Comparing socioeconomic inequalities in healthy ageing in the US, England, China and Japan: evidence from four longitudinal studies of ageing

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Abstract

Healthy ageing has become a popular topic worldwide. So far, a consensus measure of healthy ageing has not been reached; and no studies have compared the magnitude of socioeconomic inequality in healthy ageing outside of Europe. This study aims to create a universal measure of healthy ageing and compare socioeconomic inequalities in healthy ageing in the US, England, China, and Japan. We included 10305 American, 6590 English, 5930 Chinese and 1935 Japanese participants for longitudinal analysis. A harmonised healthy ageing index (HAI) was developed to measure healthy ageing multi-dimensionally. Educational, income and wealth rank scores were derived accounting for the entire socioeconomic distribution and the sample size of each category of socioeconomic indicator. Associations between socioeconomic rank scores and HAIs were assessed using multilevel modelling to calculate the Slope Indices of Inequality. Healthy ageing trajectories were predicted based on the full-adjusted age-cohort models. We found that education was a universally influential socioeconomic predictor of healthy ageing. Moving from the highest to the lowest educational groups was associated with a 6.7% (5.2% to 8.2%), 8.2% (6.0% to 10.4%), 13.9% (11.4% to 16.3%) and 6.1% (3.9% to 8.2%) decrease in average HAI at 60 years in the US, England, China and Japan, respectively. After 60 years, the educational inequality in healthy ageing kept increasing in the US and China. The educational inequality in healthy ageing in China was also greater than any other socioeconomic inequality in the four countries. Wealth was more influential in predicting healthy ageing inequality among American, English, and Japanese participants, while income was more influential among Chinese participants. The socioeconomic inequality in healthy ageing in Japan was relatively small. Chinese and American participants had worse healthy ageing profiles than Japanese and English participants.

Key words: US, England, China, Japan, Healthy Ageing, Socioeconomic Inequality

Introduction

Theories and Measurements of Healthy Ageing

Ageing can be seen as a success story for public health policies, socioeconomic development and medical advancements in relation to disease and injury; but it also challenges countries to adapt in order to maximise older people's health and functional capacities, and to maintain their social participation and security (World Health Organization 2002). "Healthy ageing" has become a popular topic worldwide in past decades. The term is often used interchangeably with other terms such as "active", "successful" or "productive" ageing. Healthy ageing refers to the process of optimising opportunities for health, participation and security so as to enhance quality of life as people age, highlighting the impact of social environment on healthy ageing (World Health Organization 2002).

In the literature, Kuh's healthy biological ageing theory (Kuh *et al.* 2014) and Rowe and Kahn's successful ageing theory (Rowe and Kahn 2015) both suggested that social engagement and mental capacities are as important as biological factors for achieving healthy ageing, indicating that healthy ageing should be measured in a multi-dimensional way. Previous literature reviews also found that physical capabilities, cognitive functions, physiological and metabolic health, psychological and social well-being are fundamental phenotypic components of healthy ageing which have been frequently employed worldwide to measure healthy ageing comprehensively (Lara *et al.* 2013, Lu, Pikhart and Sacker 2019). The WHO 2015 healthy ageing model (World Health Organization 2015) and the Baltes and Baltes's "selective optimisation with compensation" model of successful ageing (Baltes and Baltes 1990) emphasised the concept of resilience, suggesting that the elderly are capable of taking advantage of their current capacities to compensate for any losses and limitations. When considering healthy ageing, a "disease-free" ageing status might not be achievable but a “resilient” status may be and classifying healthy agers by a dichotomous yes/no measure might introduce selection bias (Lu, Pikhart and Sacker 2019).

Improving the measurement of healthy ageing has also been emphasised by the WHO. The WHO 2015 healthy ageing model defined healthy ageing as “the process of developing and maintaining the functional ability that enables well-being in older age” (World Health Organization 2015). Functional abilities are the health-related attributes that allow people to do what they have reason to value, which can be determined by intrinsic capacities (the composite of all the physical and mental capacities that an individual can draw on) and social environment (both the individual- and environmental-level social factors in the extrinsic world), as well as the interactions between them (World Health Organization 2015). The WHO suggested that building and maintaining intrinsic capacity is one fundamental way of enhancing functional ability (World Health Organization 2015). A literature review identified five domains of intrinsic capacity, including cognition (memory, intelligence and problem solving), psychological (mood and emotional vitality), vitality (hormonal function and cardio-respiratory function), locomotion (balance, muscle strength and gait) and sensory (vision and hearing) (Cesari *et al.* 2018). Another two literature reviews also proposed similar domains constituting the intrinsic capacity construct, including physical capabilities, cognitive function, physiological health and psychological well-being (Lara *et al*. 2013, Lu, Pikhart and Sacker 2019). Besides, researchers suggested that social well-being (e.g. social network, functioning or support) should also be considered as a key component for developing metrics of healthy ageing (Hodes *et al.* 2013, Lara *et al.* 2013, Lu, Pikhart and Sacker 2019), which is an indicator of social environment and interconnected with intrinsic capacities (World Health Organization 2015).

Regarding the established scales of measuring intrinsic capacities and social well-being, according to the literature review based on fifty healthy ageing studies across twenty-three countries or regions (Lu, Pikhart and Sacker 2019), (Instrumental) Activities of Daily Livings ((I)ADLs) were recommended for community-based studies to predict physical capabilities. It is also better to test direct observations of performance, such as grip strength, walking speed, balance and the chair rise test, to improve predictability. Measures of cognitive function were diverse across countries. But the word recall (immediate and delayed recall) and date naming (month, day of month, year, day of week) tests to measure short-term memory and orientation to time had been universally employed. Questions about self-reported absence of chronic diseases (e.g. high blood pressure, diabetes, cancer, lung disease, stroke, heart problems or arthritis) had also been frequently used to measure physiological health in many studies. For psychological well-being, each measure must focus on a clear conceptual domain. For example, the depressive symptoms could be measured using the Centre for Epidemiological Studies-Depression (CES-D) scale. Moreover, it is recommended that social participation should be measured in terms of specific social roles. Questions about participation in a variety of social activities, such as social or sports clubs, exercise classes, music groups, or Neighbourhood Watch had been frequently used.

Socioeconomic Inequalities in Healthy Ageing Worldwide

A literature review in 2010 identified six future areas for the long-term study of ageing, based on 51 longitudinal studies of ageing worldwide; socioeconomic inequality in health and well-being among the ageing population was one of those six areas (Stanziano *et al.* 2010). During the past decade, research questions regarding socioeconomic inequalities in healthy ageing have been discussed in many articles worldwide. In general, older people with disadvantaged SEPs are less likely to achieve healthy ageing than those with advantaged SEPs in many countries (Hirai, Kondo and Kawachi 2012, Li *et al.* 2006, McLaughlin *et al.* 2010, Perales *et al.* 2014, Sowa *et al.* 2016).

However, the magnitude of socioeconomic inequalities in healthy ageing across countries may be different due to variations in political, cultural, economic and epidemiological histories (Mackenbach *et al.* 2008). Previous studies have applied different measures of healthy ageing due to the inconsistency in definitions of healthy ageing (Hirai, Kondo and Kawachi 2012, Li *et al.* 2006, McLaughlin *et al.* 2010, Perales *et al.* 2014, Sowa *et al.* 2016), which made the comparison of the magnitude of socioeconomic inequalities in healthy ageing across countries difficult. For example, one US study applying Rowe and Kahn's theory defined healthy ageing as no major diseases or disability, good cognitive and physical functioning, and active engagement in social activities (McLaughlin *et al.* 2010), but another study from Japan included mortality and loss of healthy life to assess healthy ageing (Hirai, Kondo and Kawachi 2012).

Moreover, comparative studies about socioeconomic inequalities in healthy ageing are also rare. Each of these is based on a single database, and the regions are restricted to European countries (Perales *et al.* 2014, Sowa *et al.* 2016). One study assessed factors associated with healthy ageing in Finland, Poland and Spain, finding that Finish participants achieved healthy ageing better than Polish and Spanish participants, and that higher education and occupation were commonly associated with higher levels of healthy ageing in the three countries (Perales *et al.* 2014). Another study found a positive educational gradient in healthy ageing in southern and central-eastern European countries, and a positive income gradient in healthy ageing among females in western European countries (Sowa *et al.* 2016). To our knowledge, no studies in the literature to date have compared socioeconomic inequalities in healthy ageing among countries from different continental regions in the world.

Researchers have suggested that Europe offers excellent opportunities for comparative research, since good data on health inequalities are often available (Kunst, Bos and Mackenbach 2011). But the conduct of comparative research should not be driven by data alone; countries outside Europe with large ageing populations also need to explore strategies to eliminate socioeconomic inequalities in healthy ageing. Evidence shows that for life expectancy at birth, Japan, the US and China ranked as the top three among countries with populations greater than 100 million in 2017 (G. B. D. Mortality Collaborators 2018), but the percentages of the working-age population had continuously decreased in all three countries up to that date (The World Bank 2018).

Similarly to high-income European countries, labour force ageing in the US and Japan is also likely to be substantial over the next decades. Between 1995 and 2030, the share of workers aged 60 years and older was expected to rise, from 12.5% and 5.8% to 30.1% and 16.1% in Japan and the US respectively; this is similar to or larger than the increase in the average share (from 4.7% to 17.1%) in Organization for Economic Cooperation Development (OECD) Europe (OECD 1998). The number of older workers aged 60 years or more is unclear in China, but it too will increase in future decades as the retirement ages for both genders increase (World Economic Forum 2016). The WHO proposed that healthy ageing assumes that ageing is a valuable process which permits older people to make crucial contributions to society, leading to personal fulfilment and economic growth; healthy ageing also shifts the traditional stereotypes of “old age”, and views the phenomenon of ageing as an opportunity (World Health Organization 2002). Given the phenomenon of labour force ageing among top economies including the US, England, China and Japan, through conducting this cross-country comparison, this study will help explore universal and region-specific public health practices to support healthy ageing among both Western and Asian countries. Ensuring a successful demographic transition among the world's top economies will also be beneficial to the world economy.

Conducting an international comparsion to identify universal socioeconmic determinants of healthy ageing is also in line with the WHO's suggestion: ageing research needs to be better coordinated across countries, to discover the most cost-effective approaches to maintain older people's health and well-being (World Health Organization 2011).

