




Cohort Profile

Cohort Profile: The Ageing Trajectories of Health – Longitudinal Opportunities and Synergies (ATHLOS) project

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Why was the cohort set up?

The number of people aged 60 years or older is projected to significantly increase in the coming decades worldwide. According to United Nations estimates, this figure is expected to more than double by 2050 and to more than triple by 2100.¹ Population ageing poses major challenges for the traditional social welfare state due to the greater needs for health and social care of older people.¹

This project, Ageing Trajectories of Health – Longitudinal Opportunities and Synergies (ATHLOS), funded by the European Union's Horizon 2020 Research and Innovation Program, aims to achieve a better understanding of the impact of ageing on health by developing a new single measure of health status. With this measure, the project intends to identify patterns of healthy ageing trajectories and their determinants, the critical points in time when changes in trajectories are produced, and to propose timely clinical and public health interventions to optimize and promote healthy ageing. To achieve this, a new cohort has been composed from harmonized datasets of existing international longitudinal cohorts related to health and ageing.

The ATHLOS project follows the World Health Organization's definition of healthy ageing by studying healthy ageing as an ongoing process of developing and maintaining the functional ability that enables wellbeing in older age.² This ongoing process interacts with the environment in which people live and can either favour health or be harmful to it. Environments are highly influential on individual behaviour, exposure to health risks, access to quality health and social care and the opportunities that ageing brings.² Healthy ageing is thus not a unitary phenomenon but must be deconstructed into its components: mental (e.g. cognitive decline), physical (e.g. activities of daily living) and social functioning (e.g. participation in community activities).^{3–5}

National and international research funding agencies and governments have supported several follow-up studies of population cohorts since the early 1990s [e.g. the 'Health and Retirement Study' (HRS)⁶]. HRS has been used as a model for many other longitudinal studies in a number of countries, such as the 'English Longitudinal Study of Ageing' (ELSA),^{7,8} the 'Japanese Study of Aging and Retirement' (JSTAR),⁹ the 'Mexican Health and Aging Study' (MHAS),¹⁰ the 'China Health and Retirement Longitudinal Study' (CHARLS),¹¹ the 'Longitudinal Aging Study in India' (LASI)¹² or the 'Korean Longitudinal Study of Ageing' (KLOSA),¹³ also called the 'HRS-family' studies.¹⁴ More recently, multi-country projects have also been initiated, such as the Study on Global Ageing and adult health (SAGE) funded by the World Health

Organization,¹⁵ the Survey of Health, Ageing and Retirement in Europe (SHARE) funded by the European Commission¹⁶ and the 10/66 dementia research study.¹⁷

Although these studies have been powered to provide relevant national estimates, sample sizes might be limited for assessing the joint effect of several predisposing and protective factors.¹⁸ Additionally, although cross-country comparisons provide evidence of how contextual and health care factors impact population health, the few existing multi-country studies are limited to a selected group of countries and require a significant amount of time, co-ordination and financial resources.

Recently, strategies to harmonize data a posteriori from different longitudinal studies have been proposed to overcome some of the challenges stated above. For example, the Gateway to Global Ageing (G2AGING) is a platform funded by the National Institute on Aging, National Institutes of Health that aims to achieve data harmonization of longitudinal studies on ageing and to facilitate cross-national comparisons in population survey data.¹⁴ To date, G2AGING has harmonized the HRS datasets with the datasets of the other nine 'HRS-family' studies. In a broader context, an international research programme, called Maelstrom Research, provides systematic harmonization methodology and tools with the aim of leveraging the creation of research collaborations.¹⁸ In the context of ageing, Maelstrom Research has facilitated research consortia including the Integrative Analysis of Longitudinal Studies of Aging and Dementia (IALSA), which harmonized 9 studies, and the Promoting Mental Well-being and Healthy Ageing in Cities (MINDMAP), which incorporates 10 studies.¹⁹ These consortia have a specific focus on ageing and health and cover populations mostly from North America and Europe.

