but the effect size was small (model 2B). After adjusting for age and sex, variation in intercept and slope was found across cohort studies (figure 1; appendix p 12). Compared with HRS, a higher baseline score was found in JSTAR (estimated score difference between cohorts of 8·38, 95% CI 7·92 to 8·83) and a lower baseline in MHAS (–2·85, –3·15 to –2·56; appendix p 12). Rates of decrease in score were generally higher in HRS and MHAS than in the other cohort studies. The lowest BIC was found in model 2A and the value further decreased when adding cohort study in modelling (table 2).

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 had little effect on the rate of decrease in score after adjusting for age, sex, and cohort study. Participants with middle level (5·66, 95% CI 5·49–5·83) and high level of education (10·54, 10·31–10·77) had higher baseline scores than those with low level education (60·18, 59·96–60·41). A 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 2). In these cohorts, participants with a middle level of education had higher baseline scores (by approximately 6 points) than those with low level education, and the difference increased to nearly 10 points for those with high level education. In JSTAR, Seniors-ENRICA, ALSA, and KLOSA, the estimated difference in score between those with high level and low level 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 steeper gradients than the other cohort studies (figure 2). Due to small numbers of participants in ALSA in the third and fourth wealth quintiles, the 95% CIs were very wide. When we included both education and relative wealth in one model, the effect sizes remained similar across all cohort studies (appendix p 14). Education and relative wealth had similar effects on the trajectory of healthy ageing scores in both men and women with very clear gradients from lowest to highest levels of education and relative wealth (appendix p 15). Furthermore, adding chronic conditions did not reduce the gaps across education and wealth levels (appendix pp 16–18) and the effect of education did not

vary across birth cohorts (appendix pp 19–20). The scatter plot of Gini coefficients and effect sizes of inequalities across education and wealth did not show clear patterns (appendix p 21).

The results of sensitivity analyses are provided in the appendix (pp 22–24). Although the quadratic model showed increased goodness of fit, the effect sizes of quadratic terms were small (appendix p 22). The results of joint modelling showed a slightly greater rate of decrease in score than our main analysis when including mortality data in the longitudinal analysis (–1·24, 95% CI –1·25 to –1·22; appendix p 24). A higher baseline score (HR 0·96, 95% CI 0·95 to 0·96) and slower rate of decrease in score (0·57, 0·55 to 0·58) than the main analyses were associated with lower risk of mortality after adjusting for age and sex.

Discussion

Using a harmonised dataset of eight ageing cohorts from the USA, the UK, Spain, Europe, Australia, Japan, South Korea, and Mexico, we investigated changes in health and functioning over the ageing process and the potential effect of demographic and socioeconomic factors on health trajectories. Baselines scores and the rate of decrease in healthy ageing scores varied across different age groups, by sex, and by cohort study. Education and wealth had a strong effect on baseline scores but almost no influence on the rate of decrease in score. 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 most pronounced in the HRS.

The ATHLOS consortium harmonised data from different ageing cohorts across the world and provides a large sample size for longitudinal analysis. Here we focused on eight population-based cohorts and included participants from different settings. Compared with harmonised datasets in the Gateway to Global Aging Data platform, the ATHLOS consortium incorporated additional cohort studies from Australia and Spain and we generated an indicator for healthy ageing that comprises 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 might be present in an older patient, which has been the focus of other relevant but distinct concepts such as frailty.[4] Although cognitive and motor reserve also focuses on functioning processes and the neural network, reserve is mainly determined by factors in earlier stages of life.[23] Healthy ageing is considered a process of maintaining functional ability and interactions between individual and environmental factors that can modify this process in later life.

Our study had some limitations. Most studies in the ATHLOS consortium from low-income 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 should be considered when interpreting the findings. We accounted for variation in follow-up waves with multilevel modelling but only two studies (HRS and ALSA) had 20 years of follow-up and were used to inform trajectories after 10 years of follow-up in the other studies. The linear models might not sufficiently capture changes in the rate of decrease in score particularly in the final 10-year follow-up period. However, rates of decrease in score seemed to be similar in the first 10-year period across cohorts and sensitivity analyses showed similar results. Another modelling approach could use country as a multilevel factor; however, only SHARE included multiple countries and so generating specific estimates