Researchers from countries including the US, England, China and Japan are currently conducting nationally representative longitudinal studies of ageing; these are sister ageing studies, and they commonly incorporate measures of health, economic status, family and well-being (Hidehiko, Satoshi and Hideki 2010, Sonnega *et al.* 2014, Steptoe *et al.* 2013, Zhao *et al.* 2014). Employing these four studies, which contain nationally representative samples of older people in the four countries, provides a unique opportunity to conduct a multinational comparison of socioeconomic determinants of healthy ageing, on a scale not done before.

Therefore we created a universal and multi-dimensional measure of healthy ageing, conducted comparative analysis to assess the magnitude of educational, income and wealth inequalities in healthy ageing in the US, England, China and Japan, and identified influential socioeconomic predictors of healthy ageing in each country.

We hypothesised that education is an influential predictor of inequalities in healthy ageing in the US, as it is a key mechanism involved in raising a person's status in the US (Bartley 2004, Hollingshead 2011); but education is not an influential predictor in China, as older Chinese people are generally illiterate or low-educated (Krieger and Fee 1994) (hypothesis one). We also hypothesise that low- or middle-income countries such as China have greater socioeconomic inequalities in healthy ageing (Fang *et al.* 2010), while countries such as

England and Japan, which have been covered by free or low-cost national health services, have lesser socioeconomic inequalities in healthy ageing (NHS 2018, Reich and Shibuya 2015) (hypothesis two). Chinese participants are less likely to achieve healthy ageing than participants from the US, England and Japan (hypothesis three).

Methods

Data

The data were from the US Health and Retirement Study (HRS) (Sonnega *et al.* 2014), the English Longitudinal Study of Ageing (ELSA) (Steptoe *et al.* 2013), the China Health and Retirement Longitudinal Study (CHARLS) (Zhao *et al.* 2014) and the Japanese Study of Aging and Retirement (JSTAR) (Hidehiko, Satoshi and Hideki 2010). For the HRS, the analysis included data from waves 7–12 (2004–2014). Wave 7 rather than wave 1 of the HRS was used as the baseline wave. The reason is that some variables, such as social well-being-related variables, only started being recorded from 2004 (wave 7) in the HRS. For ELSA, data from waves 1–7 (2002–2015) were used. In CHARLS, data from waves 1, 2 and 4 (2011–2015) were included. Wave 3 of CHARLS was a life history survey, and is not eligible for the current longitudinal analysis. In JSTAR, only participants from the original five cities from waves 1–3 (2007–2011) were included.

See supplementary Figure S1 for sample selection details. Participants were aged 60 years or more at baseline. Individuals without healthy ageing outcomes and booster samples without baseline weights were excluded. We finally included 10305 (6056 women) American, 6590 (3685 women) English, 5930 (2862 women) Chinese and 1935 (995 women) Japanese participants.

Healthy Ageing Index

We followed three principles for creating a healthy ageing index (HAI, time-varying). First, healthy ageing should be measured in a multi-dimensional way. Both biological and psychosocial components should be considered. Psychological and social well-being are measured in order to examine the effects of self-efficacy, social roles and social support on functional well-being (Lara *et al.* 2013, Lu, Pikhart and Sacker 2019). Second, "resilience" should be taken into account when measuring healthy ageing. Healthy ageing is not simply a "disease free" ageing status and should not be a binary variable (yes versus no). Older people are capable of taking advantage of their current capacities to deal with their illnesses or impairments. (Baltes and Baltes 1990, World Health Organization 2015). Third, each scale or method which is applied to measure healthy ageing should reflect a specified conceptual domain. Measuring physical capabilities by (I)ADLs, grip strength and other functional limitations (e.g. mobility, large muscle and fine motor skill), cognitive functions by verbal memory and orientation to time, physiological health by self-reported absence of chronic diseases, psychological well-being by CES-D Scale and questions about life satisfaction, and social well-being by participation in social activities were recommended (Lu, Pikhart and Sacker 2019).

The HAI included thirty-three indicators in physical, cognitive, physiological, psychological and social components of healthy ageing, considered resilience and chose established scales with clear conceptual domains (Figure 1). Each health indicator was dichotomised or organised into quartiles or quintiles, and then coded for the interval 0–100 (supplementary Table S1). For each individual, the scores on all indicators were summed and divided by the total number of measured indicators to yield an HAI score ranging from 0 to 100. A higher score of HAI indicates healthier ageing status.

<Insert Figure 1 about here>

See supplementary Tables S2, S3 and S4, and Figure S2 for validity and reliability check in detail. The test-retest reliability and internal consistency of HAI were both >0.7, in an acceptable range (McDowell 2006). The prediction of mortality by HAI was similar to that of phenotypic frailty (PF) (Fried *et al.* 2001). However, compared to the measure of PF, the HAI measured more psychosocial components such as social participation and life satisfaction. The $\log_e$-transformed HAI was used for analysis due to HAI's left-skewed distribution.

Socioeconomic Indicators

The socioeconomic indicators were baseline education, and time-varying income and wealth. The International Standard Classification of Education (1997) was applied (UNESCO Institute for Statistics 2014). Educational categories were first stage of tertiary education or more (FI), post-secondary non-tertiary education (PO), upper secondary education (UP), lower secondary education (LO), primary education or less and others (PR). Total household income was divided by the square root of household size to give income per capita (OECD 1995). Wealth was the total family assets. Both income and wealth were organised into quintiles, ranging from the highest to the lowest level in each country.

Covariates

Both baseline and time-varying covariates known to be associated with SEP and healthy ageing were included (Hirai, Kondo and Kawachi 2012, Li *et al.* 2006, Perales *et al.* 2014, Sowa *et al.* 2016). Baseline variables were gender (male and female), ethnicity (white, black and others in HRS, white and non-white in ELSA, and Han and minority in CHARLS) and self-rated health in childhood (excellent, good, fair, poor and very poor). Time-varying variables were age in years, cohort (birth year), marital status (married/partnered, separated/divorced/single and widowed), smoking (current, previous and non-smokers) and drinking (frequency of drinking). Occupation (time-varying) and father's occupation (baseline) were also included as important socioeconomic predictors during adulthood and childhood, respectively. Full harmonisation of occupational measures across the four countries was not achievable due to the disparities in societal background. Supplementary Table S5 shows semi-harmonising strategies for occupation in the four countries.

Statistical Analyses

The two-fold fully conditional specification (FCS) algorithm was applied to deal with missing values in socioeconomic indicators and covariates (Welch, Bartlett and Petersen 2014). Age in each wave was used as the timing variable. Compared to the wave number, which assumes that every respondent is measured at the same time point, age is more accurate in measuring the changes of HAI over time as it specifies entry and exit time for each individual differently. Records with imputed values for non-respondents in each wave were automatically excluded as the two-fold FCS algorithm only imputed non-responded items within each wave rather than non-responders in that wave. See supplementary Table S6 for percentages of missing values in each study. Fifty imputed datasets were generated in each country, to ensure the number of imputations was large enough not to impact conclusions or inhibit analysis reproducibility. Baseline weighting adjustment was employed to account for complex survey designs.

To compare socioeconomic inequalities in healthy ageing across countries, socioeconomic rank scores (0-1, from the highest to lowest) were derived based on distributions of the education, income and wealth in each country (Regidor 2004). See Supplementary Figure S3 for a hypothetical example using the educational classification to derive a socioeconomic rank score.

Associations between socioeconomic rank scores and $\log_e$-transformed HAIs were assessed using multilevel modelling to calculate the Slope Index of Inequality (SII), accounting for the entire socioeconomic distribution and the sample size of each category of socioeconomic indicator to make results comparable across countries (Regidor 2004). An advantage of applying a multilevel approach is that the methodology is capable of handling attrition and wave non-response, unequal time spacing, and the inclusion of time-varying covariates that are either continuous or discrete measures (Raudenbush and Chan 1992). Age-cohort (AC) models were estimated adjusting for all covariates and relevant interactions, and allowing for random intercepts and slopes. The AC model does not constrain the linear effect of period. Rather the period effect is integrated into slopes in the age and cohort dimensions (Nielsen and Nielsen 2014). SII was interpreted as the percentage of change in predicted mean HAI when individuals moved from the most to the least advantaged socioeconomic groups (score changed from 0 to 1). Larger values reflect greater inequality. Coefficients for socioeconomic rank scores indicated the cross-sectional relationships between socioeconomic rank scores and HAIs at 60 years. Coefficients for interactions between socioeconomic rank scores and age indicated the trend of change in the SII thereafter.

Additionally, healthy ageing trajectories were predicted based on the results of AC models, to compare older people's healthy ageing profiles across countries. The "observed value" approach was applied to draw conditional trajectories, which holds each covariate at the observed value for each individual in the sample, calculates the relevant predicted marginal effect for each individual, and averages over all cases (Hanmer and Kalkan 2013).

Besides, in each country, trajectories of $\log_e$-transformed HAIs by different categories of education were also drawn, based on the fully adjusted AC model. The AC model in each country was estimated from a non-standardised base since the original variable of education was used for longitudinal analysis. We illustrated these trajectories in order to set an example for visualising socioeconomic inequalities in healthy ageing during the entire later life and helping interpret the interaction terms between SEP and age.

STATA 15.1 was applied for data analysis and $P < 0.05$ was considered statistically significant.

Results

Table 1 shows baseline characteristics. There were more females in the US, England and Japan, but more males in China. Participants were mainly white in the US and England, and Han in China. Most participants had the upper secondary education in the US, primary education or less in England and China, and upper or lower secondary education in Japan. The majority of American participants had already retired at baseline. English participants mainly had intermediate occupational positions. More than 70% of Chinese participants were in unpaid agricultural work only. 22.25% of Japanese participants were in the most disadvantaged occupations. American participants' fathers had mainly been in disadvantaged occupational positions (around 70%) while English fathers' occupational positions were mainly at intermediate levels (around 70%). Most Chinese and Japanese participants' fathers were farming workers (78.30%) and self-employed (52.46%), respectively. Fewer American and English participants consumed alcohol every day and reported poor childhood health than Chinese and Japanese participants. Moreover, there was a great proportion of current smokers among Chinese and Japanese participants.

<Insert Table 1 about here>

In Table 2, the linear coefficients of education, income and wealth present the SII at 60 years: the proportions of average change in HAI at 60 years if individuals had moved from the most to the least advantaged socioeconomic groups in the four countries; the linear coefficients of interactions between education/income/wealth and age present the trends of SII thereafter: the gap in average HAI changes after 60 years between the most and the least advantaged socioeconomic groups. Figure 2 summarises the results in Table 2, by illustrating the predicted SIIs for education, income and wealth at 60 years in the four countries, to compare the magnitude of healthy ageing inequalities by education, income and wealth within and across countries.