The ATHLOS consortium constitutes a new collaborative research project that, among other things, uses the Maelstrom Research resources. Unlike G2AGING, Maelstrom Research offers open-source software and guidelines to harmonize data according to concrete research aims. Thus, a harmonized dataset comprising at least 17 longitudinal population studies, from Europe and international countries, was created. These studies include information on common health conditions, as well as a detailed assessment of participants' functioning. Integrating data from existing cohort studies leads to greater sample size and statistical power to more precisely estimate the determinants and risk factors of healthy ageing. Furthermore, ageing trajectories can be compared between different countries and populations to evaluate if different cultures have diverse risk factors impacting the population's healthy ageing.

Who is in the ATHLOS cohort?

The cohort comprises more than 411 000 individuals who participated in 17 general population longitudinal studies in 38 countries. The studies are the 10/66 Dementia Research Group Population-Based Cohort Study,¹⁷ the Australian Longitudinal Study of Aging (ALSA),²⁰ the ATTICA Study,²¹ CHARLS,¹¹ Collaborative Research on Ageing in Europe (COURAGE),²² ELSA,⁷ Study on Cardiovascular Health, Nutrition and Frailty in Older Adults in Spain (ENRICA),²³ the Health, Alcohol and Psychosocial factors in Eastern Europe Study (HAPIEE),²⁴ the Health 2000/2011 Survey,²⁵ HRS,⁶ JSTAR,⁹ KLOSA,¹³ MHAS,¹⁰ SAGE,¹⁵ SHARE,¹⁶ the Irish Longitudinal Study of Ageing (TILDA)²⁶ and the Uppsala Birth Cohort Multigenerational Study (UBCoS).^{27,28}

Each study includes one or more populations and provides data on health determinants and age-related events. An overview of the included studies and their target populations is provided in [Table 1](#). [Table 2](#) presents sample sizes and response rates at baseline for each study and population. The median percentage of response rate at each study's baseline was 75%, and the range was from 53% (SAGE-Mexico) to 96% (10/66-Rural China). It should be noted that the sample sizes of the CHARLS, ELSA, Health 2000/2011, HRS, JSTAR, MHAS and SHARE studies were increased in posterior waves of data collection. [Supplementary Table S1](#), available as [Supplementary data](#) at *IJE* online, presents sample sizes, number of new participants, deceased participants and drop-outs for each study, population and wave.

All studies are cohorts based on questionnaires except for the UBCoS study, which collects routine health and social data for all babies born in the Uppsala Academic Hospital between the years 1915 and 1929, and their descendants. The UBCoS data were converted into periods of data collection to resemble the design of the other studies.

Finally, the study on the Identification of health and disability determinants on ageing in Italy (IDAGIT) will be subsequently included in the cohort.

How often have participants been followed up?

Most of the longitudinal studies included in the ATHLOS harmonized dataset started between 2000 and 2010 and have at least 2 waves of data collection (see [Table 2](#)). ALSA and HRS started much earlier, in the 1990s, and have more than 10 waves of data collection. SAGE has only 1 wave of data harmonized to date. However, new waves of data are expected to be harmonized in the future.

Regarding UBCoS, as register data have been collected approximately every 10 years from 1960 to 2008, we distributed the data in 6 waves.

What has been harmonized?

The data harmonization requires an a priori definition of the variables of interest and their possible values. Thus, the ATHLOS consortium defined a wide range of variables, called DataSchema variables, which included all health conditions, sociodemographic variables, personal functioning and contextual factors. These are usually assessed in population studies. Variables that have international standards or have been created by well-known scales and measured tests were employed in the harmonization process. For example, the International Classification of Functioning, Disability and Health (ICF) biopsychosocial model²⁹ and the conceptualization of health suggested by the World Health Organization³⁰ were used for characterizing the functioning-related variables.

The DataSchema variables were classified as follows: (i) sociodemographic and economic characteristics; (ii) lifestyle and health behaviours; (iii) health status and functional limitations; (iv) diseases; (v) death; (vi) physical measures; (vii) psychological measures; (viii) laboratory measures; (ix) social environment and life events; and (x) other administrative information. In [Table 3](#), a list of core variables within the aforementioned domains, together with the individual studies, is provided.

