



A Global Indicator to Track Well-Being in the Silver and Golden Age

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Abstract

In this work, we design a protocol to obtain global indicators of health and well-being from weighted and longitudinal heterogeneous multivariate data. First, we consider a set of thematic sub-indicators of interest observed in several periods. Next, we combine them using the Common Principal Component (CPC) model. For this purpose, we put a new straightforward CPC model to cope with weighted and longitudinal data and develop a new statistic to test the validity of the CPC-longitudinal model, whose distribution is obtained by stratified bootstrap. To illustrate this methodology, we use data from the last three waves of the Survey of Health, Ageing and Retirement in Europe (SHARE), which is the largest cross-European social science panel study data set covering insights into the public health and socio-economic living conditions of European individuals. In particular, we first design four thematic indicators that focus on general health status, dependency situation, self-perceived health, and socio-economic status. We then apply the CPC-longitudinal model to obtain a global indicator to track the well-being in the silver and golden age in the 18 participating European countries from 2015 to 2020. We found that the latest survey wave 8 captures the early reactions of respondents successfully. The pandemic significantly worsens people's physical health conditions; however, the analysis of their self-perceived health presents a delay. Tracking the performances of our global indicator, we also found that people living in Northern Europe mainly have better health and well-being status than in other participating countries.

Keywords Ageing · Bootstrap · Common principal components · Longitudinal data · Public health · Well-being

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1 Introduction

During the last decades, people have never stopped talking about health. The World Health Organization (WHO) constitution states that health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Although health is often discussed as a concept associated with everyone, it contains many aspects. Mental health, as WHO addressed, is an integral and essential component of health. It is also a state of well-being in which an individual can accurately evaluate his/her abilities, cope with the normal stresses of life, think, emote, interact with each other well, or earn a living and enjoy life (World Health Organization, 2022b). However, the fast development of the economy speeds up people's lifestyles, and an increasing number of sub-optimal health problems. People may recover from illness, in some cases, may not, until old age. At the same time, increased life expectancy and a shift in the demographic pyramid have also become severe worldwide problems. As WHO reported, the proportion of the world's population over 60 years will nearly double from 12% to 22% between 2015 and 2050. The population of people over 60 years and older may achieve 2.1 billion, which will be twice than estimated 1.4 billion in 2030 (World Health Organization, 2022a). The ageing problem started in high-income countries and nowadays is also experienced in low- and middle-income countries. From a biological perspective, increasing age leads to a proportionally decrease in physical and mental capacity and a more likely risk of diseases and ultimately death. WHO also points out that life transitions, such as retirement, relocation, and lack of accompanying friends and partners, are also associated with ageing. Indeed, we can also think that living longer is almost equal to having more opportunities, especially when an individual is well-equipped by his/her experience in his/her career. Older people can contribute to families, communities, and societies in many ways when they have good health and good well-being. It is common to see that studies involving health and well-being are designed as case studies; researchers may make a comparison between countries or, as often, compare before and after an event. Although a case study has many advantages, researchers may face the problem, including being hard to generalize, limited representation, subjective research outcomes, and time-consuming. In this work, we aim to explore another perspective to generate a global indicator that can serve in broader fields and use existing historical data efficiently.

Various studies have been conducted using SHARE data from different perspectives. Ryser et al. (2023) analyze the association between personality traits based on SHARE data from Switzerland. They emphasize the necessity for targeted public health policies that address the specific needs of older adults with lower levels of openness and reduced engagement in self-examination. They believe facing and helping to solve the difficulties in processing the health information of this population can effectively bridge the health literacy gap and promote informed decision-making. SHARE data are not limited to being used in policymaking. Serrat et al. (2023) investigate civic engagement among foreign-born and native-born older adults using SHARE data, indicating that their study proved that foreign-born European older adults exhibit lower levels of volunteering and less engagement in political organizations compared to their native counterparts. Gharbi-Meliani et al. (2023) employ machine learning clustering techniques to identify dementia cases based on SHARE data, and their algorithm shows good discriminative power across all waves. Moreover, researchers also extract specific data for their research. Kovács et al. (2023) apply multilevel logistical regression analysis on a group of SHARE data from Wave 5 to 8, revealing an increasing disparity in the utilization of dental care

services between socio-economic groups, particularly in income level and resident areas. Their findings underscore the potential benefits of implementing policies that reduce financial barriers to dental care utilization, particularly in Southern and Eastern European countries, for the elderly population. Hajek et al. (2023) primarily explore the association between anxiety, oral health, and depressive symptoms among older individuals, finding a significant relationship between diminished oral health and higher anxiety and depressive symptoms. Jayanama et al. (2022) examine how body mass index relates to frailty and mortality using survey data from the SHARE and Nutrition Examination Survey. Ogliari et al. (2022) investigate pain levels and risk of falls in this population. Santini et al. (2020) apply a structural equation model to analyze the association between formal social participation and depressive symptoms and chronic conditions. Han et al. (2021) provide their studies on depressive symptoms and cognitive impairment based on multiple waves spanning 10 years.

Principal Component Analysis (PCA) and Common Principal Component Analysis (CPC) are powerful multivariate exploratory tools for interpreting high-dimensional data in many fields. PCA is a classical method created before the Second World War (Pearson, 1901; Hotelling, 1933), and widely applied during the quantitative revolution in the Natural and Social Sciences in the 1960s (Maćkiewicz and Ratajczak, 1993). Benefiting from the development of computers, multivariate statistical methods, such as principal components can be applied to computers handily. Technically, the PCA method uses a vector space transformation to reduce the dimensionality of large data sets and retain the variation present in the data sets from interrelated variables as much as possible. It is also suitable in increasing industries, especially data nowadays. However, the computation determines that the PCA can only deal with a single population. The extension of applying to various populations, common principal component analysis (CPC model) raised by Flury (1984, 1988) and Flury and Gautschi (1986). The CPC method has no given order of the set of eigenvectors due to the rank order of the eigenvalues coming from multiple groups. The common variance among the groups is assumed to be more generalization in gathering the information. CPC is implemented in applications not as much as PCA; one reason could be that Flury-Gautschi's CPC was unsuitable for making dimensionality reduction because of the unnecessary same rank order of their common eigenvectors. Trendafilov (2010) proposed a stepwise CPC method in which the common eigenvectors are estimated sequentially; this method gives an analogous ranking within all the k populations by assessing a stopping point of $q < p$ common eigenvectors. It might lose small information, but it may save computing time and ensure an optimal presentation of q dimensional approximations. The interpretation of common eigenvectors of CPC is similar to the eigenvectors of PCA with one single group. Whereas, as noted by Flury (1984), the precondition of receiving well-explained common eigenvectors is that they are well-defined. This well-explained means that variations between different groups might come from the same, but it simultaneously allows various importances between them. Understanding the different variations for each common eigenvector within each group also helps to explore the relative importance between groups. Except for the traditional definition of groups, when we split the same data structures at k different time points, they became k groups longitudinally. The advantage of this type of group is that, for example, it ensures the consistency of variables, it is latent to see an evolution of information given by data over time, and it likely combines to multivariate time-series analysis (Li, 2016). The aim of this work is to explore the horizons that the time-point mentioned above-defined groups offer to huge survey longitudinal data sets.

The calibration approach was introduced by Deville and Särndal (1992); now, it is commonly used in survey sampling and includes auxiliary information to improve the precision of estimators of population parameters. Afterward, Singh (1998) developed the calibration estimation in stratified sampling design by referring to Särndal's approach. Commonly admitted, there are three key advantages of using a calibration approach in survey data. It leads to consistent estimates, it could play a role as an important proxy for efficiently combining the data sources, and it has the computational advantage in calculating estimates (Kim et al., 2007). Data set types do not constrain the applications of the calibration approach; conversely, much additional information is available to construct more efficient estimators according to data features. In our case, each observation in the SHARE survey has a calibrated weight, so that weighted survey estimates match the known population totals.

The main contribution of this paper is to extend the CPC-model for huge longitudinal and weighted data sets, and apply it to design a comprehensive indicator (whose loadings remain stable along time) based on several thematic sub-indicators of interest. We also develop a bootstrap-based statistic to test the validity of the model. The methodology is illustrated on waves 6, 7, 8 of the SHARE data set, where a global data-driven indicator is proposed in order to visualize the changes in well-being on older EU citizens along the period 2015-2021. Other well-being indicators have been proposed recently. Some of them focus on specific well-being aspects (Peiró-Palomino and Picazo-Tadeo, 2018); others pay attention to cultural identity (Herrero-Prieto et al., 2019), and most of them are developed for specific countries or regions (Hollander et al., 2020; Sarra and Nissi, 2020; Tomaselli et al., 2021; Acosta-González and Marcenaro-Gutiérrez, 2021; de Maya Matallana et al., 2022). However, our proposal differs from theirs in the sense that we develop a global indicator able to track a phenomenon of interest on a target population across different countries and along time.

The paper proceeds as follows. In Sect. 2, we introduce the methodology and describe the proposed new method of the CPC-longitudinal model, and Sect. 3 contains a brief introduction to the Health, Ageing, and Retirement in Europe (SHARE) survey data. In Sect. 4 the outcomes of experimental evaluations and global indicator are provided, in-depth analysis are given, and the bootstrap test is performed. Conclusions and lines of future work are discussed in Sect. 5.

2 Methodology

In this section, an extension of the Common Principal Components technique for weighted and longitudinal data is presented. The development of a bootstrap-based test statistic to validate the model follows.

2.1 Traditional Flury's CPC model

The Common Principal Component model was introduced by Flury (1984) as a generalization of principal components to the case of several groups.

The situation is the following: We have observed p quantitative variables X_1, \dots, X_p on g different groups of individuals of sizes n_1, \dots, n_g . For each group α , $\alpha = 1, \dots, g$, we have a data matrix \mathbf{X}_α of size $n_\alpha \times p$, and a vector of weights \mathbf{w}_α , such that $\mathbf{1}'_{n_\alpha} \mathbf{w}_\alpha = 1$, where $\mathbf{1}_{n_\alpha}$ is a vector of ones of dimension $n_\alpha \times 1$.

We are interested in representing the g groups in the same system of coordinates, that is, we want to describe the information contained in the \mathbf{X}_α 's matrices with a set of $m < p$ variables, that will be linear combinations of the X_1, X_2, \dots, X_p variables, and will have common loadings in all the g groups.