<Insert Table 2 and Figure 2 about here>

There was a non-linear relationship between age and $\log_e$-transformed HAI among American, English and Japanese participants (Table 2). The decline of healthy ageing accelerated with increased age. Among Chinese participants, both linear and quadratic age terms were non-significant.

Relationships between educational rank scores and HAIs at 60 years were significant in the four countries (Model 1). Participants with lower levels of education were less likely to achieve healthy ageing than those with higher levels of education. Moving from the highest to the lowest educational groups was associated with a 6.7% (5.2% to 8.2%), 8.2% (6.0% to 10.4%), 13.9% (11.4% to 16.3%) and 6.1% (3.9% to 8.2%) decrease in average HAI at 60 years in the US, England, China and Japan, respectively. This inequality in HAI between the highest and lowest educational groups kept increasing with age after 60 years in the US and China, due to significant and negative interactions between age and education.

Relationships between income rank scores and HAIs at 60 years were significant only in the US and China (Model 2). Participants with lower levels of income were less likely to achieve healthy ageing than those with higher levels of income. Moving from the highest to the lowest income quintiles was associated with a 1.4% (0.7% to 2.2%) and 3.2% (1.7% to 4.8%) decrease in average HAI at 60 years in the US and China, respectively. However, this inequality in HAI between the highest and lowest income groups did not change with age after 60 years in the US and China, due to boundary or non-significant interactions between age and income.

Relationships between wealth rank scores and HAIs at 60 years old were significant in the US, England and Japan (Model 3). Participants with lower levels of wealth were less likely to achieve healthy ageing than those with higher levels of wealth. Moving from the highest to the lowest wealth quintiles was associated with a 3.3% (2.4% to 4.3%), 6.2% (4.9% to 7.5%) and 1.5% (0.1% to 3.0%) decrease in average HAI at 60 years in the US, England and Japan, respectively. However, this inequality in HAI between the highest and lowest wealth groups only increased with age after 60 years in the US, due to a significant and negative interaction between age and wealth.

Figure 3 shows predicted healthy ageing trajectories after 60 years across countries. The gradient in healthy ageing across countries was clear. Japanese participants were healthier after 60 years than participants in any other country. Chinese participants had the worst health profiles in each year after the age of 60. English and American participants' healthy ageing ranked second and third respectively. However, the four trajectories might aggregate in very old age. The rates of decline in healthy ageing accelerated with increased age in the US, England and Japan. However, in China, the slope did not change across ages, due to the non-significant non-linear effect of age, suggesting a constant rate of decline in HAI across ages after 60 years.

<Insert Figure 3 about here>

Figure 4 illustrates predicted trajectories of healthy ageing by categories of education in each country. Generally in the four countries, the educational gradients in healthy ageing were clear after 60 years. Participants with higher levels of education had better health profiles than those with lower levels of education in each year after the age of 60. In both the US and China, due to significant and negative interactions between education and age, trajectories for primary education or less declined much faster than any other educational trajectory; the inequality in healthy ageing between the highest and lowest educational groups kept increasing during the entire later life. In either England or Japan, even though the declining rates of trajectories were similar at each age, the trajectory for participants with primary education or less kept staying lower than any other trajectory in later life.

<Insert Figure 4 about here>

Discussion

In summary, participants with advantaged SEP were more likely to achieve healthy ageing than participants with disadvantaged SEP. Education was the strongest predictor of healthy ageing in the four countries (hypothesis one for the US and China was accepted and rejected, respectively). The inequality in healthy ageing between the highest and lowest educational groups kept increasing with age after 60 years in the US and China. Wealth was an influential indicator in the US, England and Japan, while income was an influential indicator in the US and China. The educational inequality in healthy ageing in China was distinctly larger than any other socioeconomic inequality in healthy ageing in the four countries (hypothesis two for China was accepted). The wealth inequality in healthy ageing in England was larger than that in the US and Japan. The magnitude of socioeconomic inequalities in healthy ageing was relatively small in Japan (hypothesis two for Japan was accepted). Japanese, English, American and Chinese participants' healthy ageing in later life ranked first, second, third and last respectively (hypothesis three was accepted).

Educational Inequalities in Healthy Ageing

Education was the strongest predictor of healthy ageing in the four countries. Education is widely used as a measure of social status, since it is a key mechanism involved in raising a person's status (Hollingshead 2011). Many studies have found a strong association between education and later-life health. For example, education-related differences in mortality and life expectancy have widened over the past 20–25 years in the US (Hummer and Hernandez 2013). In England, having lower education was related to reporting poorer later-life health (Grundy and Holt 2001). In China, persons who were illiterate and low-educated had significantly higher levels of depression (Li *et al.* 2015a). In Japan, older people with lower education had a higher risk of experiencing early mortality than people with higher education (Fujino *et al.* 2005).

Researchers believed that attaining more education makes people pay greater attention to their health (Wang and Yu 2016). More importantly, a higher level of education may lead to a higher level of income and a more advantaged occupational position. People with better socioeconomic conditions are more likely to be healthy (Marmot 2005).

The educational inequality in healthy ageing among the Chinese participants was distinctly larger than any other socioeconomic inequalities in healthy ageing in the four countries. Education in China is a ladder to social success, especially among the older generations. China started making tremendous efforts to improve the quality of education only after the late 1950s; the major transformations of the educational system only started in the early 1980s (Rong and Shi 2001). Therefore, most Chinese participants in our study ended up illiterate or with an education at less than secondary-school level; few of them went to university for bachelor's or higher studies (see Table 1). However, enterprises and governments desperately needed highly educated "talent" to contribute to economic acceleration and capital accumulation in the late 20th century in China (Rong and Shi 2001). In this context, educational inequalities created significant income and occupational gaps, since persons with bachelor's degrees or more during that time quickly achieved upward social mobility, gaining higher incomes and occupational positions and greater asset accumulation (Rong and Shi 2001). From a lifecourse perspective, this is intra-generational mobility – a change from a disadvantaged SEP to an advantaged SEP within one's own lifecourse (Hallqvist *et al.* 2004). During this time, highly educated people might have had a healthier working life, a less deprived living environment, more positive social participation, and stronger economic and social security. Therefore, among the older generations, compared with those who did not even go to secondary school, people with bachelor's degrees or more in China were far more likely to achieve healthy ageing.

Wealth versus Income Inequalities in Healthy Ageing

Wealth was another influential predictor of healthy ageing among American and English participants. A study found that compared with education and income, wealth was the strongest predictor of mortality among the American elderly (Hoffmann 2011). Researchers also suggested that total net non-pension household wealth was the most robust indicator of current SEP in England since it captured financial and other material resources at older ages the most accurately (Steptoe *et al.* 2013). A US/UK study found that those in the lowest wealth quintile had higher risks of death and disability than their counterparts in the highest wealth quintile (Makaroun *et al.* 2017).

However, wealth was not an influential predictor of healthy ageing in China. Wealth inequality in healthy ageing was unclear in China in this study. In the literature, evidence for wealth inequality in health among the Chinese elderly is limited. We only found one English publication, suggesting that more luxury items and better housing quality were associated with less depression among the rural Chinese ageing population (Li *et al.* 2015b). Wealth inequality in property ownership in China has been rising dramatically during the past decades. In 2012, 78.7% and 60.9% of household wealth consisted of housing assets in urban and rural China respectively; from 2013 to 2015, property income rose by 9.9%, while salary income increased by only 8.9% (National Bureau of Statistics of China 2016). However, some researchers believe that compared with developed countries, the achievement of high levels of population health in China might not require a generally high level of national wealth. Social investments to eliminate illiteracy, improve the quality of education, protect farmers' benefits, provide universal primary healthcare services and meet basic living needs were more important for achieving healthy ageing in China (Schweiger 1997).

We found that income was less influential in the US, and not influential in England. For older people, the source of income was mainly pensions and other public benefits. Researchers found that in the US, compared with the working-age population, government transfers had been more equally distributed among the ageing population (Bosworth, Burtless and Zhang 2016). Similarly, pension income inequality was substantially lower in the UK than that in other developed countries (Sefton, Evandrou and Falkingham 2007). Equally distributed government transfers might buffer the effect of income on inequalities in healthy ageing. Therefore fewer income disparities in healthy ageing were found among American and English participants.

However, previous studies still found income inequalities in health among the elderly in the US and England. For example, a US study found that low income was a more influential risk factor for mortality than low education (Hoffmann 2011). Another UK study found worse self-reported health among older people on low incomes (Grundy and Holt 2001).

Researchers found that the distribution of private pension was unequal in the US: private pensions increased annual income inequality by 21% among low-income workers (Benedict and Shaw 1995). In the UK, researchers held the opinion that the pension system was effective in preventing the "very bottom" but not "low to moderate" poverty (Sefton, Evandrou and Falkingham 2007). Unequal pension income might still contribute to disparities in healthy ageing. Disaggregating income into pension or unearned income versus earned income and assessing their associations with healthy ageing respectively might be more instructive for finding out income inequalities in healthy ageing in each country.

Differently in China, income was an influential indicator. Income inequality in healthy ageing tended to be larger than that in any other country. A study found that income was the dominant risk factor for inequalities in healthcare utilisation among outpatients in both developed and developing provinces of China (Wang *et al.* 2012). Pension income is an important socioeconomic determinant of health in China. However in 2013 the ratio of average benefits in China was estimated at 50:25.5:1 for civil servants', workers' and residents' pensions respectively; more than 400 million people in China had no old age pension at all (International Labour Office 2015). The huge gaps among pension schemes, and between pension receivers and non-receivers, greatly contribute to inequalities in living standards and in the utilisation of health services in China.

Equity in Healthy Ageing in Japan

The magnitude of healthy ageing inequalities in Japan was relatively small. Japanese participants had the best healthy ageing profile. Since 1986, Japan has ranked first in the world for women's life expectancy in childbirth (Reich and Shibuya 2015). Low-cost health services in Japan during the past decades have maintained people's health and increased social equity among the general population (Reich and Shibuya 2015). Japanese society became more economically egalitarian after the Allied occupation of Japan (1945–1952). Japanese people focused on productive outcomes, and on societal rather than market or individual opportunities, which had profound health effects among the general population (Bezruchka, Namekata and Sistrom 2008). By 1970, the income ratio between the top and bottom income quintiles had decreased to 4.3:1 in Japan, while in the same year the ratio was 7.1:1 in the US (Vogel 1979).