What has ATHLOS found? Key findings and publications

ATHLOS includes data from all populated continents, with Europe being the most represented. Sociodemographic information by continent and country is shown in [Table 4](#). The median year of birth was around the 1940s, with people from America being older (born in the 1930s) and those in Australia much older (born in 1914). Overall, the median age at baseline was about 60 years. Sweden exhibits a younger average age at baseline, as UBCoS cohorts were based on register data starting in 1960. The percentage of female participants was slightly above 50%, other than in Australia and Ghana, which had lower percentages. The average percentage of primary education or less stood at about 37%, but in general there was heterogeneity even in countries from the same study as in SHARE. In Europe, for example, the lowest percentage was observed in Germany (2%) and the highest percentage in Spain (58%); in South America, the percentage was very high in Venezuela (81%) and Dominican Republic (90%).

Advanced analytical approaches have already been applied to some studies of the ATHLOS dataset to test the methodology for developing a single measure of health status and to identify different patterns of health trajectories over time. This measure will allow for the comparison of

Table 1. List of studies included in the ATHLOS project

Studies		Countries/populations ^a	Recruitment ^d	Refreshment
Acronym	Name			
10/66	The 10/66 Dementia Research Group Population-Based Cohort Study	Cuba, India, China, Dominican Republic, Venezuela, Peru, Mexico and Puerto Rico	All 65+ respondents in a household	No
ALSA	The Australian Longitudinal Study of Aging	Australia: Participants drawn from the South Australian Electoral Roll	All 65+ respondents in a household	No
ATTICA	The ATTICA Study	Greece: Metropolitan Athens area	18+ participants	No
CHARLS	The China Health and Retirement Longitudinal Study	China: All counties except Tibet	45+ participants and spouses	Wave 2
COURAGE	Collaborative Research on Ageing in Europe	Spain and Poland	18+ participants	No
ELSA	The English Longitudinal Study of Ageing	UK and Northern Ireland	50+ participants and spouses	Wave 3, 4, 6
ENRICA	Study on Cardiovascular Health, Nutrition and Frailty in Older Adults in Spain	Spain	60+ participants	No
HAPIEE	The Health, Alcohol and Psychosocial factors in Eastern Europe Study	Poland, Czech Republic and Lithuania	45–69 participants	No
HEALTH 2000-11	The Health 2000–2011 Survey	Finland	30+ participants	Wave 2
HRS	The Health and Retirement Survey	United States: 6 birth sub-cohorts	50+ participants and spouses	All waves
JSTAR	The Japanese Study of Aging and Retirement	Japan: 5 cities sub-cohort, 2 cities sub-cohort and 3 cities sub-cohort ^b	50–75 participants	No
KLOSA	The Korean Longitudinal Study of Ageing	South Korea	45+ participants and spouses	No
MHAS	The Mexican Health and Aging Study	Mexico	50+ participants and spouses	Wave 3
SAGE	WHO Study on Global Ageing and Adult Health	South Africa, Ghana, China, India, Russia and Mexico	All 50+ respondents in a household (small sample 18+)	No
SHARE	The Survey of Health, Ageing and Retirement in Europe	20 countries ^c	50+ participants and spouses	All waves
TILDA	The Irish Longitudinal Study of Ageing	Ireland	50+ participants and spouses	No
UBCOS	The Uppsala Birth Cohort Multigenerational Study	Sweden: Births at the Uppsala Academic Hospital between 1915 and 1929	Hospital records, census records, and register data. Spouses, descendants and spouses of descendants	Descendants cohort

^aAlthough several studies were conducted in the same countries, the probability that the same individual participated in more than one study is likely very small because all study designs included a probability sample from the general population.

^b5 cities: Adachi-Kanazawa-Shirakawa-Sendai-Takikawa; 2 cities: Tosu-Naha; 3 cities: Chofu-Tondabayashi-Hiroshima.