The underlying idea of CPC model is to represent in the same common orthogonal axes several groups of individuals, of possibly different sample sizes, for which the same number of variables have been observed. The basic assumption in the CPC model is that the principal component transformation is identical in all the considered groups, while the variances associated with the components may vary between groups. This transformation can be viewed as a rotation yielding variables that are "as uncorrelated as possible" simultaneously in several groups. This distribution-free property justifies the application of the CPC model to non-normal data.

As in classical principal component analysis, the goal is to determine the number of uncorrelated linear combinations of the variables that maximize their variance for each group. In this case, however, despite the fact that the linear combinations will be the same for all groups, the associated variances to each component may change among them, which results in a reduction of the number of parameters to estimate when maximizing the variance explained by the model.

The problem we want to solve is the following: Given $\mathbf{S}_{w,1}, \dots, \mathbf{S}_{w,g}$, the covariance matrices of the same p variables observed in g groups, we want to find an orthogonal matrix \mathbf{U} and g diagonal matrices $\Lambda_1, \dots, \Lambda_g$, such that:

$$\mathbf{S}_{w,\alpha} = \mathbf{U}\Lambda_\alpha\mathbf{U}', \quad \alpha = 1, \dots, g,$$

where matrix \mathbf{U} contains the common eigenvectors of $\mathbf{S}_{w,1}, \dots, \mathbf{S}_{w,g}$, and Λ_α is a diagonal matrix containing the eigenvalues of each $\mathbf{S}_{w,\alpha}$ ordered in descending order.

In general, the problem has not an analytical solution, since two symmetric matrices diagonalize simultaneously on the same basis if and only if they fulfil the commutative property (Horn and Johnson, 1985). Thus, in general, $\mathbf{S}_{w,1}, \dots, \mathbf{S}_{w,g}$ will not have a common basis of eigenvectors. Therefore, the problem has to be solved numerically, and the idea is to find a matrix \mathbf{U} and g matrices $\Lambda_1, \dots, \Lambda_g$, such that each $\mathbf{U}\Lambda_\alpha\mathbf{U}'$ is as similar as possible to $\mathbf{S}_{w,\alpha}$. In this sense, the CPC-model can be viewed as a rotation yielding variables that are "as uncorrelated as possible" simultaneously in g groups.

To determine how similar those matrices are, (Flury and Gautschi, 1986) propose a numerical algorithm, called the FG-algorithm, that minimizes the following discrepancy measure of "simultaneous diagonalisability":

$$F(\mathbf{U}) = \prod_{\alpha=1}^g \left[\frac{\det(\text{diag}(\mathbf{U}'\mathbf{S}_{w,\alpha}\mathbf{U}))}{\det(\mathbf{U}'\mathbf{S}_{w,\alpha}\mathbf{U})} \right], \tag{1}$$

which arises in the context of maximum likelihood estimation in the principal component analysis of several groups under the assumption of multivariate normality. However, as explained in Section 9.3 of Flury (1988), the FG-algorithm goes beyond the maximum likelihood theory of CPCs and, indeed, the algorithm can be justified and understood without its statistical origin since it is a generalization of the well-known Jacobi method for computing eigenvectors and eigenvalues of a single symmetric matrix.

Proposition 2.1 *Let $S_{w,\alpha}$, $\alpha = 1, \dots, g$, be positive definite symmetric matrices of dimension $p \times p$. Then, the function defined in Eq. (1) satisfies that (i) $F(\mathbf{U}) \geq 1$ and (ii) $F(\mathbf{U}) = 1$ if $S_{w,\alpha} = \mathbf{U}\Lambda_\alpha\mathbf{U}'$, for $\alpha = 1, \dots, g$.*

Proof Proof of part (ii) of Proposition 2.1 is straightforward, while for part (i), the upper bound for $F(\mathbf{U})$ follows from Hadamard’s inequality. The proof is done in Appendix of Flury (1988), where Hadamard’s inequality is proven for a general positive definite symmetric matrix of dimension $p \times p$, and the proof proceeds by induction on p . Thus, the measure of deviation from diagonally defined by equation (1) is still valid beyond multivariate normality. □

By means of the FG-algorithm, the matrix \mathbf{U} is obtained from the minimization of function $F(\mathbf{U})$ given in formula (1). Thus, the common principal components of $\mathbf{X}_1, \dots, \mathbf{X}_g$, are given by

$$\mathbf{Y}_\alpha = \mathbf{X}_\alpha\mathbf{U}, \quad \alpha = 1, \dots, g,$$

and $\Lambda_\alpha = \text{diag}(\mathbf{U}'S_{w,\alpha}\mathbf{U})$ contain the explained variability of the principal components in group α , for $\alpha = 1, \dots, g$.

The FG-algorithm is implemented in the R-package multi-group, designed to study multi-group data, where the same set of variables are measured on different groups of individuals. Within this package, we specifically use the function FCPA to perform the CPC calculation.

2.2 Validation of the CPC-Longitudinal Model

2.2.1 The Null Hypothesis

Let $S_{w,\alpha}$, $\alpha = 1, \dots, g$ be the sample covariance matrices of dimension $p \times p$ of g groups, which we assume to be positive definite. The null hypothesis of the CPC model is defined as

$$H_0 : S_{w,\alpha} = \mathbf{U}\Lambda_\alpha\mathbf{U}', \tag{2}$$

where \mathbf{U} is a $p \times p$ orthogonal matrix and $\Lambda_\alpha = \text{diag}(\lambda_{\alpha,1}, \dots, \lambda_{\alpha,p})$, with $\lambda_{\alpha,1} > \dots > \lambda_{\alpha,p}$, for $\alpha = 1, \dots, g$.

Additionally, consider the classical PC-model for each group, that is, consider the eigendecomposition of each $S_{w,\alpha}$:

$$S_{w,\alpha} = \mathbf{T}_\alpha\Psi_\alpha\mathbf{T}_\alpha',$$

where \mathbf{T}_α is a $p \times p$ orthogonal matrix and $\Psi_\alpha = \text{diag}(\psi_{\alpha,1}, \dots, \psi_{\alpha,p})$, with $\psi_{\alpha,1} > \dots > \psi_{\alpha,p}$, for $\alpha = 1, \dots, g$.

To test the null hypothesis (2) we propose the following test statistic, derived from Chapter 4 in Flury (1988):

$$X^2_{CPC} = \frac{1}{\sum_{\alpha=1}^g n_\alpha} \sum_{\alpha=1}^g n_\alpha \log \left(\frac{\prod_{i=1}^p \lambda_{\alpha,i}}{\prod_{i=1}^p \psi_{\alpha,i}} \right). \tag{3}$$

The null hypothesis (2) is rejected for large values of X_{CPC}^2 , that is, when the experimental value of X_{CPC}^2 is greater than a given percentile, say 95%. When this happens the intuition behind is that the axes rotations that should be applied to each group are too forced to reach a common set of orthogonal axes.

We propose to obtain the distribution of the test statistic by stratified bootstrap. The bootstrap resampling method was introduced by Efron (1979), and made simulations of the original sample by using random sampling with replacement. In what follows, we outline the process.

2.2.2 Bootstrap Scheme

Let \mathcal{X} be a data matrix $n \times p$, coming from the observation of X_1, \dots, X_p quantitative random variables on g different groups of individuals of sizes n_1, \dots, n_g , with $n = n_1 + \dots + n_g$, that is

$$\mathcal{X} = \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_g \end{bmatrix}.$$

1. Take $B = 1000$. Other values for B can be considered, for example, $B = 2000, 5000$.
2. For $b = 1, \dots, B$, select a random sample of individuals of size n , with replacement, within the rows of \mathcal{X} .
 - (a) Compute the CPC of the selected sample and store their variances (eigenvalues).
 - (b) Compute the classical PC of each subgroup of the selected sample and store their variances (eigenvalues).
 - (c) Compute and store the test statistic defined in (3).
3. Using the B bootstrap values for X_{CPC}^2 , plot the probability density function (kernel-estimation) of the statistic and compute its 90%, 95%, 99% percentiles.

3 Experimental with SHARE

The World's population is ageing rapidly. The United Nations Department of Economic and Social Affairs Population Division predicts that one in six people will be 65 and over by 2050 (United Nations, 2022). According to Eurostat, the median age of Europe's population keeps increasing for years, and it may reach 49 in 2070, which is up around five years from demography in 2020. The proportion of people over 65 years in Europe is estimated to increase to 30% from about 20% in 2020. Doubtlessly, increasing life expectancy is by reason to the development of medical technologies, pharmaceutical research, and changes in perception of lifestyle and healthcare. Eurostat also estimates that the share of people aged 80 and over will be projected to increase to 13% by 2070 (Eurostat, 2020, 2022). However, living long is not equal to living well. We expect by understanding "how the well-being and health situations actually are" and "what tendency we are facing

now” to learn how to make strategies for turning challenges of ageing population into further opportunities.

3.1 Data Source

The Survey of Health, Ageing and Retirement in Europe (SHARE) survey data is the largest cross-European social science panel study dataset covering insights into European individuals’ public health and socioeconomic living conditions (Börsch-Supan et al., 2013). To date, SHARE has collected panel waves from 2004 between 11 participating countries until today, of 28 European countries and Israel. The more than 530,000 in-depth interviews with 140,000 people give a broad picture of life over 50 years, evaluating physical and mental health status, socio-economic and non-economic activities, income and wealth benefits, and life satisfaction and well-being. SHARE provides valuable data on doing relevant research and data collected from questionnaires consisting of 20 modules on the aspects mentioned earlier and 28 countries participating in the recent survey (see Table 1). The multinational background of the SHARE survey might involve differences in sampling resources in countries. Hence, SHARE uses full probability sampling to guarantee sampling qualities as much as possible. Also, it implements sampling design weights to compensate for selection bias which could not be avoided entirely.

We first choose the three most recent waves (wave 6, wave 7, and wave 8) to apply the CPC-longitudinal model with SHARE data with more similarities to variable frames. Three surveys were officially released in the years 2015, 2017, and 2019–2020, and data represent the target population of all persons aged 50 and older in those years. It is worth noting that the process of collecting questionnaires started in October 2019, whereas approximately 45.2% of work was done during the first three months of 2020. Then, because of the worldwide lock-down, the data collection was stopped until June 2020. Although European responses helped prevent the spread of COVID, the virus had started to threaten people’s lives, especially elders (Börsch-Supan, 2022a, b, c).