However, we still found significant educational and wealth inequalities in healthy ageing among Japanese participants. A previous study found that older people with lower levels of education had a higher risk of experiencing early mortality than people with higher levels of education (Fujino *et al.* 2005). Socioeconomic inequalities in life expectancy and mortality increased continuously between 1995 and 2000 in Japan (Fukuda *et al.* 2007). Therefore, Japan's achievement in promoting healthy ageing among the general population in a more equal society cannot be denied. However, more empirical evidence is needed regarding socioeconomic inequalities in healthy ageing in Japan, based on data with fewer missing values, less skewed distributions of variables and a wider age range.

The Great Gap in Healthy Ageing across Countries

Japanese, English, American and Chinese participants' healthy ageing in later life ranked first, second, third and last respectively. This rank is similar to the rank of life expectancy after 60 years in 2017 in the four countries (G. B. D. Mortality Collaborators 2018). Chinese participants had the worst health profiles on average. This lag in achieving healthy ageing might be affected by great health disparities in China. The educational inequality in China was distinctly larger than any other socioeconomic inequality in healthy ageing across countries in this study. However the socioeconomic gap in health is still enlarging due to unequal distribution of income, wealth and health care services in China (Fang *et al.* 2010).

The US government spends more on healthcare than any other developed country (OECD Data 2015). However, the American population is still less healthy than the Japanese and English populations. Compared with England and Japan, adults in the US were more economically disadvantaged in attaining health care services: 37% of adults in the US did not see a doctor or failed to fill a prescription because of high costs (The Commonwealth Fund 2016). The socially produced inequalities in health status in the US have made the achievement of healthy ageing more difficult than in the UK and Japan.

Strengths

First, we referred to multiple theories for the measurement of healthy ageing. The HAI was developed to include both biological and psychosocial components of healthy ageing, and to consider social opportunities and resilience, thus measuring healthy ageing in a comprehensive way. The HAI can be applied as a preliminary screening of healthy agers after 60 years of age in the four countries, which might help clinicians and researchers identify patients' healthy ageing profiles.

Second, this research fills a research gap by comparing socioeconomic inequalities in healthy ageing among Asian, European and North American countries. The use of four national longitudinal studies of ageing, with around 25000 representative older adults, has provided a unique opportunity to conduct a Western-Asian comparison of healthy ageing, which to our knowledge has never been done before. Identifying influential socioeconomic predicators of healthy ageing in each country is instructive for exploring universal and country-specific public health practices in supporting healthy ageing among both Western and Asian countries.

Third, advanced statistics were employed appropriately. The two-fold FCS algorithm is able to specify an entry and exit time for each participant; automatically consider interactions between age and other variables; and impute non-responding items only, but not non-responders, in each wave. We also calculated the SII based on a multilevel linear regression equation with full adjustment. Confounding and random effects were taken into account. This multilevel approach allows the prediction of the SII at 60 years and of changing rates of SII after 60 years.

Limitations

First, this study included US data from 2004 to 2014 (11 years) and English data from 2002 to 2015 (14 years), while Chinese data were only available from 2011 to 2015 (five years) and Japanese data from 2007 to 2011 (five years). The data from the US and England had stronger statistical power for conducting longitudinal analyses than the data from China and Japan, due to the larger sample sizes and longer follow-up durations.

Second, to make results comparable, only variables common to the four studies were included in the HAI and for conducting data analyses. However, some country–specific variables, such as Index of Multiple Deprivation scores in England, financial support from children in China, and home ownership in Japan might also be markers of healthy ageing and explain variations in SEP – healthy ageing relationships. Besides, geographical variables are unavailable in JSTAR; and for other countries, variables measure region at various area levels due to different degrees of data confidentiality. However, disparities in healthy ageing across regions within each country could exist. Future study with detailed geographical information could explore the regional inequality in healthy ageing in each country.

Third, an occupational rank score was not derived since occupation does not have a strict hierarchical ranking (Regidor 2004), although occupation was included as a covariate.

Fourth, a selective survival bias might exist. When we conducted the data analysis, participants without valid HAIs at baseline were excluded. We only imputed item non-response for main exposures and covariates in each wave. Those respondents without HAIs were more likely to have severe illness (Delgado-Rodríguez and Llorca 2004). Moreover, this research excluded individuals aged less than 60 years at baseline. Distributions of some covariates among respondents might be altered and variation in risk factors might also be reduced due to survival selection.

Last, SIIs only represent the average change in healthy ageing by SEP, accounting for less than 20% of the variability in HAIs. Moreover, variations in HAIs were small especially in Japan (Std. Dev. = 6.89).

Conclusions

In conclusion, Japanese and English participants achieved healthier ageing than American and Chinese participants. A positive socioeconomic gradient in healthy ageing existed in all countries. Socioeconomic inequality in healthy ageing was relatively small in Japan, but more evidence over time is needed. In China, inequality in healthy ageing, especially by education, was daunting.

Education was a universally influential socioeconomic predictor of healthy ageing across countries. After 60 years, the educational inequality in healthy ageing in the US and China kept increasing, indicating that this early-life socioeconomic factor could affect individuals' healthy ageing later in the life course. Wealth inequality in healthy ageing was greater in England than in any other country. Wealth was more influential than income in predicting inequalities in healthy ageing in the US, England and Japan, while income was more influential than wealth in China. More evidence is needed for the effects of pension income on healthy ageing in the US and UK, and the effects of wealth on healthy ageing in China.

Declaration of Interests

None declared.

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ELSA was developed by a team of researchers based at NatCen Social Research, University College London, and the Institute for Fiscal Studies. The data were collected by NatCen Social Research. The funding was provided by the National Institute of Ageing in the USA, and by a consortium of UK government departments coordinated by the Office for National Statistics. The ELSA data were made available through the UK Data Archive at http://www.data-archive.ac.uk/.

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JSTAR was conducted by the Research Institute of Economy, Trade and Industry (RIETI), Hitotsubashi University, and the University of Tokyo. JSTAR datasets are distributed by RIETI in Tokyo (see https://www.rieti.go.jp/en/projects/jstar/).

Harmonised datasets from the Gateway to Global Aging Data website (https://g2aging.org/) were used where possible. Not all of the variables in the analysis came from that website, since the harmonisation of some variables needed for this study had not been completed, and some variables were only semi-harmonised, despite notable differences in measures and categories. Instead, many variables were taken from the four original databases and harmonised for analysis in this study.

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Ethical Approval

This study is based on secondary data analysis. No ethical approval is needed.

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Figure 1 Indicators of constructing the HAI