^cCountries included in the SHARE study from waves 1 to 5: Denmark, Sweden, Austria, France, Germany, Switzerland, Belgium, the Netherlands, Spain, Italy, Greece, Israel, Czech Republic, Poland, Ireland, Estonia, Hungary, Slovenia, Portugal and Luxembourg.

^dValues are ages in years.

health status across populations and longitudinal studies included in ATHLOS. Specifically, these analyses have already been conducted on harmonized datasets comprising ELSA and HRS studies. Evidence suggests that the average health scores and trajectories are sensitive to age and that the health status measure is a good predictor of mortality.^{31,32}

Additionally, a large systematic review (with more than 90 000 articles screened) was conducted to summarize and synthesize the current evidence on social, biological, behavioural, psychological and sociodemographic determinants of healthy ageing.³³ This systematic review indicated limited research about healthy ageing in low- and middle-

Table 4. Descriptive statistics of some sociodemographic variables by continent and country

Continent	Country	<i>n</i>	Year of birth (median)	Age at participant's baseline (median)	Female (%)	Primary education or less (%)	Studies involved
Europe	Austria	6411	1945	63	58	14	SHARE
	Belgium	8720	1948	60	55	21	SHARE
	Czech Republic	18092	1946	60	56	14	HAPIEE, SHARE
	Denmark	5553	1948	60	54	13	SHARE
	Estonia	7075	1945	65	59	6	SHARE
	Finland	9673	1948	47	54	47	Health2000
	France	8105	1946	61	57	40	SHARE
	Germany	8690	1946	62	54	2	SHARE
	Greece	6969	1949	55	54	38	ATTICA, SHARE
	Hungary	3076	1948	63	57	2	SHARE
	Ireland	9638	1948	62	46	29	SHARE, TILDA
	Italy	7158	1945	63	55	48	SHARE
	Lithuania	7111	1945	61	55	12	HAPIEE, SHARE
	Luxembourg	1610	1950	62	53	37	SHARE
	Netherlands	6547	1946	61	54	14	SHARE
	Poland	17532	1947	58	54	20	COURAGE, HAPIEE, SHARE
	Portugal	2080	1947	64	57	56	SHARE
	Slovenia	3755	1948	63	56	10	SHARE
	Spain	15952	1944	65	54	58	COURAGE, ENRICA, SHARE
	Sweden	66243	1945	16	50	35	SHARE, UBCoS
Switzerland	4571	1946	62	55	11	SHARE	
United Kingdom	18489	1944	59	54	38	ELSA	
Eurasia	Russia	4947	1946	62	64	9	SAGE
Asia	China	38990	1951	59	53	60	10/66, CHARLS, SAGE
	India	14202	1947	55	61	58	10/66, SAGE
	Israel	3857	1946	61	55	21	SHARE
	Japan	7268	1945	63	52	25	JSTAR
	South Korea	10254	1945	61	56	45	KLOSA
North America	United States of America	37317	1938	56	56	27	HRS
	Cuba	2813	1930	74	65	58	10/66
	Dominican Republic	2011	1931	74	66	90	10/66
	Mexico	28817	1944	59	58	72	10/66, MHAS, SAGE
	Puerto Rico	2009	1932	76	67	44	10/66
South America	Peru	1933	1932	74	61	56	10/66
	Venezuela	1965	1935	71	64	81	10/66
Africa	Ghana	5573	1950	60	49	47	SAGE
	South Africa	4227	1947	60	57	62	SAGE
Oceania	Australia	2087	1914	78	49	36	ALSA
Total		411320	1945	58	54	37	The 17 studies

income countries and confirmed the heterogeneity in the conceptualization and definition of healthy aging.

What are the main strengths and weaknesses of ATHLOS?

The harmonized dataset in the ATHLOS project constitutes a new cohort that has been created by collecting data from 17 longitudinal studies from five continents. The

harmonization approach and tools used in this project were adapted from the methodology developed by Maelstrom Research.¹⁸ This approach is systematic and rigorous to ensure that harmonized variables are comparable.