Based on the previous discussions, we capture four dimensions of objective and subjective well-being. In particular, we focus on four sub-aspects: health status, dependency situation (lack of autonomy), self-perceived health, and socio-economic status. These thematic sub-indicators are made on more than 20 variables, which are described in the Appendix. The process to design and construct the sub-indicators is described in Grané et al. (2021). These authors’ proposal is a sub-indicator design that guarantees the flexibility of using both quantitative and qualitative variables; it also allows for rescaling qualitative variables

Table 1 Participating countries in the SHARE survey

Wave 6: 2015 (18 countries)	Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia France, Germany, Greece, Israel, Italy, Luxembourg Poland, Portugal, Slovenian, Spain, Sweden, Switzerland
Wave 7: 2017 (12 countries)	Austria, Belgium, Czech, Republic, Denmark, France Germany, Greece, Italy, Poland, Spain, Sweden, Switzerland
Wave 8: 2020 (26 countries)	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic Denmark, Estonia, Finland, France, Germany, Greece Hungary, Israel, Italy, Latvia, Lithuania, Luxembourg, Malta Poland, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland

and transforming them into binary variables. Furthermore, since sub-indicators are additively constructed, we can add external variables as proper supplementary. We use the same number of qualified variables from each wave, re-group them by relevant concepts and scale newly generated sub-indicators as 0-10 score variables. Notably, a higher score indicates a worse condition in the aspect. After that, we generate our global Well-Being and Dependency Indicator (WBDI), by implementing the CPC model in R with a modified FCPCA function while considering household weights in waves. For better comparison, final WBDI values were rescaled to 0-10.

3.2 Implementation in R

In R programming language, the function `FCPAC()` based on Flury's model only requires the number of groups as a significant parameter. It gives the concatenated centered data, group-centered data, matrix of common loadings, and percentages of total variance recovered associated with each dimension (output as *exp.var*). Thus, we add weights as new parameters into the function via `trace()` to modify its root code.

4 Results

In the following we present the results of applying the methodology described above to the SHARE database. We start by analysing the WBDI mean values across Europe and along time, next we give some descriptive statistics and study the contribution of each sub-indicator to the WBDI along time. The next subsection contain a more in-depth analysis of the sub-indicators and the WBDI.

4.1 WBDI: A Data-Driven Global Indicator

Our composite global indicator WBDI generated by the CPC method describes the health and well-being situation of the European citizens in the silver and golden age. In consistency with the definition of each sub-indicator, the higher the score of WBDI is, the worse

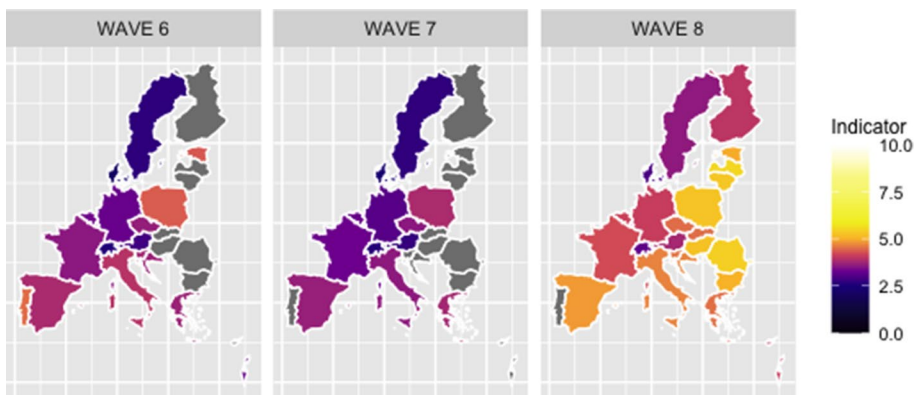


Fig. 1 WBDI per country (mean values) along time

the general health and well-being of the individual. Its evolution across Europe and along time is provided in Fig. 1.

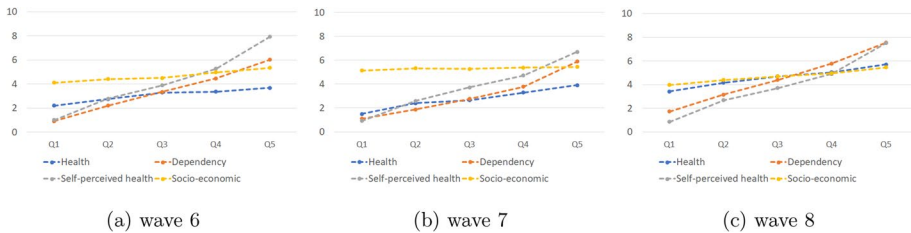
As expected, the global indicator shows that status in health and well-being in wave 8 is large and highly significant worse than outcomes in the previous two waves. Only a few countries experience some changes in wave 6 and wave 7. People living in Denmark remain the best in both wave 6 and 7, and Denmark is the only country with a 10% increase in WBDI score from wave 6 (2.07) to wave 7 (2.29), although the difference is almost negligible in the map. We also find positive changes in Poland, France, and Italy with a 9% to 10.5% lower score respectively in wave 7, and around 6% lower in Spain and Germany. Unfortunately, the excellent turning tendency did not last long. In wave 8, most countries are highlighted with a much higher WBDI score than ever, except for Denmark and Switzerland. Still, WBDI evaluated people living in Poland who do not have excellent health and well-being status since the first survey. This straggling situation lasts until the recent survey. Most recent WBDI scores in countries such as Austria, Italy, and Spain have increased by approximately 1 point, so colour changes are easily noticed on the map.

Besides, the country's differentials in status can also be distinguished by region. As we mentioned, countries with better status are mainly in Northern Europe. In contrast, the situation in Central European countries is more fragmented, such as Poland, compared to Austria and Switzerland. Tur-Sinai et al. (2020) also stress the importance of knowing the number of informal caregivers in ageing societies from both macro- and micro perspectives; they employ the SHARE, European Health Interview Survey, and the European Quality of Life Survey data to measure the prevalence of informal caregivers in EU population and point out a much higher percentage (22%) of informal caregivers in northern EU countries such as Luxembourg, Belgium, and Denmark than Portugal and Spain (13%). This prevalence rate partially explains the difference in health care for elders across the countries, particularly those with a chronic illness or disability. Due to a shortage of sample countries, we can only provide limited information that residents living in western EU countries, France and Belgium, are slightly healthier and happier with their lives than those living in the South.

Compared with regular participating countries, recently joined countries' status is the worst. Notably, for people living in Latvia, Lithuania, and Romania, their WBDI scores are historically high in three surveys, which indicate feeble health and well-being status during wave 8. There are few case studies rooted in health or well-being in these countries. According to Country Health Profile (2021), life expectancy in Latvia remains low (75.7 years in 2020) due to the relatively high prevalence of behavioural risk factors, low public spending on health and care accessibility issues, and the shortage of physicians and hospital beds. Another problem is the massive gap between men and women, with 69.2 for men more than ten years lower than 79.7 for women. Differently, Lithuania's population health has steadily grown in the past decade, and the increase in life expectancy was the fastest between 2010 and 2019 in EU countries. However, the high mortality registered during the pandemic in 2020 temporarily led to a significant drop in life expectancy of 1.4 years in one year; life expectancy is still five years below the OECD average. The problems people face in Romania are as severe as the countries mentioned earlier. As reported, life expectancy in Romania is the lowest in Europe, higher alcohol consumption, unhealthier diets, and other risky health behaviours highly threaten people's security. Cardiovascular diseases also lead to a high mortality rate in Romania. From these limited resources, we have seen that the WBDI indicator reasonably reflects the actual situation of these countries.

Table 2 Summary statistics for WBDI

	Wave 6	Wave 7	Wave 8
Mean	3.47	3.25	4.34
Median	3.36	3.17	4.19
Std. Dev	1.74	1.61	1.99
Min	0	0	0.2
Max	8.95	9.13	10

**Fig. 2** Sub-indicators' contribution to WBDI by quintiles

In addition, the country rankings did not change much over time. WBDI score of Denmark was ranked the 1st with the lowest score before and after the pandemic, remaining 0.2–0.4 points lower than in Austria, Luxembourg, Sweden, and Switzerland. The rankings among these four countries might differ from one survey to another, but they are in a group of countries with mid-best status. Of the remaining countries, WBDI scores in Belgium, France, Germany, Greece, and the Czech Republic fluctuate similarly, from 3 to 3.5 before the pandemic and over 4 points afterward; Poland, Greece, Spain, and Italy are at lower levels consistently.

4.1.1 Descriptive Statistics

Summary statistics for the WBDI are shown in Table 2. The highest WBDI 10 presents the worst situation, which was attained in wave 8 only, and points out that part of the population in the last survey has the worst health and well-being status in three surveys. The maximum WBDI scores increase by approximately 1 point from the earliest wave to the latest one. However, the result shows that the population in wave 7 live in the healthiest and best well-being conditions, indicated by the lowest average (3.25) and the median value (3.17).

4.1.2 Sub-Indicators' Contribution to WBDI

Figure 2 contains an analysis based on quintiles by sub-aspects. To define quintiles, we split each survey data into five groups of equal size based on ascending WBDI values. We consider sampling weights in the splitting process so that the top quintile represents the first 20% of the population whose indicator values are the lowest. The next group is the second quintile, and the last 20% of the population having the highest scores are in the fifth quintile, known as the worst health and well-being group. Next, the mean values of the

four sub-indicators were computed within groups. As shown in Fig. 2, all sub-indicators increase as the quintiles go from the least (1) to the most (5) risk of health and well-being status. We also observe that the average in each sub-aspect does not fluctuate in the same pattern. Regarding health and socio-economic aspects, fluctuations are much more stable than in dependency and self-perceived health among quintiles and surveys. The average in health rises gradually from 2 to 4 points across five quintiles in wave 6 and in wave 7. In wave 8, the evaluation scores represent an apparent worsening tendency from 4 to 6 points, although we see slopes between quintiles shown similarly in other surveys. The fluctuation pattern of Dependency of wave 8 remains the same as in wave 6. Interestingly, we also find that Socioeconomic was not a significant key to the WBDI indicator, as it is a horizontal line with only a few ups and downs.