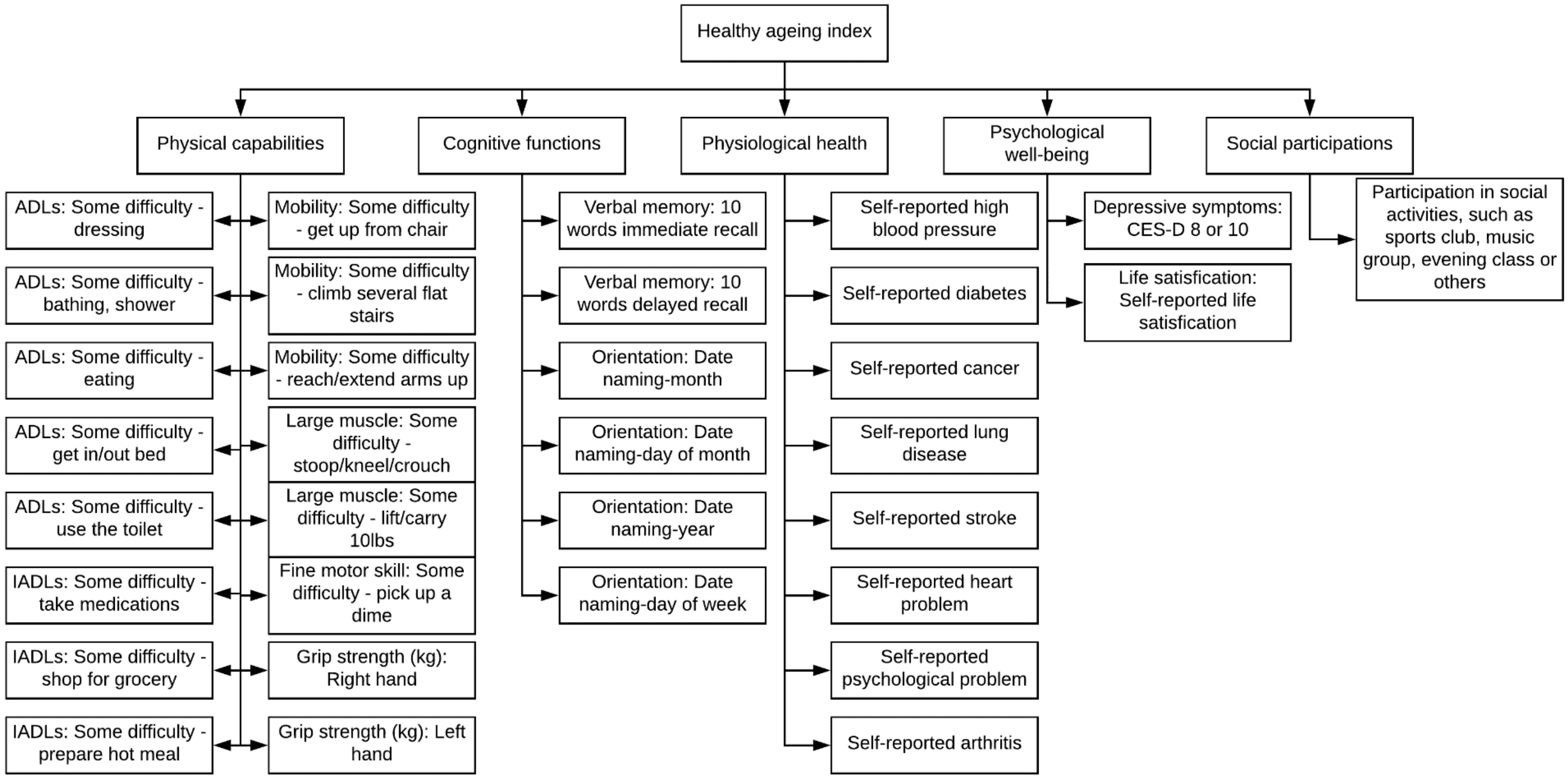


Table 1 Sample characteristics at baseline

	US	England	China	Japan*
HAI (Mean)	76.54 (10.87)	79.44 (11.91)	75.11(13.00)	85.54 (6.89)
Age (Mean)	72 (8.25)	71 (7.78)	68 (6.98)	67 (4.24)
Gender (%)				
Male	41.23	44.08	51.74	48.59
Female	58.77	55.92	48.26	51.41
Ethnicity (%)**				
1	83.84	98.29	93.14	-
2	12.86	1.71	6.86	-
3	3.30			-
Education (%)				
First stage of tertiary or more	20.90	9.41	2.12	10.59
Post-secondary non-tertiary	-	10.42	3.24	5.20
Upper secondary education	54.10	4.51	2.26	39.70
Lower secondary education	16.34	18.43	37.67	43.86
Primary education or less	6.66	57.22	54.70	0.65
Income (%)				
Highest	19.85	20.61	20.18	19.32
2nd	20.40	20.44	20.22	20.29
3rd	20.50	20.12	20.25	20.39
4th	20.17	19.79	20.43	20.41
Lowest	19.08	19.04	18.93	19.59
Wealth (%)				
Highest	20.52	20.54	20.05	19.84
2nd	20.47	20.43	19.81	20.23
3rd	20.29	20.35	20.40	18.47
4th	19.89	19.71	20.44	21.52
Lowest	18.83	18.96	19.30	19.94
Occupation* (%)**				

	US	England	China	Japan*
I	4.17	8.37	2.08	6.94
II	3.79	20.75	2.73	13.29
III	1.95	14.19	6.76	22.25
IV	0.62	11.30	18.28	0.46
V	0.87	12.46	70.16	57.06
VI	1.38	17.04	-	-
VII	5.74	14.20	-	-
VIII	73.39	1.69	-	-
IX	0.65	-	-	-
X	0.78	-	-	-
XI	6.66	-	-	-
Marital status (%)				
Married or partnered	57.96	59.71	79.39	83.00
Separated, divorced or single	13.23	11.72	2.19	4.60
Widowed	28.81	28.57	18.41	12.40
Father's occupation* (%)**				
I	13.47	10.71	4.88	28.75
II	10.98	10.46	3.94	52.46
III	4.45	35.49	1.96	3.09
IV	26.86	4.46	4.12	15.70
V	21.61	8.28	78.30	-
VI	21.70	27.16	3.69	-
VII	0.93	0.88	3.11	-
VIII	-	2.57	-	-
Self-rated health in childhood (%)				
Excellent	50.06	29.44	10.18	-
Good	25.53	34.64	36.75	-
Fair	18.15	22.90	27.83	-
Poor	4.84	9.02	17.69	-

	US	England	China	Japan*
Very poor	1.42	4.00	7.56	-
Smoking status (%)				
Never smoke	43.13	35.86	56.53	55.60
Ever smoked, now no smoke	47.94	53.44	12.59	27.04
Smoke	8.94	10.70	30.88	17.36
Frequency of drinking** (%)**				
0	69.07	38.02	77.56	43.54
1	9.36	13.92	4.20	12.45
2	5.08	12.28	4.17	6.42
3	3.83	8.56	1.71	15.59
4	1.87	5.56	12.36	22.01
5	2.03	4.40	-	-
6	1.04	3.87	-	-
7	7.73	13.39	-	-

[*] Japan does not have ethnicity and self-rated health in childhood variables. The ethnicity was recoded as one for all in data analyses. The sensitivity analysis confirmed that not adjusting for the self-rated health in childhood in Japan would not bias the comparison of socioeconomic impact on HAI across countries.

[**] In the US, 1=White/Caucasian 2=Black/African American 3=Others; In England, 1=White 2=Non-white; In China, 1=Han 2=Minorities.

[***] See Supplementary Table S3 for detailed categories of occupation and father's occupation in the four countries.

[****] In the US and England, frequency of drinking = days of drinking per week (0=None 1=1 day 2=2 days 3=3 days 4=4 days 5=5 days 6=6 days 7=7 days); In China, frequency of drinking= times of drinking per month (0=non or less than once per month 1=one to several times per month 2=one to several times per week 3=most days of the week 4=every day of the week; In Japan, frequency of drinking= times of drinking per month (0=None 1=A few times in month 2=1-2 in a week 3=3-4 in a week 4=(Almost) every day)

Table 2 Results of fully adjusted linear multilevel models* for associations between socioeconomic rank scores and HAI (log_e-transformed) across countries *

Main exposures	US		England		China		Japan	
Model 1 – Educational rank scores								
Fixed effects	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**
Age	-0.012 (-0.013 to -0.010)	<0.001	-0.008 (-0.010 to -0.007)	<0.001	-0.014 (-0.039 to 0.012)	0.295	-0.002 (-0.006 to 0.002)	0.259
Age^2	-0.0001 (-0.0002 to -0.00001)	0.027	-0.0003(-0.0004 to -0.0002)	<0.001	0.0002(-0.0002 to 0.0005)	0.317	-0.001 (-0.002 to -0.001)	<0.001
Education	-0.067 (-0.082 to -0.052)	<0.001	-0.082 (-0.104 to -0.060)	<0.001	-0.139 (-0.163 to -0.114)	<0.001	-0.061 (-0.082 to -0.039)	<0.001
Education*age	-0.004 (-0.005 to -0.002)	<0.001	-0.0001 (-0.002 to 0.001)	0.340	-0.003 (-0.006 to -0.0001)	0.044	-0.002 (-0.005 to 0.0005)	0.102
Intercept	4.440 (4.426 to 4.453)	<0.001	4.511 (4.492 to 4.530)	<0.001	4.415 (4.283 to 4.547)	<0.001	4.484 (4.463 to 4.505)	<0.001
Random effects	**S.D. (95%CIs)**		**S.D. (95%CIs)**		**S.D. (95%CIs)**		**S.D. (95%CIs)**	
Level 1: residual	0.081 (0.080 to 0.081)	-	0.076 (0.075 to 0.077)	-	0.116 (0.114 to 0.118)	-	0.050 (0.048 to 0.052)	-
Level 2: intercept	0.132 (0.130 to 0.134)	-	0.136 (0.134 to 0.139)	-	0.153 (0.149 to 0.158)	-	0.076 (0.073 to 0.080)	-
Level 2: age	0.010 (0.009 to 0.010)	-	0.009 (0.008 to 0.009)	-	0.005 (0.004 to 0.008)	-	0.008 (0.007 to 0.009)	-
Model 2 – Income rank scores								
Fixed effects	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**
Age	-0.012 (-0.013 to -0.010)	<0.001	-0.008 (-0.010 to -0.007)	<0.001	-0.014 (-0.039 to 0.012)	0.297	-0.002 (-0.006 to 0.002)	0.247
Age^2	-0.0001 (-0.0002 to -0.00001)	0.028	-0.0003 (-0.0004 to -0.0002)	<0.001	0.0002 (-0.0002 to 0.0005)	0.320	-0.001 (-0.002 to -0.001)	<0.001
Income	-0.014 (-0.022 to -0.007)	<0.001	0.005 (-0.004 to 0.014)	0.296	-0.032 (-0.048 to -0.017)	<0.001	-0.009 (-0.022 to 0.005)	0.207
Income*age	0.00006 (-0.00004 to 0.001)	0.065	0.001 (0.0001 to 0.002)	0.027	-0.0001 (-0.002 to 0.002)	0.950	-0.001 (-0.003 to 0.001)	0.273
Intercept	4.452 (4.439 to 4.465)	<0.001	4.509 (4.490 to 4.528)	<0.001	4.422 (4.290 to 4.553)	<0.001	4.480 (4.459 to 4.501)	<0.001
Random effects	**S.D. (95%CIs)**		**S.D. (95%CIs)**		**S.D. (95%CIs)**		**S.D. (95%CIs)**	
Level 1: residual	0.081 (0.080 to 0.081)	-	0.076 (0.075 to 0.077)	-	0.116 (0.114 to 0.118)	-	0.050 (0.048 to 0.052)	-

Level 2: intercept	0.132 (0.130 to 0.135)	-	0.137 (0.134 to 0.139)	-	0.153 (0.149 to 0.158)	-	0.076 (0.073 to 0.080)	-
Level 2: age	0.010 (0.009 to 0.010)	-	0.009 (0.008 to 0.009)	-	0.005 (0.004 to 0.008)	-	0.008 (0.007 to 0.009)	-
Model 3 – Wealth rank scores								
Fixed Effects	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**	**b (95%CIs)**	**P-values**
Age	-0.012 (-0.013 to -0.010)	<0.001	-0.008 (-0.010 to -0.007)	<0.001	-0.014 (-0.039 to 0.012)	0.298	-0.002 (-0.006 to 0.002)	0.245
Age^2	-0.0001 (-0.009 to -0.008)	0.028	-0.0003 (-0.0004 to -0.0002)	<0.001	0.0002 (-0.0002 to 0.0005)	0.334	-0.001 (-0.002 to -0.001)	<0.001
Wealth	-0.033 (-0.043 to -0.024)	<0.001	-0.062 (-0.075 to -0.049)	<0.001	-0.007 (-0.023 to 0.009)	0.378	-0.015 (-0.030 to -0.001)	0.037
Wealth*age	-0.0007 (-0.001 to -0.0001)	<0.001	-0.001 (-0.002 to 0.0002)	0.108	0.000004 (-0.002 to 0.002)	0.997	0.002 (-0.0004 to 0.005)	0.096
Intercept	4.433 (4.420 to 4.446)	<0.001	4.507 (4.488 to 4.526)	<0.001	4.421 (4.289 to 4.552)	<0.001	4.481 (4.460 to 4.501)	<0.001
Random effects	**S.D. (95%CIs)**		**S.D. (95%CIs)**		**S.D. (95%CIs)**		**S.D. (95%CIs)**	
Level 1: residual	0.081 (0.080 to 0.081)	-	0.076 (0.075 to 0.077)	-	0.116 (0.114 to 0.118)	-	0.050 (0.048 to 0.052)	-
Level 2: intercept	0.132 (0.130 to 0.134)	-	0.137 (0.134 to 0.140)	-	0.153 (0.149 to 0.158)	-	0.076 (0.073 to 0.080)	-
Level 2: age	0.010 (0.009 to 0.010)	-	0.009 (0.008 to 0.009)	-	0.005 (0.004 to 0.008)	-	0.008 (0.007 to 0.009)	-

[*] Each model was adjusted for other socioeconomic rank scores, age, age^2, cohort, cohort^2, gender, ethnicity, self-rated health in childhood, father's occupation, occupation, marital status, smoking and drinking, as well as interactions between gender and the main socioeconomic rank scores, age and the main socioeconomic rank scores, age and cohort, age and marital status, and age and smoking.