It should be noted that the harmonization is a retrospective process, as studies were not initially designed to be harmonized. The heterogeneity in study design, instruments and data collection limits the amount and quality of

information that can be pooled.³⁴ Thus, we are conducting thorough documentation of the whole process, not only for the sake of reproducibility and transparency, but also to estimate the quality of harmonization for every variable.

What are the main problems inherent to the harmonization?

In the course of the harmonization process, we encountered several challenges. First, the harmonization potential is a trade-off between the number of studies (quantity) that can be included and the content equivalence (precision) within the study-specific variables. For example, education can be harmonized using standard criteria, such as the ISCED2011,³⁵ creating a categorical variable based on the highest qualification or generating a continuous variable for years of education. Greater precision in the definition of education would entail a lower number of studies that could be included. Second, some variables were at times conceptually different across studies, even though they described the same underlying construct. For example, employment may be addressed directly (e.g. are you employed?) or indirectly (e.g. are you retired?). The same applies to energy level, which can be addressed in terms of presence of energy (e.g. do you have energy for daily life?) or inversely (e.g. did you feel tired out or low in energy?). In this case, our intention was to address the variable in aggregate and not the way in which the question was asked. Further, ethical and legal issues may restrict the sharing and pooling of individual data. For example, studies may not publicly provide biomarker or mortality information of participants who have been lost to follow-up. Therefore, managing and pooling large datasets from different studies poses significant challenges, but the advantages seem worthwhile if we consider the global coverage and the gain in statistical power.³⁶

Can I get hold of the data? Where can I find out more?

A platform of free software applications, developed by Maelstrom Research, is used to store the original datasets, guide the harmonization process and create a web portal for the studies from the ATHLOS Consortium, as well as the final harmonized databases.³⁷ These software applications have General Public Licences and can therefore be used and freely modified according to the ATHLOS project needs. The web catalogue can be found at: <https://athlos.pssjd.org>. Full access to statistical summaries and reports of the harmonization process for each variable in each study requires registration. Documentation of the whole harmonization process for each variable in each study is

publicly shared at: <https://github.com/athlosproject/athlos-project.github.io/>

No individual dataset can be downloaded from these websites. Harmonized datasets with individual data are stored on a secure server. At this stage of the project, only researchers and collaborators of the ATHLOS Consortium can download harmonized datasets, unless study owners provide their consent. Thus, external users should contact the Scientific Committee (athlos@pssjd.org), comprised of members of the ATHLOS Consortium, to access the harmonized datasets. Alternatively, users could access original datasets directly from the study owners and follow the documentation and codes published in the abovementioned github webpage.

Profile in a nutshell

- The Ageing Trajectories of Health – Longitudinal Opportunities and Synergies (ATHLOS) cohort harmonizes existing longitudinal data from 17 international cohort studies.
- It aims to achieve a better understanding of the impact of ageing on health and to propose timely clinical and public health interventions to optimize and promote healthy ageing.
- The cohort comprises more than 411 000 individuals from 38 countries. Most of the studies started between 2000 and 2010 and have between 2 and 13 waves of data collection. New waves of data collected during the ATHLOS project and other studies will be incorporated in updated versions of the harmonized dataset.
- Harmonized datasets include variables classified in the following areas: (i) sociodemographic and economic characteristics; (ii) lifestyle and health behaviours; (iii) health status and functional limitations; (iv) diseases; (v) death; (vi) physical measures; (vii) psychological measures; (viii) laboratory measures; (ix) social environment and life events; and (x) other administrative information.
- The catalogues of the studies and final harmonized databases, together with documentation of the whole harmonization process, can be found in the web portal: (<https://athlos.pssjd.org>). External users interested in using the harmonized datasets should contact the ATHLOS Scientific Committee: (athlos@pssjd.org).

Supplementary data

Supplementary data are available at *IJE* online.