4.2 Visualization of Sub-Indicators Along Time

In this section, we discuss performances in each aspect individually and explore changes from perspectives by timeline and region. To generate a global indicator that can present health and well-being, we fully consider the possible combinations of current variables. Indeed, physical and mental health are core aspects of a generalized definition of “Health”. We also take disability into account as a result of the progressive spread of chronic diseases. A severe chronic disability may no longer respond adequately to elders’ daily needs. Older people facing this situation are likely to have psychological problems to a certain extent, aggravating their existing health problems. Hence, evaluating one’s dependency levels is necessary. No doubt, public care services are essentially crucial to society, but people’s financial status can also directly determine whether they can receive timely treatments in most cases.

Table 5 of the Appendix contains which variables in the survey contribute to each sub-indicator.

4.2.1 Health Sub-Indicator

To prepare the dimension in Health, we consider whether an individual spends more than 14 days in the hospital overnight, whether he/she needs home nursing in daily life, whether he/she has chronic diseases, and his/her physical conditions such as BMI and smokers. In panel (a) of Fig. 3 we depict the mean values per country of this sub-indicator along time. We capture several points by seeing the colour changes in the maps. Residents in Sweden are healthier than in their previous performances as the colour turns colder in wave 7. These positive transitions may benefit from enormous health spending in the local medical healthcare system (2019), higher spending on health per person, and an increased number of people with private voluntary health insurance coverages, which facilitates quick access to private specialist care for people. Similar colour transitions from purple to dark blue indicate an excellent turn in Spain and France. Differently, a situation such as in Italy is hardly to be distinguished by colour in the first two surveys. Other positive transitions concentrate on the geographical centre, although the status in those countries is less healthy than in previously discussed countries. WBDI score in wave 8 increased by 1.8 points among common participating countries in wave 7 and 8, it has been reflected by an entirely lighted-up map of wave 8. Indeed, the average indicator score in Health has increased 1.9 points from 2.76 in wave 7 to 4.65 in wave 8. Compared to the first two surveys, it was a

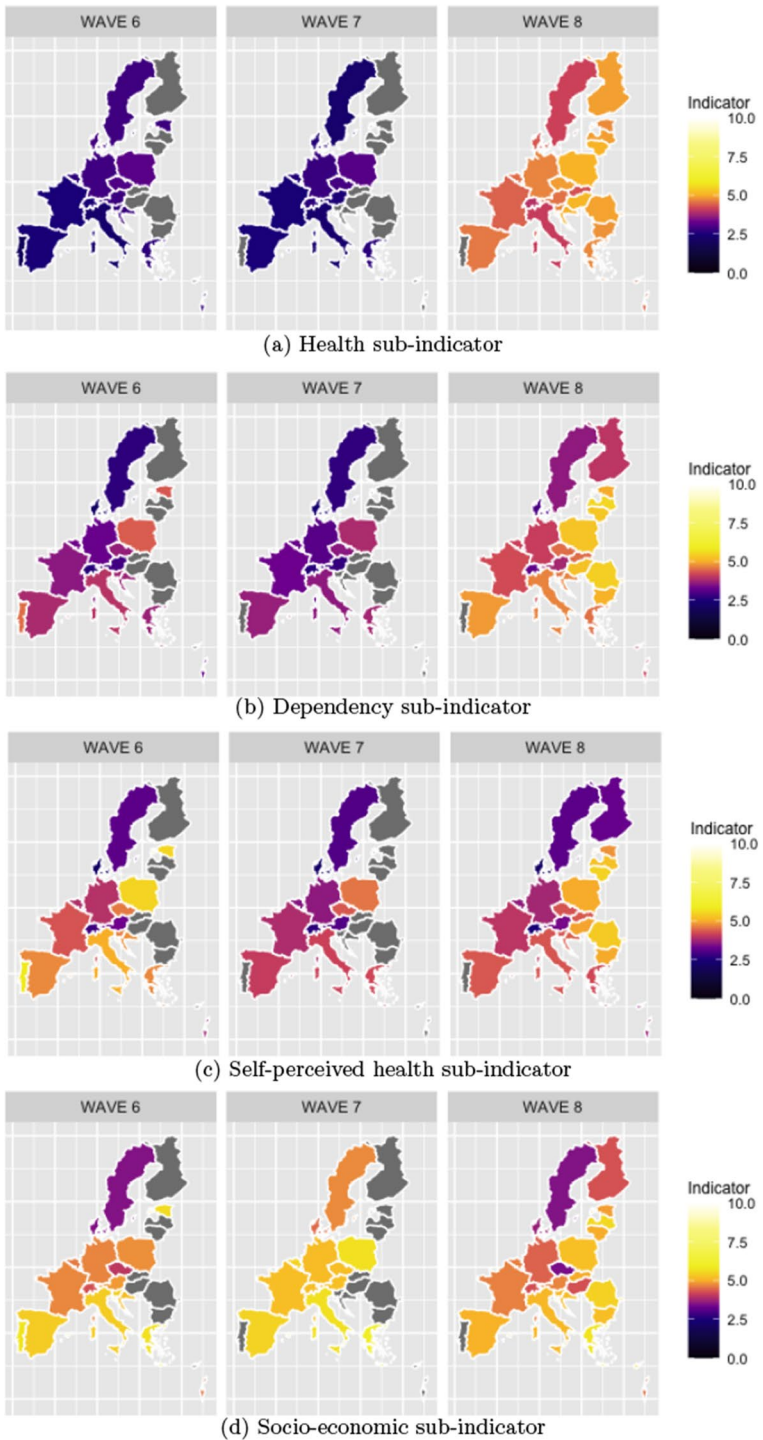


Fig. 3 Sub-indicators (mean values) per country along time

0.4 points decrease, which was good. Undoubtedly, the occurrence of the pandemic has unforgettable impacts on the whole world, which is also partially interpreted by sharp changes of colour in the map wave 8. Regarding research reported by the European Centre for Disease Prevention and Control Public Health Emergency Team from the beginning of 2020 until mid-April 2020, it estimates the number of all-cause deaths in 24 EU countries by age group, and 92% of deaths are persons aged over 65 years old in week 14, 2020, which was turning out one week after Wave 8's data collection process; In contrast, the estimated deaths of 2020 excess more than twice in 2017 during the same week (Vestergaard et al., 2020).

4.2.2 Dependency Sub-Indicator

In terms of dependency (lack of autonomy), we evaluate respondents' capacities for self-mobilization, whether one respondent can see clearly and listen well, whether he/she is restricted on walking, running, and doing specific actions all by himself/herself, and whether he/she can repeat test words correctly and clearly. In panel (b) of Fig. 3 we depict the mean values per country of this sub-indicator along time. The maps have been filled with at least four colours, respectively. However, we did not find many differences between wave 6 and wave 7, except for Poland. The colour change fully indicates that residents living in Poland have a better dependency status in wave 7. In late 2017, the Polish government committed to increasing the share of public expenditures on the healthcare sector to reach 6% of GDP by the year of 2024 (Sowada et al., 2021). Notably, the consistent growth of GDP in Poland, exceeding 10% per year until the present, indicates that residents have likely experienced improvements in the availability and allocation of healthcare resources throughout subsequent waves. The colour change can be observed in the dependency status of Poland in wave 7. Not surprisingly, the map of wave 8 also indicates how negative impacts happened after the outbreak and situations in countries; visually, we see almost none of these countries maintain the same as before. Colour differences in Poland, Spain, and Italy are straightforward to be noticed. Besides, the average score of wave 7 is 0.2 points lower than the average of wave 6, as well as score ranges. The range of indicator values in all commonly joined countries decreases from 2.15 to 1.18; in other words, the narrowing difference reflects the fact that countries' gaps are more petite and moving forward to a better status together.

4.2.3 Self-Perceived Health Sub-Indicator

The Self-perceived health indicator consists of questions associated with life happiness, life satisfaction, self-perception of health, and a series of questions based on the EURO-D depression scale. In panel (c) of Fig. 3 we depict the mean values per country of this sub-indicator along time. Generally, the country's situation in wave 7 is better than in wave 6 in the majority of participating countries. The colour variations are presented by an 11% increase in Spain, 10.9% in Greece, and 10.5% in France. The situation in Poland (16.5%) and Italy (14.1%) is even more apparent. Polish consider themselves living much better and satisfied with their status in the seventh survey. Indeed, the Covid-19 outbreak has also affected people's mental health. In contrast, the impacts of Covid-19 are not as severe as in other aspects. The self-perceived score in 9 of 12 common countries decreased on a small scale, such as 0.4 in Poland and 0.07 in Belgium. Czech, Danish, and Swiss self-evaluations are also slightly better than in wave 7. Steckermeier (2021) finds that societal conditions

enhance both choice and opportunities, along with an individual's perceived autonomy, also having a positive association with life satisfaction. He also proves that the lowest individuals' perceived autonomy mainly locate in the South Eastern European countries and the highest in the Anglophone and Nordic countries such as Denmark, Austria, and Sweden. Likely, people had not known sufficiently about the new virus or its considerable impact on people's lives when they were interviewed in 2020. Until now, this crisis has not passed yet. Both individuals and authorities delayed the response to the pandemic. García-Basteiro et al. (2020) highlight that Spain was initially reported as one of the best-performing health systems in the works and ranks 15th in the Global Health Security Index, it paradoxically became one of the worst-affected countries during the early stage of the pandemic. They raise a crucial question of why and what result in this disparity situation in Spain. They mention several potential reasons, including a lack of pandemic preparedness and a delayed reaction by central and regional authorities, a slow decision-making process, an ageing population, vulnerable groups experiencing health and social inequalities, and a lack of preparedness in nursing homes. Indeed, it is crucial to acknowledge that the actions and attitudes of authorities also can directly influence the behavior and response of individuals' in such situations. In a cross-sectional study conducted during the early times of the Covid-19 outbreak, García-Fernández et al. (2020) observe that older individuals have shown less emotional distress.