Figure 2 Predicted SIIs of HAI by education, income and wealth at 60 years in each country

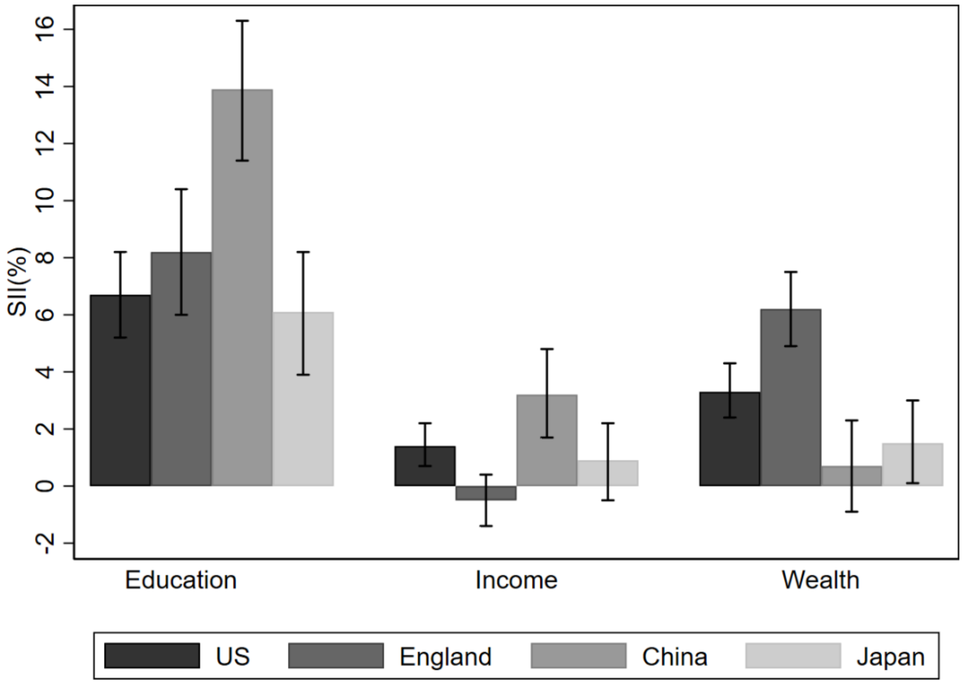
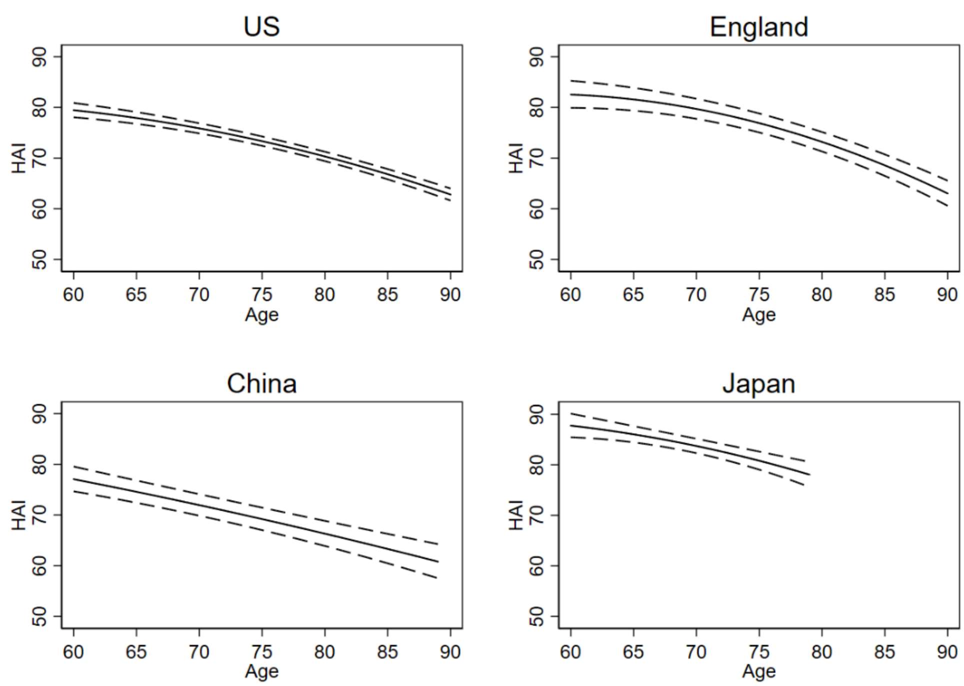
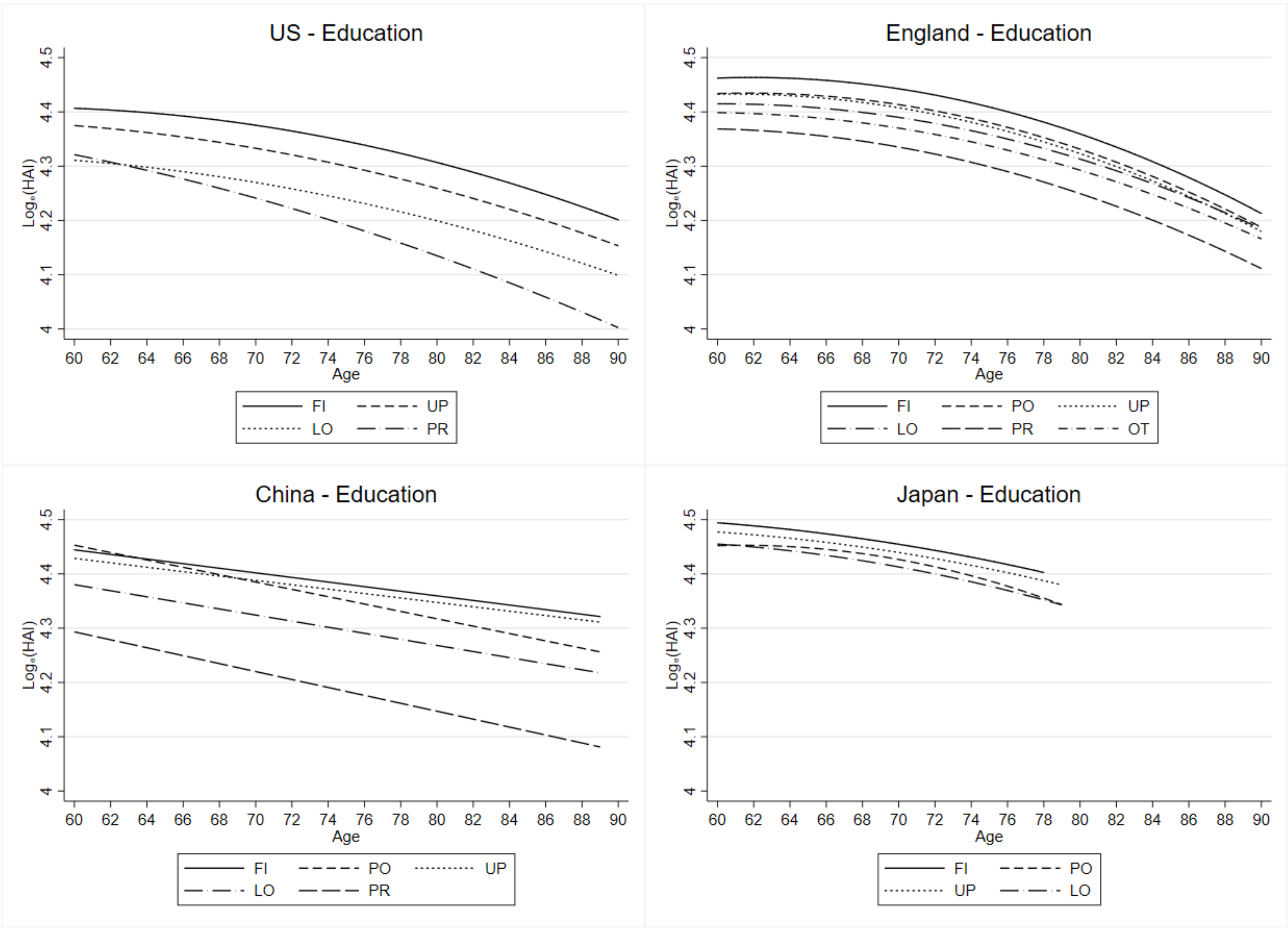


Figure 3 Predicted trajectory of healthy ageing after 60 years in each country*



* In Japan, the trajectory before 79 years was presented since all participants aged 79 or less.

Figure 4 Predicted trajectories of healthy ageing by categories of education after 60 years in each country*



* In Japan, the trajectory before 79 years was presented since all participants aged 79 or less.