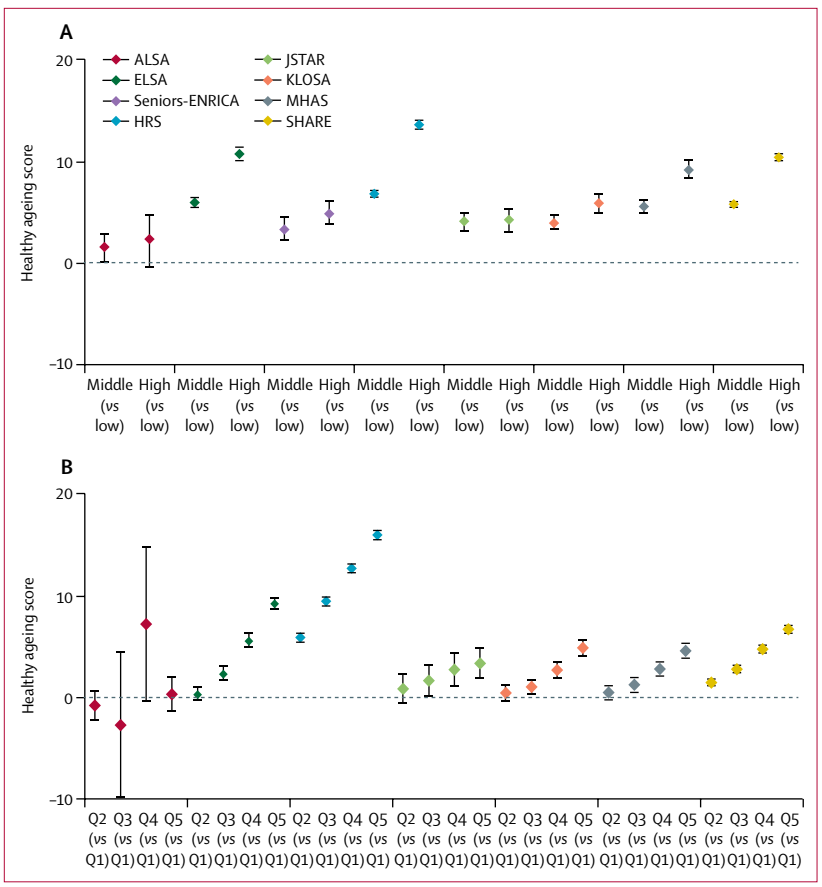

Figure 2: **Differences in baseline healthy ageing score across education levels (A) and wealth quintiles (B) by cohort study, adjusted for age and sex**

Data points are estimated differences in healthy ageing scores, with whiskers showing 95% CIs. For education, low is primary education or less, middle is secondary education, and high is tertiary education. For wealth, cohort-specific quintiles range from least affluent (Q1) to most affluent (Q5), and Seniors-ENRICA is not included because it did not measure wealth. 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. 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.

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for each cohort study would be difficult. 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 others 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 associations between education, wealth, and trajectories of healthy ageing. However, we adjusted for cohort study in the analysis and these two socioeconomic factors still had important effects on baseline healthy ageing scores. Although multiple imputation could be used to address missing or unavailable data on education and relative wealth,[24] imputing such a large dataset while accounting for multilevel data structure was too challenging and computationally intensive for this study. However, the effect sizes that we calculated here are unlikely to be overestimates and the statistical power of our study should not be affected given the large study population. Some societal and historical factors such as health systems, welfare policies, or economic crises in different societies might also 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, however, no apparent associations with health inequalities across education and relative wealth were observed.

Education and wealth were found to have little effect on the rate of decrease in healthy ageing scores in older people across different cohorts. This finding corresponds with another analysis of SHARE that identified several indicators for early-life socioeconomic circumstances (eg, number of books at home, housing quality, and overcrowding) and reported their consistent associations with baseline levels but not rates of decrease in physical, cognitive, and emotional functioning.[25] Given the lack of effect on rates of decrease in healthy ageing scores, cumulative disadvantage due to low socioeconomic status might have largely deteriorated health conditions in early life stages and led to persistent differences throughout older age. The differences in baseline healthy ageing scores across education and wealth levels can be clinically relevant, with a strong effect on mortality in later life. A 10-point difference in baseline healthy ageing score was associated with an approximate 33% decreased risk of mortality.

For **documentation and metadata** see https://athlos.pssjd.org

Inequalities in healthy ageing across education and wealth levels were apparent but the scale of the gradient varied across cohort studies. Wider gaps were found in HRS and ELSA than in the other studies, while the effect sizes of education and wealth in these cohorts were nearly half the magnitude of those seen in the other cohorts. This finding 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 systematic differences in the distribution of education groups across the sexes, birth cohorts, and time. Based on the theory of health inequality,[26] 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, and little access to health care and insurance, which might have direct effects on poor health across the lifetime and affect functional ability in older age.[27,28] Education is likely to be related to behavioural and psychological factors, such as smoking, diet, and social support.[26] These factors might also affect physical and mental health and capability to maintain functional ability in later life.[8] Here we found both education and relative wealth had independent effects on trajectories of healthy ageing scores across cohort studies and the effect sizes remained similar when we accounted for 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.

Our findings highlight health inequalities in later life across education and wealth; with effects that appear to vary across different contexts. To identify potential mechanisms that explain the differential effect of education and wealth, a lifecourse approach is needed to understand how risk of poor health can accumulate from early life stages and to investigate key material, behavioural, and psychological factors that generate health inequalities in different societeties.[26,29] More longitudinal studies are needed in low-income and middle-income countries to enable the comparison of trajectories of healthy ageing across older populations living in various cultural, social, and environmental contexts. Such comparisons will inform policy planning on addressing determinants of healthy ageing across the world and reducing health inequalities in later life.

Contributors

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

Declaration of interests

We declare no competing interests.

Data sharing

Documentation and metadata of the ATHLOS harmonisation process can be accessed online. The original cohort data are publicly available for HRS, ELSA, KLOSA, MHAS, and SHARE, or can be accessed by contacting the study management teams of the studies on reasonable request.

Acknowledgments

The ATHLOS project was funded by the European Union Horizon 2020 Research and Innovation Programme (grant number 635316). This study

was supported by the 5-year ATHLOS project. We thank the ATHLOS consortium for useful discussions and we thank the institutions who funded and the people who worked on the studies that provided data for this Article. Further acknowledgments are in the appendix (pp 2–3).

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