4.2.4 Socio-Economic Sub-Indicator

We define respondents' socio-economic status by evaluating the following questions: Whether the respondent earned more than 60% of median incomes in his/her residence country, whether he/she received any social or financial support, how much his/her insurance covers, and we also consider if there exists other possible financial assistance from society or organizations as one factor which might help the respondent avoiding money problems. In panel (d) of Fig. 3 we depict the mean values per country of this sub-indicator along time. Many studies have proved that people's health is associated with economic status. Poor income increases the likelihood of depression in older people in Finland, Poland, and Spain (Domènech-Abella et al., 2018); the difference in old age mortality between income groups is significant in Denmark. In the same study of Hoffmann (2011), he finds generous healthcare and lowers social inequality in Denmark than in the United States. Regarding this, we find this indicator also interprets a worsened financial situation in 2017, even in those northern European countries. Sweden used to be the wealthiest country in wave 6, whereas the indicator score jumps to 4.74 in wave 7 from 3.41 in wave 6, a 39% increase. This sharp deterioration is only a microcosm of all participating countries in wave 7, which indicates a crisis during that period.

4.3 Visualization of WBDI by Group and Along Time

In this Section we provide a more in-depth analysis of the WBDI by considering its conditional distribution according to socio-demographic variables such as gender, age group, and marital status.

4.4 By Gender

Discussions on gender inequality always involve a variety of perspectives, including topics such as health, welfare, and so on. Weber et al. (2019) pointed out that many previous

studies focus on how gender norms affect people's health and how to reduce gender-based health inequities. Palència et al. (2014) find that women had poorer self-perceived health than men in countries with traditional family policies when they study the influence of gender equality policies in a multilevel cross-sectional study in European countries. Arber and Khlal (2002) summarize that gender inequalities arise in power, culture, financial status, and local labor market (Borrell et al., 2014). In terms of mental health, women are almost twice as likely as men to have depression (Salk et al., 2017). However, men are more likely to do harmful actions or intend suicide than women (Schrijvers et al., 2012). Such differences may come from gender roles in the family, work, and society, as well as in the diagnosis and treatment process itself for depression (Schrijvers et al., 2012) and medical perspectives. Besides, some studies investigating the gender gap vary by socio-economic status, and some outbreak the conventional research paths on gender equality. Arias-de la Torre et al. (2018) provide evidence that in Spain, the prevalence of depressive disorder in women is higher than in men, and is strongly associated with their socio-economic disadvantage, including but not limited to the unemployed, homemakers, and lower educational levels or pre-retired groups. Högberg (2018) first took a comprehensive view of the impacts of social policies on genders in health among older Europeans. In his study, he proves that women benefit more from higher spending on eldercare and a higher degree of eldercare formalizations, while men benefit more from generous standard pension systems.

Among extensive discussions, we also see gender studies based on the SHARE survey. Schmitz and Brandt (2019) stress prevalence of depression by gender and gender gap were lower in Northern Europe and higher in Southern Europe. The gender gap can be partially explained by psychosocial, socio-economic, and health-related factors but significant gender differences still remain. They suggested reducing the health-related risk factors

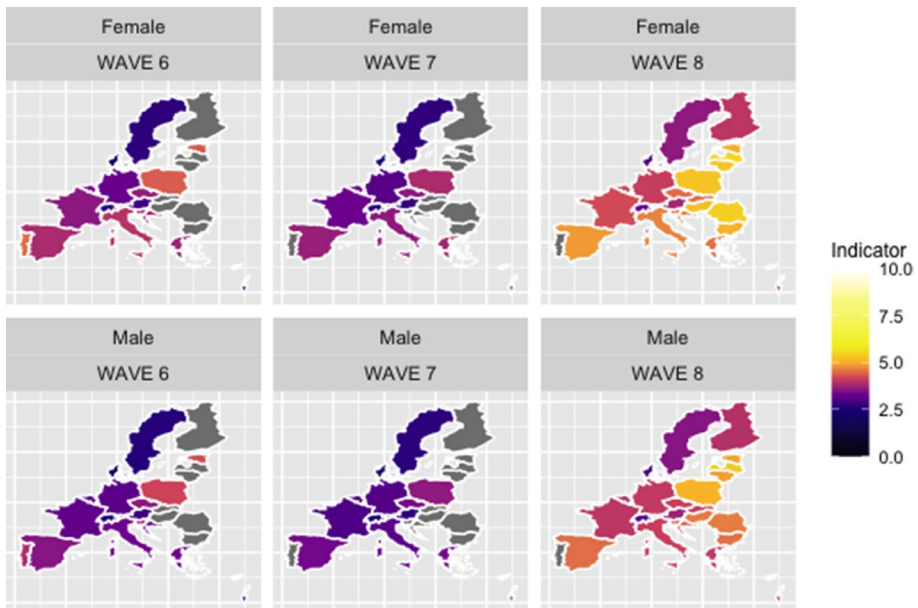


Fig. 4 WBDI by gender along time

in all European countries and improving socio-economic and psychosocial service areas according to gender- and context-specific. Besides, they implement the GEE model to examine the association of depression trajectories to cognitive functions by gender and level of depression. The model results show gender differences in depression trajectories, older women are more likely to have depression problems than men, and moderate and persistent high depression trajectories impact women on some domains of cognitive impairment only.

In our longitudinal study, we find evidence supporting gender differences by country and wave. In all target populations (see Fig. 4), people living in Denmark have continuously had better health and well-being status in survey years. The situation of lately new joined country Latvia is worrying. Compared with men, all of the WBDI scores of women are higher than men's in all survey countries and periods, in other words, men's health and well-being status are better than women's in the SHARE survey. However, differences vary from a negligible 0.02 of Austria in wave 7 to a significant level, e.g., over 0.6 in Portugal in wave 6 and Hungary in wave 8. Of 12 common participating countries, gender differences in Belgium, France, Greece, and Italy used to be very obvious in the first two surveys. In the last survey, those differences in Belgium and France were reduced significantly by a faster worsening tendency of men.

We also observed the sub-indicator scores among aspects, health outcomes for women are better than men's except for a few countries in wave 8, while women's status in the rest aspects is not as good as men's in the majority of countries. Bwire (2020), Pradhan and Olsson (2020) also find that men are more vulnerable to Covid-19 than women; Bwire's findings elucidate that the difference in the number of death can be attributed to gender-related behaviours. Women tend to exhibit a more responsible attitude towards the virus, whereas men demonstrate a higher degree of irresponsibility, which affects their undertaking of preventive measures such as regular handwashing, wearing masks and staying at home, etc. And Pradhan and Olsson discuss the variation from medical perspective, saying that there exists a notable distinction in immune system responses between men and women; women elicit stronger immune responses to pathogens. A similar conclusion also be provided by Pivonello et al. (2021) in their research about elderly Covid-19 patient groups. Tracking in health only, in Spain, the health score of women was 2.48, and men's was 3.70 in wave 6, the difference reduced to women with 2.49, men with 2.91 in wave 7, this reduction explained a positive change deriving from the improvement of men's physical health; however, the sudden happened pandemic redirected this trend directly, although the difference shirked to 0.13 immediately, the actual status turn down to women 4.58 and men 4.71 sharply. Those newly joined countries in wave 8 are highlighted with brighter colours than regular participants, and their female status is shown as the most brilliant in all waves and genders. In addition, the physical health conditions of men are always worse than women's in three waves, conversely with the situations described by dependency and self-perceived health sub-indicators. In the latest wave, there is a significant worsening trend in health and socio-economics. The indicator scores of Polish females decrease 0.6 points from wave 6 (3.11) to wave 7 (3.07), with a sudden increase to 5.05 in wave 8. The health conditions of males in the Czech Republic also show a considerable rise from 3.85 to 5.05. The pandemic might cause such unexpected changes. Only half of the interviews were completed in late 2019 and after March 2020, which is the beginning of spreading dramatically. The sharply worse economy might be affected by multi-reason, multi reasons might affect sharply worse of financial.

4.4.1 By Age Group

When considering disease and health, age is an essential factor. A study of ageing perceptions says that older adults perceived themselves as more senior, but those perceptions were younger than their actual age. Besides, older interviewees expect longer desired lifetimes comparing younger adults (Chopik et al., 2018). Getting old is irreversible. However, only a few studies examined how to instruct people to acknowledge ageing in positive aspects. Levy et al. (2014) and their team designed an intervention to train their participants to change stereotypes of being old; the results are not as positive as expected due to the hypothesis that “being a mentally and physically healthy senior citizen” is invalid to participants’ actual thoughts. Analysis of the prevalence of loneliness in the Netherlands (2016) shows that late middle-aged adults (50–65 years) are more likely to feel lonely than younger respondents. Pressures may come from living alone, low frequency of social contact, psychological distress, and a perceived social exclusion which is highly associated with loneliness (Franssen et al., 2020). Besides, they also claim that imbalanced financials and loneliness are firmly related, and the strength of association increase with increasing age. Ageing problem worries not only individuals but also nations. The 2021 Ageing Report by Commission predicted an increasing number of future Long-Term-Care (LTC) expenditures due to a rising number of older adults. This prediction results from demographic transitions, the increase in life expectancy, and the decrease in fertility rates. An increasing LTC may also come from the prevalence of physical or mental disability increases with age and, in many cases, can even result in dependency. In Ageing Europe (Eurostat, 2020), less than half (47.8%) of people aged between 65 to 74 years evaluate their health as good or very good. This proportion is much lower (less than 32.3% in those aged 75–84 and 20% in those over 85 years) in other older age groups.

For a study referring to age, defining period age is also essential. Although we know the importance of defining age groups, in our research, we divide them into three unbalanced groups by estimating their life rhythms and whether they are occupied by working and family issues. Thus, age was split into three groups: 50–64, 65–79, and 80 or over.

For the same age group, we display these maps (see Fig. 5) from left to right to present how general health and well-being status changes over time. Those changes in colours show a similar pattern among the three groups. Compared to wave 6, available status in most countries remains or becomes better in wave 7 and suddenly lights up with much brighter colours in wave 8, which signals worsening situations. In wave 6, respondents from Denmark live with the best status. Younger respondents aged 50 to 64 have the best WBDI score of 1.81, comparable with 2.05 in the age group 65 to 79 and better than 3.1 in the 80+ group. Although general health and well-being status in Portugal are not as competitive as in northern EU countries, a WBDI score of 3.93 in the youngest, 4.6 in the second, and 5.40 in the oldest group fully presents the existence of age differences. Indeed, in some countries, it is even more significant, such as in Italy and Israel. Also noted, these differences are not linearly associated with ages; gaps are more visible between older age groups than younger ones.

Furthermore, three maps listed horizontally track respondents in the exact age spans crossing the target period. Aligned with outcomes by gender, colours change gradually from wave 6 to wave 7, then suddenly light up in wave 8, particularly in the group over 80 years shown in the right-down corner. In this map, we can even see a more straightforward situation in eastern EU countries than in other regions.