Supplementary Material
Figure S1 Procedures of sample selection

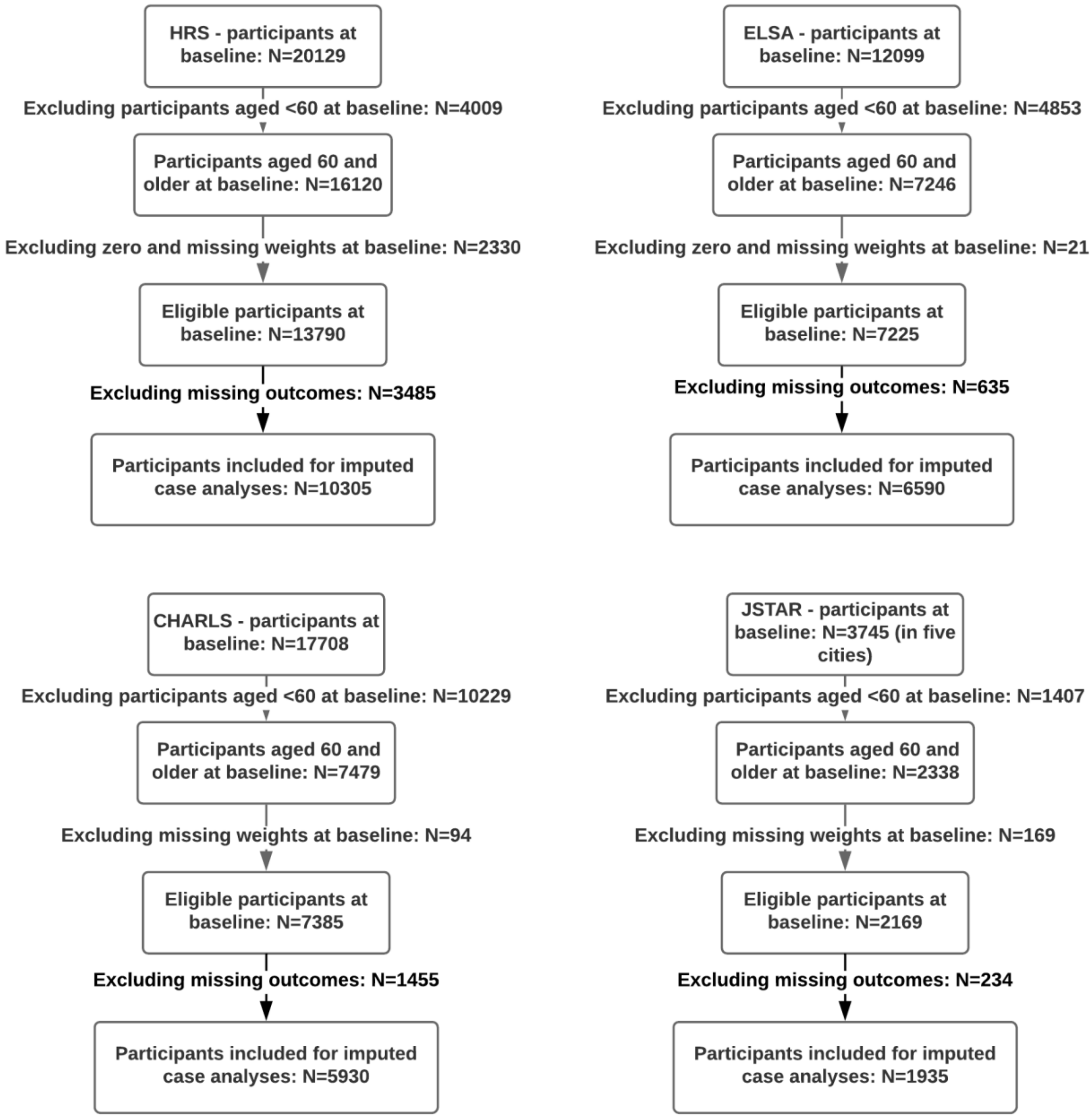


Table S1 Indicators of healthy ageing index and harmonising strategies

Variables	Categories	Scores
Verbal Memory - 10 words immediate recall	0-10	0-2=0
		3-4=25
		5-6=50
		7-8=75
		9-10=100
Verbal Memory - 10 words delayed recall	0-10	0-2=0
		3-4=25
		5-6=50
		7-8=75
		9-10=100
Orientation - date naming- month	0.incorrect	0=0
	1.correct	1=100
Orientation - date naming- day of month	0.incorrect	0=0
	1.correct	1=100
Orientation - date naming- year	0.incorrect	0=0
	1.correct	1=100
Orientation - date naming- day of week	0.incorrect	0=0
	1.correct	1=100
ADL: some diff. in dressing	0. No	0=100
	1. Yes	1=0
ADL: some diff. in bathing, shower	0. No	0=100
	1. Yes	1=0
ADL: some diff. in eating	0. No	0=100
	1. Yes	1=0
ADL: some diff. in get in/out bed	0. No	0=100
	1. Yes	1=0
ADL: some diff. in using the toilet	0. No	0=100
	1. Yes	1=0
ADL: some diff. in taking medications	0. No	0=100
	1. Yes	1=0
ADL: some diff. in shop for grocery	0. No	0=100
	1. Yes	1=0
ADL: some diff. in prepare hot meal	0. No	0=100
	1. Yes	1=0
Some diff. in get up from chair	0. No	0=100
	1. Yes	1=0
Some diff. in climb several flat stairs	0. No	0=100
	1. Yes	1=0
	0. No	0=100

Some diff. in reach/extend arms up	1. Yes	1=0
Some diff. in stoop/kneel/crouch	0. No	0=100
	1. Yes	1=0
Some diff. in lift/carry 10lbs	0. No	0=100
	1. Yes	1=0
Some diff. in pick up a dime	0. No	0=100
	1. Yes	1=0
Grip strength (kg) – Left hand	kg (quintiles)	1=0
		2=25
		3=50
		4=75
		5=100
Grip strength (kg) – Right hand	kg (quintiles)	1=0
		2=25
		3=50
		4=75
		5=100
CES-D score*	0-8 (quintiles)	0=100
		1-3=75
		4-5=50
		6-7=25
		8=0
CES-D score**	0-30 (quintiles)	0-6=100
		7-13=75
		14-20=50
		21-26=75
		27-30=0
Self-reported life satisfaction	0. Very satisfied	0=100
	1. Satisfied	1=75
	2. Somewhat satisfied	2=50
	3. Unsatisfied	3=25
	4. Very unsatisfied	4=0
High blood pressure	0. No	0=100
	1. Yes	1=0
Diabetes	0. No	0=100
	1. Yes	1=0
Cancer	0. No	0=100
	1. Yes	1=0
Lung disease	0. No	0=100
	1. Yes	1=0

Stroke	0. No	0=100
	1. Yes	1=0
Heart problem	0. No	0=100
	1. Yes	1=0
Psychological problem	0. No	0=100
	1. Yes	1=0
Arthritis	0. No	0=100
	1. Yes	1=0
Participations in social activities	0.No	0=0
	1. Yes	1=100

* CES-D scores for HRS and ELSA ** CES-D scores for CHARLS and JSTAR

Table S2 Correlation between HAIs across waves in HRS, ELSA and CHARLS

HRS	Wave 7	Wave 8	Wave 9	Wave 10	Wave 11	Wave 12	
Wave 7	1.000						
Wave 8	**0.811**	1.000					
Wave 9	0.769	**0.792**	1.000				
Wave 10	0.732	0.771	**0.792**	1.000			
Wave 11	0.697	0.720	0.773	**0.820**	1.000		
Wave 12	0.652	0.693	0.709	0.788	**0.812**	1.000	
ELSA	**Wave 1**	**Wave 2**	**Wave 3**	**Wave 4**	**Wave 5**	**Wave 6**	**Wave 7**
Wave 1	1.000						
Wave 2	**0.847**	1.000					
Wave 3	0.803	**0.835**	1.000				
Wave 4	0.773	0.797	**0.844**	1.000			
Wave 5	0.756	0.763	0.811	**0.845**	1.000		
Wave 6	0.720	0.737	0.790	0.821	**0.841**	1.000	
Wave 7	0.694	0.670	0.750	0.776	0.800	**0.848**	1.000
CHARLS	**Wave 1**	**Wave 2**	**Wave 4**				
Wave 1	1.000						
Wave 2	**0.685**	1.000					
Wave 4	0.680	**0.738**	1.000				

Table S3 Scale reliability coefficients for the HAI at each wave in HRS, ELSA and CHARLS

Cronbach's α	Wave 1 (7 in HRS)	Wave 2 (8 in HRS)	Wave 3 (9 in HRS)	Wave 4 (10 in HRS)	Wave 5 (11 in HRS)	Wave 6	Wave 7
HRS	0.819	0.831	0.832	0.833	0.840	0.836	-
ELSA	0.815	0.827	0.829	0.831	0.847	0.851	0.840
CHARLS	0.849	0.834	-	0.858	-	-	-

Table S4 Comparison of predictive performance between phenotypic frailty and HAI by Area Under Curves (AUCs) in each study

Studies	AUCs	Standard Errors	95%CIs	P-values
US (N=1837)				
PF-Criterion	0.676	0.011	(0.655 to 0.698)	0.410
HAI	0.687	0.012	(0.662 to 0.711)	
England (N=3548)				
PF-Criterion	0.671	0.010	(0.651 to 0.690)	0.177
HAI	0.684	0.011	(0.664 to 0.705)	
China (N=3015)				
PF-Criterion	0.628	0.025	(0.580 to 0.678)	0.166
HAI	0.589	0.031	(0.528 to 0.649)	

Figure S2 Empirical Receiver Operating Characteristic (ROC) curves of phenotypic frailty and HAI in the US (N=1837), England (N=3548) and China (N=3015)