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References

1. *World Population Prospects: The 2017 Revision | Multimedia Library - United Nations Department of Economic and Social Affairs [Internet]*. <https://www.un.org/development/desa/publications/world-population-prospects-the-2017-revision.html> (22 June 2018, date last accessed).
2. *World Report on Ageing And Health*. 2015. www.who.int (18 July 2018, date last accessed).
3. Cosco TD, Prina AM, Perales J, Stephan BCM, Brayne C. Lay perspectives of successful ageing: a systematic review and meta-ethnography. *BMJ Open* 2013;3:e002710.
4. Cosco TD, Prina AM, Perales J, Stephan BCM, Brayne C. Operational definitions of successful aging: a systematic review. *Int Psychogeriatr* 2014;26:373–81.
5. Perales J, Martin S, Ayuso-Mateos JL *et al*. Factors associated with active aging in Finland, Poland, and Spain. *Int Psychogeriatr* 2014;26:1363–75.
6. Sonnega A, Faul JD, Ofstedal MB, Langa KM, Phillips JWR, Weir DR. Cohort profile: the Health and Retirement Study (HRS). *Int J Epidemiol* 2014;43:576–85.
7. Steptoe A, Breeze E, Banks J, Nazroo J. Cohort profile: the English longitudinal study of ageing. *Int J Epidemiol* 2013;42:1640–48.
8. Marmot M, Oldfield Z, Clemens S *et al*. *English Longitudinal Study of Ageing: Waves 1–7, 1998–2015*. Swindon: UK Data Service, Economic and Social Research Council; 2017.
9. Hidehiko I, Satoshi S, Hideki H. *JSTAR First Results 2009 Report. Discuss Pap. Research Institute of Economy, Trade and Industry (RIETI)*. 2009. <https://www.rieti.go.jp/jp/publications/dp/09e047.pdf> (9 November 2015, date last accessed).
10. Wong R, Michaels-Obregon A, Palloni A. Cohort profile: the Mexican Health and Aging Study (MHAS). *Int J Epidemiol* 2017;46:e2.
11. Zhao Y, Hu Y, Smith JP, Strauss J, Yang G. Cohort profile: the China Health and Retirement Longitudinal Study (CHARLS). *Int J Epidemiol* 2014;43:61–68.
12. Arokiasamy P, Bloom DE, Feeney KC, Ozolins M. *Longitudinal Aging Study in India: Vision, Design, Implementation, and Some Early Results. PGDA Work Pap #812011 [Internet]*. 2011. <https://lasi.hsph.harvard.edu/publications/longitudinal-aging-study-india-vision-design-implementation-and-some-early-results> (22 June 2018, date last accessed).
13. Park JH, Lim S, Lim JY *et al*. An overview of the Korean Longitudinal Study on Health and Aging. *Psychiatry Invest* 2007;4:84–95.
14. Wang S, Min J, Lee J. *Harmonization of Cross-National Studies of Aging to the Health and Retirement Study: USER GUIDE, Health Behavior, Version A*. 2014. https://www.rand.org/content/dam/rand/pubs/working_papers/WR800/WR861z8/RAND_WR861z8.pdf (8 June 2018, date last accessed).
15. Kowal P, Chatterji S, Naidoo N *et al*. Data resource profile: the World Health Organization Study on global AGEing and adult health (SAGE). *Int J Epidemiol* 2012;41:1639–49.
16. Börsch-Supan A, Brandt M, Hunkler C *et al*. Data resource profile: the Survey of Health, Ageing and Retirement in Europe (SHARE). *Int J Epidemiol* 2013;42:992–1001.
17. Prina AM, Acosta D, Acosta I *et al*. Cohort profile: the 10/66 study. *Int J Epidemiol* 2017;46:406–6i.
18. Fortier I, Raina P, Van den Heuvel ER *et al*. Maelstrom Research guidelines for rigorous retrospective data harmonization. *Int J Epidemiol* 2017;46:103–105.
19. Beenackers MA, Doiron D, Fortier I *et al*. MINDMAP: establishing an integrated database infrastructure for research in ageing, mental well-being, and the urban environment. *BMC Public Health* 2018;18:158.
20. Luszcz MA, Giles LC, Anstey KJ, Browne-Yung KC, Walker RA, Windsor TD. Cohort profile: the Australian Longitudinal Study of Ageing (ALSA). *Int J Epidemiol* 2016;45:1054–63.
21. Pitsavos C, Panagiotakos DB, Chrysohooou C, Stefanadis C. Epidemiology of cardiovascular risk factors in Greece: aims, design and baseline characteristics of the ATTICA study. *BMC Public Health* 2003;3:32.
22. Leonardi M, Chatterji S, Koskinen S *et al*. Determinants of health and disability in ageing population: the COURAGE in Europe Project (collaborative research on ageing in Europe). *Clin Psychol Psychother* 2014;21:193–98.
23. Rodríguez-Artalejo F, Graciani A, Guallar-Castillón P *et al*. Rationale and methods of the study on nutrition and cardiovascular risk in Spain (ENRICA). *Rev Española Cardiol* 2011;64:876–82.
24. Peasey A, Bobak M, Kubinova R *et al*. Determinants of cardiovascular disease and other non-communicable diseases in Central and Eastern Europe: Rationale and design of the HAPIEE study. *BMC Public Health* 2006;6:255.
25. Koskinen S. *Health 2000 and 2011 Surveys—THL Biobank. National Institute for Health and Welfare*. <https://thl.fi/fi/web/thl-biobank/for-researchers/sample-collections/health-2000-and-2011-surveys> (18 July 2018, date last accessed).
26. Whelan BJ, Savva GM. Design and methodology of the Irish Longitudinal Study on Ageing. *J Am Geriatr Soc* 2013;61: S265–68.
27. Koupil I. The Uppsala studies on developmental origins of health and disease. *J Intern Med* 2007;261:426–36.
28. Koupil I, Goodman A. Health equity: a life course approach. *Public Serv Rev Eur Union* 2011;11:382–83.
29. WHO | International Classification of Functioning, Disability and Health (ICF). *World Health Organization* 2018. <http://www.who.int/classifications/icf/en/> (8 June 2018, date last accessed).
30. Salomon J, Mathers C, Chatterji S, Sadana R, Üstün T, Murray C. Quantifying individual levels of health: definitions, concepts and measurement issues. In: *Health Systems Performance: Assessment Debates, Methods and Empiricisms*. Geneva: World Health Organisation, 2003, pp. 301–18.