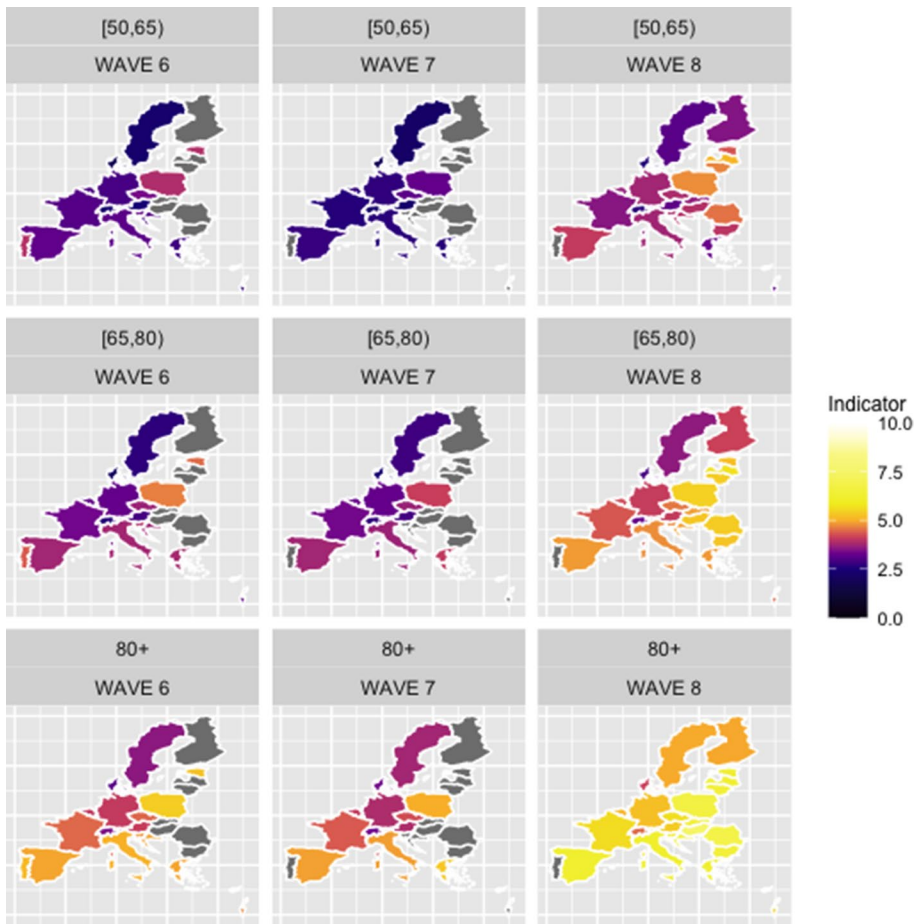


Fig. 5 WBDI by age group along time

4.4.2 By Marital Status

Marital status is another widely discussed topic associated with health status over the past few decades. Indeed, recent demographic structures have changed marriage patterns or living arrangements. Types of research focus on the importance of marriage, the association with health, and persons' general status. The primary outcomes concluded as two predominant but not mutually exclusive directions. Many population-based proportional studies report longer life spans among married persons than unmarried persons for both genders (Chiu, 2019). Consistently, Jia and Lubetkin (2020) found the same when they examined total and active life expectancy among 65 to 80 years old from a large longitudinal sample of the U.S. community-dwelling elderly population. People living only with their spouses or partners have best health/mortality profiles than other types of living arrangements, such as widows, divorced persons, or living with spouses or partners with children.

For women, the daily life of living alone and with spouses /partners is similar to men. One possible explanation for this difference is the traditional care-giving role of women (Zimmer et al., 2020), but this pattern is not unchangeable. Men's household roles are changing with society's developments and the positive impacts of education. Some researchers proposed a theory that marriage has protective effects. They claimed that, among married persons, the morbidity rate is likely lower than other living status (Toch-Marquardt et al., 2014; Rendall et al., 2011), and the difference is even widening in most high-income countries (Jaffe et al., 2007; Rendall et al., 2011). Specifically, researchers also intended from various perspectives to understand how and whom marriage is protective. However, the discussion has not been fully unified. Gove et al. (1983) pointed out that married men tend to be more satisfied with life than married women; Zick and Smith (1991) claimed men are the only benefit of marriage lives, whereas Manzoli et al. (2007) and Gutiérrez-Vega et al. (2018) stressed no gender effects nor interactions were found in their investigations. These outcomes are not contradictory; their significance in individual studies cannot be easily denied. Those differences may result in different target research, data group, and methodology, as considerable studies could not prove the association

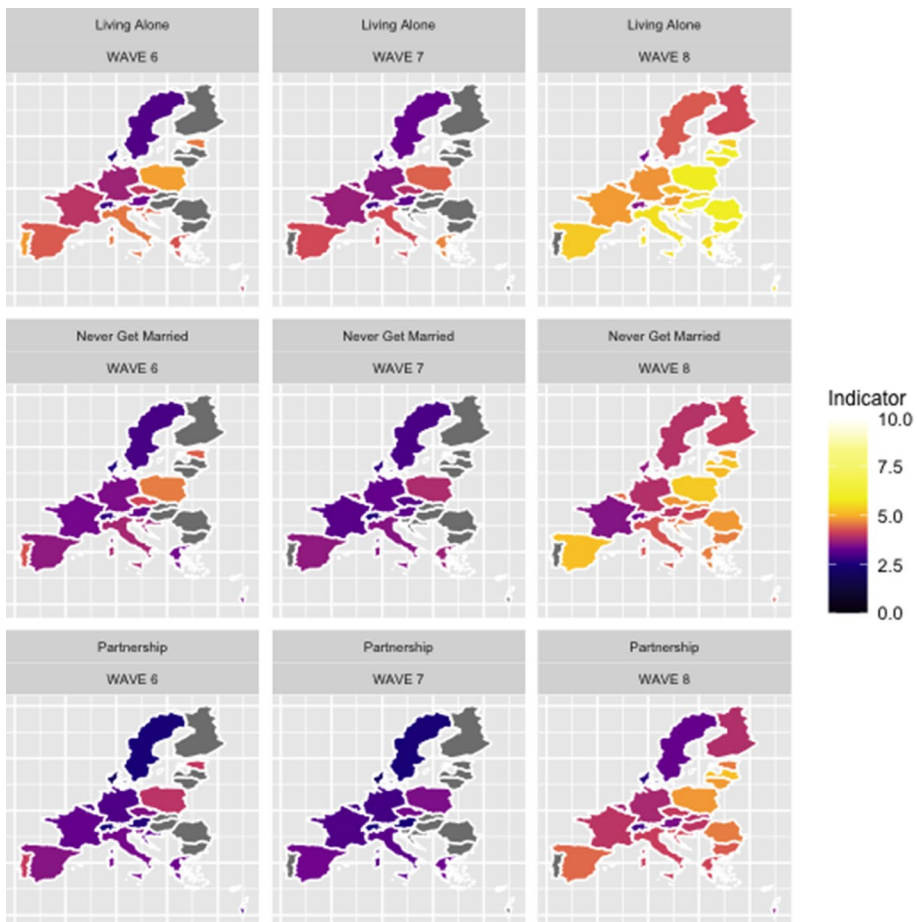


Fig. 6 WBDI by marital status along time

between marital status and health. The debate between “the protection hypothesis” and “selection hypothesis” are still being discussed (Waldron et al., 1996; Artazcoz et al., 2011).

One person’s living arrangement may move from one to another. In order to provide a comprehensive understanding of our analysis, we re-classified respondents’ marital status into three groups: people who are married or have registered partnerships as stable relations; people who may experience stable relations previously and now living alone; and people who never get married or had stable relations until now.

Consequently, measuring group status by WBDI indicates that the order of the three groups did not change much over time (see Fig. 6). The best status is people with stable partnerships; the good moderate level is those who never get married. The WBDI status of people living alone is slightly worrying, which may indicate existing adverse effects of changing one’s marital status to some extent. When tracking by timeline, we notice that the status of people “never got married” worsens much when facing external shocks, such as the pandemic, which started in the recent survey. Additionally, group differences also exist in sub-aspects.

Concerning socio-economic sub-indicator, the difference between people having a stable relationship and living alone is negligible in all surveys. However, compared to those who never got married, people with intimate relationships receive more pensions or financial support in their old age. By reviewing physical health sub-indicator, significant differences appeared until the pandemic happened, and the situation of people now living alone worsened quickly. Furthermore, outcomes related to dependency and self-perceived health sub-indicators are intriguing. When people have an intimate partner, they are likely to feel better about themselves and have better dependency status; these “better” can be explained by a 1 to 2 points lower in discussed aspects. However, people who used to have an intimate relationship have worse status in dependency than those who never got married; and past relationships or experiences may affect people’s mental health to some extent.

4.5 Some Notes on the Simulations

In this Section we provide the bootstrap percentiles of the test statistic useful to validate the CPC-model.

Following Sect. 2.2.2, we call \mathcal{X} the $n \times p$ matrix coming from the observations of X_1, X_2, \dots, X_p quantitative variables on g different groups of sizes n_1, \dots, n_g with $n = \sum_{i=1}^g n_i$.

For each bootstrap sample a matrix \mathcal{X} was built by selecting a random sample of individuals with replacement, and taking into account the household weights in the SHARE survey, and waves 6, 7, and 8. In particular, we establish an array of a given number of elements to simulate the household weights of each country according to the original survey data. For example, in wave 6, 2,909,101 people were represented by 3,358 respondents from Austria. We randomly take the same number of samples (with replacement) from all these respondents of Austria, then match them with a rescaled array, randomly generated

Table 3 Critical values for the bootstrap-based test statistic

Bootstrapped samples	90%	95%	99%
B=1000	7.406804	7.434419	7.518085
B=2000	7.407642	7.437955	7.503472
B=5000	7.410775	7.441509	7.512347

as individuals' new household weights. The sum of this array shall equal Austria's total population. Thus, we have simulated survey data with the same number of respondents and their new granted weights.

With each \mathcal{X} matrix we compute the statistic under the null hypothesis, applying formula (3). Finally, we estimate the probability distribution of the test statistic under the null hypothesis from $B = 1000, 2000, 5000$ bootstrapped samples. The critical values of the test statistic are given in Table 3.