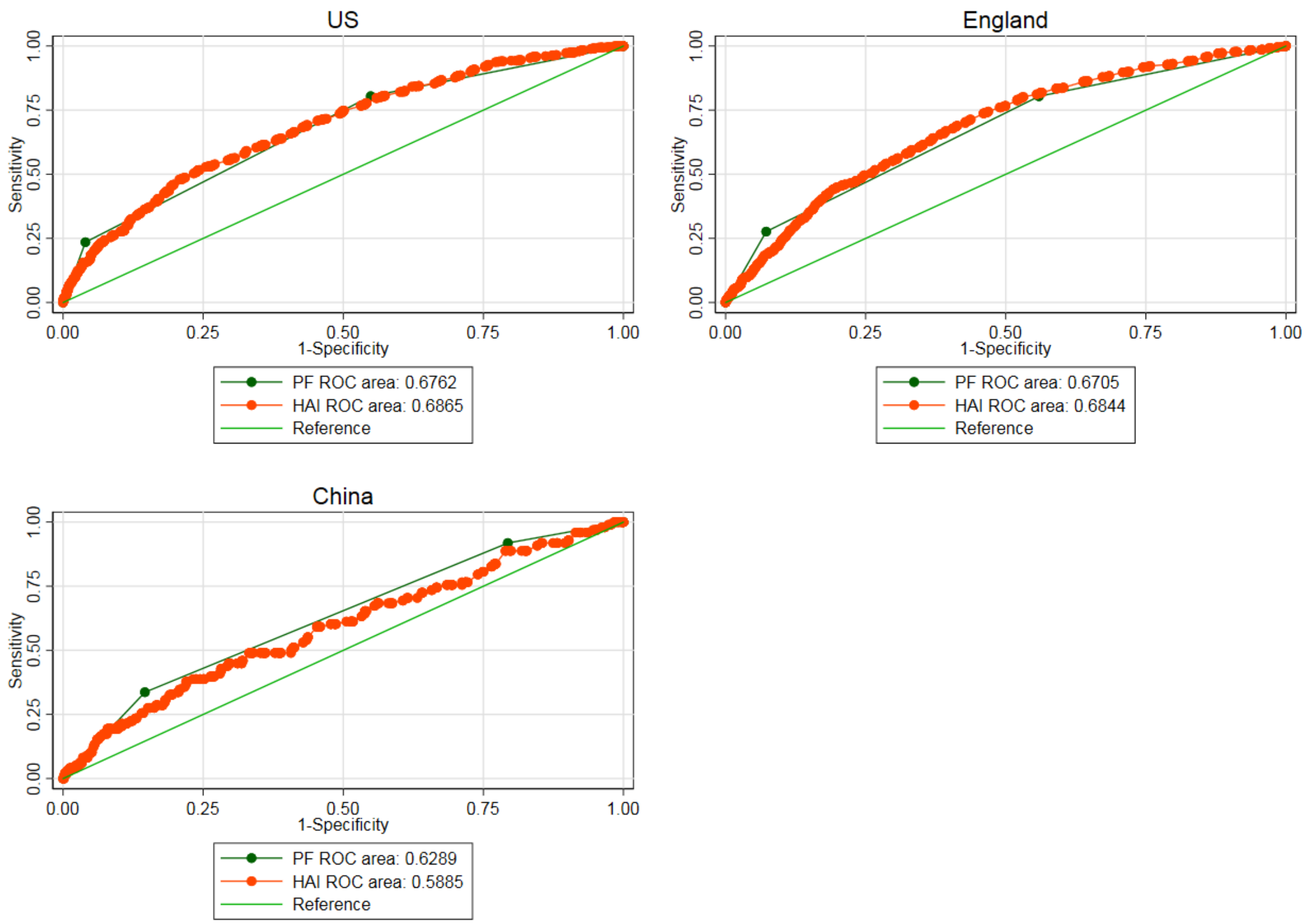


Table S5 Semi-harmonising strategies for occupational measures

Variables	Original categories	Harmonised categories
US (2004-2014)		
Occupation	0. Managerial specialty operators	I Managerial and professional specialty occupation
	1. Professional specialty opera. /technical sup.	
	2. Sales	II Technical, sales and administrative support
	3. Clerical/administration support	
	4. Service: private household/ clean/bldg.	III Service occupations
	5. Service: protection	
	6. Service: food preparation	
	7. Health service	
	8. Personal service	
	9. Farming/forestry/fishing	IV Farming, forestry and fishing occupations
	10. Mechanics/repair	V Precision production, craft, and repair occupations
	11. Construct trade/extractors	
	12. Precision production	
	13. Operators: machine	VI Operators, fabricators and labours
	14. Operators: transport, etc	
	15. Operators: handlers, etc	
	16. Member of armed forces	VII Others
	7. Retired	VIII Retired
	8. Unemployed	IX Unemployed
	9. Disabled	X Disabled
	10. Not in the labour force	XI Not in the labour force
Father's occupation	0. Managerial and professional specialty occupation	I Managerial and professional specialty occupation
	1. Technical, sales and administrative support	II Technical, sales and administrative support
	2. Service occupations	III Service occupations

	3. Farming, forestry and fishing occupations	IV Farming, forestry and fishing occupations
	4. Precision production, craft, and repair occupations	V Precision production, craft, and repair occupations
	5. Operators, fabricators and labours	VI Operators, fabricators and labours
	6. Unclassifiable	VII Unclassifiable
England (2002-2015)		
Occupation	0. Higher managerial occupations	I Higher managerial and professional employers
	1. Higher professional occupations	
	2. Lower professional & higher technical occupations	II Lower managerial and professional employers
	3. Lower managerial occupations	
	4. Intermediate	III Intermediate employees
	5. Employers in small organisations	IV Small employers and own account workers
	6. Own account workers	
	7. Lower supervisory occupations	V Lower supervisory, craft and related employees
	8. Lower technical occupations	
	9. Semi-routine occupations	VI Employees in semi-routine occupations
	10. Routine occupations	VII Employees in routine occupations
	11. Never worked	VIII Never worked
Father's occupation	0. Professional or technical	I Professional or technical
	1. Manager or senior official	II Manager, senior official, admin, cleric or secretarial
	2. Administrative, clerical or secretarial	
	3. Running his own business	III Own business, or skilled trade
	4. Skilled trade	
	5. Caring, leisure, travel or personal service	IV Service-skilled non-manual
	6. Sales or customer service	
	7. Plant process or machine drivers or operation	V Service-skilled manual
	8. Armed forces	VI Others
	9. Other jobs	

	10. Something else	
	11. Casual jobs	
	12. Retired	VII Retired
	13. Unemployed	VIII Unemployed, sick or disabled
	14. Sick/disabled	
China (2011-2015)		
Occupation*	-	I Officials/managers/leaders or Clerk/paid workers
	-	II Self-employed workers
	-	III Unpaid family business
	-	IV Others
	-	V Only agricultural work
Father's occupation	0. Manager	I Manager
	1. Professional and technician	II Professional and technician
	2. Clerk	III Clerk
	3. Commercial and service worker	IV Commercial and service worker
	4. Agricultural, forestry, husbandry and others	V Agricultural, forestry, husbandry and others
	5. Production and transportation workers	VI Production and transportation workers
	6. Cannot be specified	VII Others
Japan (2006-2011)		
Occupation**	0. Specialist and technical workers	I Highest
	1. Administrative and managerial workers	
	2. Clerical workers	II Intermediate
	3. Sales workers	
	4. Security workers	
	5. Service workers	III Lowest
	6. Agriculture, forestry and fishery workers	
	7. Transport and communication workers	

	8. Production process and related workers	
	9. Workers not classifiable by occupation	IV Others
	10. Unclassifiable	V Unclassifiable
Father's occupation	0. Employed (including public employee)	I Employed (including public employee)
	1. Executive of company or organization	
	2. Self-employed (including self-employed farmer)	II Self-employed (including self-employed farmer)
	3. Assisted a self-employed person	III Others
	4. Worked at home	
	5. Other (specify)	
	6. Did not work	IV No work (including father passed away when participants was 15 years)
	7. Not applicable (already passed away when respondent was fifteen)	

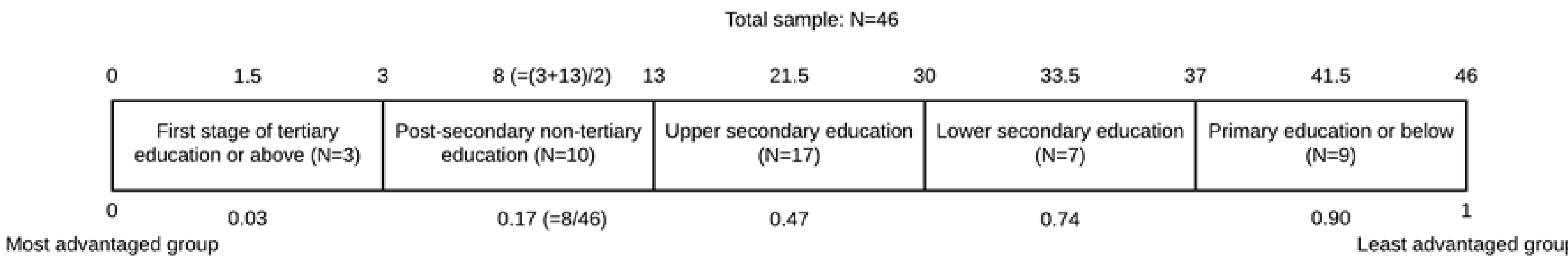
* There was no occupational variable in CHARLS. A new variable was derived based on information of major employment type, working status and current position.

** Occupation was re-categorised into three categories according to a new theory-based social classification in Japan, which was derived by Hiyoshi, et al (2013).

Table S6 Percentages of missingness in socioeconomic exposures and covariates at each wave in each study

	US						England							China			Japan		
Time-varying variables	**Wave 7**	**Wave 8**	**Wave 9**	**Wave 10**	**Wave 11**	**Wave 12**	**Wave 1**	**Wave 2**	**Wave 3**	**Wave 4**	**Wave 5**	**Wave 6**	**Wave 7**	**Wave 1**	**Wave 2**	**Wave 4**	**Wave 1**	**Wave 2**	**Wave 3**
Income	0.00	0.00	0.00	0.00	0.00	0.00	1.37	0.86	2.56	2.71	2.86	5.95	2.82	15.76	30.78	7.32	29.14	6.29	6.97
Wealth	0.00	0.00	0.00	0.00	0.00	0.00	1.36	0.86	2.56	2.71	2.86	2.62	2.82	28.57	53.44	19.05	5.62	34.22	87.85
Occupation	1.83	0.52	0.41	0.19	0.16	0.11	4.38	0.00	0.00	0.00	0.00	0.00	9.09	62.33	61.57	50.85	3.78	6.20	6.89
Age	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Marital status	0.06	0.00	0.01	0.01	0.01	0.00	0.01	0.02	0.02	0.00	0.03	0.00	0.00	0.08	0.03	2.45	0.00	2.22	3.41
Smoking	0.94	0.87	0.89	0.85	0.82	0.89	1.90	0.07	0.09	1.33	2.15	0.10	0.16	3.63	26.32	45.71	4.47	10.73	4.57
Drinking	0.01	0.02	0.01	0.02	0.01	0.15	1.45	17.31	21.72	21.00	17.87	20.71	21.28	7.33	1.06	0.67	5.76	2.03	5.11
Baseline variables																			
Education	0.01						0.17							0.12			0.46		
Gender	0.00						0.00							0.01			0.00		
Ethnicity	0.02						0.04							14.88			-		
Self-rated health in childhood	5.74						49.22							2.69			-		
Father's occupation	19.62						1.65							46.58			28.91		

Figure S3 Example illustrating the derivation of socioeconomic rank score using education[*]



[*] Steps in the calculation of the educational rank score were: the sample of interest in each country was sorted, from the most advantaged to the least advantaged group based on the classification of education; the number of cases in each educational group was counted; then a midpoint value was calculated for each category of educational group; finally each midpoint was divided by the total sample size to generate a standardised educational rank score, ranging from 0 to 1.