31. Caballero FF, Soulis G, Engchuan W *et al.* Advanced analytical methodologies for measuring healthy ageing and its determinants, using factor analysis and machine learning techniques: The ATHLOS project. *Sci Rep* 2017;7:43955.
32. de la Fuente J, Caballero FF, Sánchez-Niubó A *et al.* Determinants of health trajectories in England and the United States: an approach to identify different patterns of healthy aging. *Journals Gerontol Ser A* 2018;gly006.
33. Kralj C, Daskalopoulou C, Rodriguez-Artalejo *et al.* *Healthy Ageing: A Systematic Review of Risk Factors*. http://athlosproject.eu/wp-content/uploads/2018/05/KIOPPN_HealthyAgeing-Report2018.pdf (21 June 2018, date last accessed).
34. Wolfson M, Wallace SE, Masca N *et al.* DataSHIELD: Resolving a conflict in contemporary bioscience-performing a pooled analysis of individual-level data without sharing the data. *Int J Epidemiol* 2010;39:1372–82.
35. *International Standard Classification of Education*. <http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-iscd-2011-en.pdf> (8 June 2018, date last accessed).
36. Doiron D, Burton P, Marcon Y *et al.* Data harmonization and federated analysis of population-based studies: the BioSHaRE project. *Emerg Themes Epidemiol* 2013;10:12.
37. Doiron D, Marcon Y, Fortier I, Burton P, Ferretti V. Software application profile: Opal and Mica: open-source software solutions for epidemiological data management, harmonization and dissemination. *Int J Epidemiol* 2017;46:1372–78.

Appendix

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