In our case, the experimental value of the statistic is 7.21487, which is lower than any of the critical values given in Table 3, therefore, the null hypothesis can not be rejected, and the CPC-model is suitable for our data set.

5 Conclusions

The CPC method, which analyses the association between groups and their principal components, covers the direction of variance common for all groups. Combined with data across the timeline, we apply the CPC-longitudinal model to generate a global indicator WBDI that accurately evaluates European countries' long-term health and well-being status from different perspectives. A critical result of three surveys of the same data source is that the outbreak of COVID-19 significantly affects people's lives. This external stimulation is unexpected, but the interviewees captured very early reactions from respondents in early 2020. The global indicator WBDI evaluates a composite performance from four sub-aspects. It provides an overview of the health and well-being of people from 26 European countries.

Using a gender perspective, we prove that physically, men are always less healthy than women in the three surveys but are more confident in self-perceived health and dependency status. Despite still having debates on whether marriage is beneficial for people, after comparison among marital status, WBDI gives a ranking to the three living arrangements: living with stable partnerships is the most optimal status, then to whom never got married, and losing a beloved partner might be painful and also potentially impact people's health, particularly mental health. WBDI also measures the target status by age; apparently, for the same group of people who come from the same country, the older, the worse status they have. Similar findings were pointed out by Högberg (2018) regarding gender, Franssen et al. (2020) and Gutiérrez-Vega et al. (2018) regarding loneliness, Zimmer et al. (2020) regarding age and Weber and Loichinger (2022) regarding gender and age.

Almost all analyses make a visual distinction between regions. Countries such as Denmark, Luxembourg, Sweden, and Switzerland have the best status from a comprehensive to sub-perspective; even when the pandemic occurred, their situations worsened as all participating countries, although not as grave as what happened in other countries. The status of the population gets better in Poland and Greece in some aspects, but generally, it still needs to be improved (see Sowada et al., 2021).

Although we have considered four core aspects highly associated with health and well-being, still, we may keep extending the meaning and usage of the WBDI indicator from the following paths. To extend the data sets from the same or other data sources wherever we can ensure the data quality and integration. The PCA and PCP methods are suitable for dealing with large data sets with high dimensionalities. Technically, the WBDI indicator can give a comprehensive supplemental understanding of actual status with an increasing number of relevant variables. Indeed, the outbreak of COVID-19 was unexpected, but the impacts are not avoidable. We may provide a specific analysis that focuses on the pandemic and assist in reducing the long-term effects of the pandemic from individual to public perspectives. We could also expect to learn the governing patterns by analysing the evolution of the WBDI indicator and tracking the fluctuations before and after the pandemic to examine whether the medical system reacts well when shocks appear. Furthermore, deeper analysis among countries might be critical and meaningful, too. To distinguish why the outbreak impacts people worse in one country and less in the other, whether medical authorities made quick and correct decisions, and how we should see recovery and improved life after this once-in-a-lifetime challenge.

Appendix

Variables and Thematic Sub-Indicators

See to Tables 4 and 5.

Table 4 Variables included in the analysis and their possible values or categories

Variable	Description	Values/categories	Scale
Nhospital	Nights in hospital	Healthy=zero nights in hospital	[0, 365]
Nursing	Nursing home	1=yes/0=no	0,1
Chronic	Number of chronic diseases	Healthy=less than two chronic condition	[0, 13]
BMI	Body mass index	Healthy range from 18.5 to 25	[12.47, 98.62]
Eyeght	Eyegight reading	1=excellent/2=very good/3=good/4=fair/5=poor	1-5
Hearing	Hearing	1=excellent/2=very good/3=good/4=fair/5=poor	1-5
Mobility	Mobility limitations	Walking 100 ms/sitting for about 2 h getting up from a chair after sitting for long periods/ climbing several flights of stairs without resting/ climbing one flight of stairs without resting/ stooping, kneeling or crouching/ reaching or extending the arms above shoulder level/ pulling or pushing large objects like a living room chair/ lifting or carrying weights over 10 pounds or 5 kilos, like a heavy bag of groceries/ picking up a small coin from a table/ none of these	1-10
ADL	Limitations with activities of daily living	Dressing, including putting on shoes and socks/ walking across a room/ bathing or showering eating, such as cutting up your food/ getting in or out of the bed/ using the toilet,including getting up or down/ none of these	0-6
IADL	Limitations with instrumental activities of daily living	Using a map to figure out how to get around in a strange place/ preparing a hot meal/ shopping for groceries/ making phonecalls/ taking medications/ doing work around the house garden/ managing money, such as paying bills and keeping track of expenses/ leaving the house independently and accessing transportation services/ doing personal laundry/ none of these	0-9
Esmoked	Ever smoked daily	1=yes/0=no	0,1
Phianct	Physical inactivity	1=more than once a week/2=once a week 3=once to three times a month/4=hardly ever or never	1-4
LifeSat	Life satisfaction	From 0=completely dissatisfied to 10=completely satisfied	0-10
LifeHap	Life happiness	1=often/2=sometimes/3=rarely/4=never	1-4
Cf008tot	Ten words list learning first trial total	From 0=none to 10=all	0-10
Sphus	Self-perceived health US-scale	1=excellent/2=very good/3=good/4=fair/5=poor	1-5
EUROD	EURO-D depression scale	Evaluates 12 symptoms: depression, pessimism, wishing death, guilt, sleep, interest, irritability, appetite, fatigue, concentration, enjoyment and tearfulness	0-12

Table 4 (continued)

Variable	Description	Values/categories	Scale
Poverty	Under poverty threshold	1=yes/0=no	0,1
Social Benefit	No social financial support	1=yes/0=no	0,1
Sickness Assist	No sickness assistance	1=yes/0=no	0,1
Insurance	No private insurance	1=yes/0=no	0,1
Charity Support	No charity support	1=yes/0=no	0,1
Financial Problem	Met financial problem	1=yes/0=no	0,1

Table 5 Definition of four main sub-indicators

Sub-indicator	Variable	Description
Health status	Nhospital	Yes, I spent more than 14 nights in hospital
	Nursing	Yes, I live in a nursing home
	Chronic	Yes, I have two or more chronic conditions
	BMI	BMI is lower than 18 or higher than 25
	Esmoked	Yes, I smoked everyday
Dependency	Eyesight	Yes, I have poor eyesight
	Hearing	Yes, I have poor hearing
	Mobillity	Yes, I have at least 1 mobility limitation
	ADL_IADL	Yes, I have at least 1 ADL/IADL limitation
	Phinact	Yes, I am a physical inactive person
	Cf008tot	Yes, I repeat less than 6 words from a 10 words learning
Self-perceived health	LifeHap	Yes, I do not feel happiness of life
	LifeSat	Yes, I do not feel satisfied with life
	Sphus	Yes, I have poor self-perception of health
	EUROD	Yes, I have more than 4 in EURO-D depression scale
Socio-economic status	Poverty	Yes, I have less than 60% median income of my country
	Social benefit	Yes, I do not receive any social financial support
	Sickness assist	Yes, I do not have sickness assistance from any society/ organization
	Insurance	Yes, I do not have private insurance
	Charity support	Yes, I do not receive any charity support from any society/ organization
	Financial problem	Yes, I met financial problems

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Declarations

Conflict of interest The authors report there are no competing interests to declare.

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References

- Acosta-González, H., & Marcenaro-Gutiérrez, O. (2021). Relationship between subjective well-being and self-reported health: Evidence from Ecuador. *Applied Research Quality Life*, *16*, 1961–1981. <https://doi.org/10.1007/s11482-020-09852-z>
- Arber, S., Khlat, M., et al. (2002). Introduction to social and economic patterning of women's health in a changing world. *Social Science & Medicine*, *54*(5), 643–647.
- Arias-de la Torre, J., Vilagut, G., Martín, V., Molina, A. J., & Alonso, J. (2018). Prevalence of major depressive disorder and association with personal and socio-economic factors. Results for Spain of the European health interview survey 2014–2015. *Journal of Affective Disorders*, *239*, 203–207.
- Artazcoz, L., Cortés, I., Borrell, C., Escribà-Agüir, V., & Cascant, L. (2011). Social inequalities in the association between partner/marital status and health among workers in Spain. *Social Science & Medicine*, *72*(4), 600–607.
- Borrell, C., Palència, L., Muntaner, C., Urquía, M., Malmusi, D., & O'Campo, P. (2014). Influence of macrosocial policies on women's health and gender inequalities in health. *Epidemiologic Reviews*, *36*(1), 31–48.
- Börsch-Supan, A. (2022). Survey of health, ageing and retirement in Europe (SHARE) wave 6. *International Journal of Epidemiology*, *42*(4), 992–1001. <https://doi.org/10.6103/share.w6.800>
- Börsch-Supan, A. (2022). Survey of health, ageing and retirement in Europe (SHARE) wave 7. *Max Planck Institute for Social Law and Social Policy*. <https://doi.org/10.6103/share.w7.800>
- Börsch-Supan, A. (2022c). Survey of Health, ageing and retirement in Europe (SHARE) Wave 8. Release version: 8.0.0. Share-eric. data set. <https://doi.org/10.6103/share.w8.800>
- Börsch-Supan, A., Brandt, M., Hunkler, C., Kneip, T., Korbmacher, J., Malter, F., & Zuber, S. (2013). Data resource profile: The survey of health, ageing and retirement in Europe (SHARE). *International Journal of Epidemiology*, *42*(4), 992–1001.
- Bwire, G. (2020). Coronavirus: Why men are more vulnerable to COVID-19 than women? *SN Comprehensive Clinical Medicine*, *2*(7), 874–876.
- Chiu, C.-T. (2019). Living arrangements and disability-free life expectancy in the United States. *PLoS ONE*, *14*(2), e0211894.
- Chopik, W. J., Bremner, R. H., Johnson, D. J., & Giasson, H. L. (2018). Age differences in age perceptions and developmental transitions. *Frontiers in Psychology*. <https://doi.org/10.3389/fpsyg.2018.00067D>
- de Maya Matallana, M., López-Martínez, M., & Riquelme-Perea, P. (2022). Measurement of quality of life in Spanish regions. *Applied Research Quality Life*, *17*, 1–30. <https://doi.org/10.1007/s11482-020-09870-x>
- Deville, J.-C., & Särndal, C.-E. (1992). Calibration estimators in survey sampling. *Journal of the American Statistical Association*, *87*(418), 376–382.
- Domènech-Abella, J., Mundó, J., Leonardi, M., Chatterji, S., Tobiasz-Adamczyk, B., Koskinen, S., & Haro, J. M. (2018). The association between socioeconomic status and depression among older adults in Finland, Poland and Spain: A comparative cross-sectional study of distinct measures and pathways. *Journal of Affective Disorders*, *241*, 311–318.
- Efron, B. (1979). Bootstrap methods: Another look at the jackknife. *The Annals of Statistics*, *7*, 1–26.
- Eurostat. (2020). Ageing Europe—statistics on population developments.
- Eurostat. (2022). Ageing Europe—looking at the lives of older people in the EU—2020 edition. In *Ageing Europe - looking at the lives of older people in the EU - 2020 edition - products statistical books - Eurostat*. <https://ec.europa.eu/eurostat/web/products-statistical-books/-/ks-02-20-655>.
- Flury, B. N. (1984). Common principal components in k groups. *Journal of the American Statistical Association*, *79*(388), 892–898.
- Flury, B. N. (1988). *Common principal components & related multivariate models*. Hoboken: Wiley.

- Flury, B. N., & Gautschi, W. (1986). An algorithm for simultaneous orthogonal transformation of several positive definite symmetric matrices to nearly diagonal form. *SIAM Journal on Scientific and Statistical Computing*, 7(1), 169–184.
- Franssen, T., Stijnen, M., Hamers, F., & Schneider, F. (2020). Age differences in demographic, social and health-related factors associated with loneliness across the adult life span (19–65 years): A cross-sectional study in the Netherlands. *BMC Public Health*, 20(1), 1–12.
- García-Basteiro, A., Alvarez-Dardet, C., Arenas, A., Bengoa, R., Borrell, C., Del Val, M., & Hernández, I. (2020). The need for an independent evaluation of the COVID-19 response in Spain. *The Lancet*, 396(10250), 529–530.
- García-Fernández, L., Romero-Ferreiro, V., López-Roldán, P., Padilla, S., & Rodríguez-Jimenez, R. (2020). Mental health in elderly Spanish people in times of COVID-19 outbreak. *The American Journal of Geriatric Psychiatry*, 28(10), 1040–1045.
- Gharbi-Meliani, A., Husson, F., Vandendriessche, H., Bayen, E., Yaffe, K., & Bachoud-Lévi, L., A. C. Cleret de Langavant. (2023). Identification of high likelihood of dementia in population-based surveys using unsupervised clustering: a longitudinal analysis. <https://doi.org/10.1101/2023.02.17.23286078>
- Gove, W. R., Hughes, M., & Style, C. B. (1983). Does marriage have positive effects on the psychological well-being of the individual? *Journal of Health and Social Behavior*, 24(2), 122–131.
- Grané, A., Albarrán, I., & Guo, Q. (2021). Visualizing health and well-being inequalities among older Europeans. *Social Indicators Research*, 155(2), 479–503.
- Gutiérrez-Vega, M., Villar, E.-D., Armando, O., Carrillo-Saucedo, I. C., & Montañez-Alvarado, P. (2018). The possible protective effect of marital status in quality of life among elders in a US-Mexico border city. *Community Mental Health Journal*, 54(4), 480–484.
- Hajek, A., Lieske, B., König, H., Zwar, L., Kretzler, B., Moszka, N., & Aarabi, G. (2023). Oral health, anxiety symptoms and depressive symptoms: Findings from the survey of health, ageing and retirement in Europe. *Psychogeriatrics*, 23(4), 571–577.
- Han, F., Wang, H., Wu, J., Yao, W., Hao, C., & Pei, J. (2021). Depressive symptoms and cognitive impairment: A 10-year follow-up study from the survey of health, ageing and retirement in Europe. *European Psychiatry*, 64(1), e55.
- Herrero-Prieto, L., Boal-San-Miguel, I., & Gómez Vega, M. (2019). Deep rooted culture and economic development: Taking the seven deadly sins to build a well being composite indicator. *Social Indicators Research*, 144, 601–624. <https://doi.org/10.1007/s11205-019-02067-2>
- Hoffmann, R. (2011). Socioeconomic inequalities in old-age mortality: A comparison of Denmark and the USA. *Social Science & Medicine*, 72(12), 1986–1992.
- Högberg, B. (2018). Gender and health among older people: What is the role of social policies? *International Journal of Social Welfare*, 27(3), 236–247.
- Hollander, J., Renski, H., Foster-Karim, C., & Wiley, A. (2020). Micro quality of life: Assessing health and well-being in and around public facilities in New York City. *Applied Research Quality Life*, 15, 791–812. <https://doi.org/10.1007/s11482-019-9705-9>
- Horn, R. A., & Johnson, C. (1985). *Matrix analysis*. Cambridge: Cambridge University Press.
- Hotelling, H. (1933). Analysis of a complex of statistical variables into principal components. *Journal of Educational Psychology*, 24(6), 417.
- Jaffe, D. H., Manor, O., Eisenbach, Z., & Neumark, Y. D. (2007). The protective effect of marriage on mortality in a dynamic society. *Annals of Epidemiology*, 17(7), 540–547.
- Jayanama, K., Theou, O., Godin, J., Mayo, L., Cahill, A., & Rockwood, K. (2022). Relationship of body mass index with frailty and all-cause mortality among middle-aged and older adults. *BMC Medicine*, 20(1), 404.
- Jia, H., & Lubetkin, E. I. (2020). Life expectancy and active life expectancy by disability status in older us adults. *PLoS ONE*, 15(9), e0238890.
- Kim, J.-M., Sungur, E. A., & Heo, T.-Y. (2007). Calibration approach estimators in stratified sampling. *Statistics & Probability Letters*, 77(1), 99–103.
- Kovács, N., Liska, O., Idara-Umoren, E., Mahrouseh, N., & Varga, O. (2023). Trends in dental care Utilisation among the elderly using longitudinal data from 14 European countries: A multilevel analysis. *PLoS ONE*, 18(6), e0286192.
- Levy, B. R., Pilver, C., Chung, P. H., & Slade, M. D. (2014). Subliminal strengthening: Improving older individuals' physical function over time with an implicit-age-stereotype intervention. *Psychological Science*, 25(12), 2127–2135.
- Li, H. (2016). Accurate and efficient classification based on common principal components analysis for multivariate time series. *Neurocomputing*, 171, 744–753.
- MacKiewicz, A., & Ratajczak, W. (1993). Principal components analysis (PCA). *Computers & Geosciences*, 19(3), 303–342.

- Manzoli, L., Villari, P., Pirone, G. M., & Boccia, A. (2007). Marital status and mortality in the elderly: A systematic review and meta-analysis. *Social Science & Medicine*, *64*(1), 77–94.
- Ogliari, G., Ryg, J., Andersen-Ranberg, K., Scheel-Hincke, L., Collins, J., Cowley, A., & Masud, T. (2022). Association of pain and risk of falls in community-dwelling adults: A prospective study in the survey of health, ageing and retirement in Europe (SHARE). *European Geriatric Medicine*, *13*(6), 1441–1454.
- Palència, L., Malmusi, D., De Moortel, D., Artazcoz, L., Backhans, M., Vanroelen, C., & Borrell, C. (2014). The influence of gender equality policies on gender inequalities in health in Europe. *Social Science & Medicine*, *117*, 25–33.
- Pearson, K. (1901). Liii. On lines and planes of closest fit to systems of points in space. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, *2*(11), 559–572.
- Peiró-Palomino, J., & Picazo-Tadeo, A. (2018). OECD: One or many? Ranking countries with a composite well-being indicator. *Social Indicators Research*, *139*, 847–869. <https://doi.org/10.1007/s11205-018-0112-0>
- Pivonello, R., Auriemma, R., Pivonello, C., Isidori, A., Corona, G., Colao, A., & Millar, R. (2021). Sex disparities in COVID-19 severity and outcome: Are men weaker or women stronger? *Neuroendocrinology*, *111*(11), 1066–1085.
- Pradhan, A., & Olsson, P. (2020). Sex differences in severity and mortality from COVID-19: Are males more vulnerable? *Biology of Sex Differences*, *11*(1), 1–11.
- Rendall, M. S., Weden, M. M., Favreault, M. M., & Waldron, H. (2011). The protective effect of marriage for survival: A review and update. *Demography*, *48*(2), 481–506.
- Ryser, V., Meier, C., Vilpert, S., & Maurer, J. (2023). Health literacy across personality traits among older adults: Cross-sectional evidence from Switzerland. *European Journal of Aging*, *20*(1), 28.
- Salk, R. H., Hyde, J. S., & Abramson, L. Y. (2017). Gender differences in depression in representative national samples: Meta-analyses of diagnoses and symptoms. *Psychological Bulletin*, *143*(8), 783.
- Santini, Z., Jose, P., Koyanagi, A., Meilstrup, C., Nielsen, L., Madsen, V., & Koushede, K. R. (2020). Formal social participation protects physical health through enhanced mental health: A longitudinal mediation analysis using three consecutive waves of the survey of health, ageing and retirement in Europe (SHARE). *Social Science & Medicine*, *251*, 112906.
- Sarra, A., & Nissi, E. (2020). Spatial composite indicator for human and ecosystem well being in the Italian Urban areas. *Social Indicators Research*, *148*, 353–377. <https://doi.org/10.1007/s11205-019-02203-y>
- Schmitz, A., & Brandt, M. (2019). Gendered patterns of depression and its determinants in older Europeans. *Archives of Gerontology and Geriatrics*, *82*, 207–216.
- Schrijvers, D. L., Bollen, J., & Sabbe, B. G. (2012). The gender paradox in suicidal behavior and its impact on the suicidal process. *Journal of Affective Disorders*, *138*(1–2), 19–26.
- Serrat, R., Nyqvist, F., Torres, S., Dury, S., & Näsman, M. (2023). Trends in dental care Utilisation among the elderly using longitudinal data from 14 European countries: A multilevel analysis. *European Journal of Ageing*, *20*(1), 16.
- Singh, S. (1998). Estimation of variance of the general regression estimator: Higher level calibration approach. *Survey Methodology*, *24*(1), 41–50.
- Sowada, C., Sagan, A., Kowalska-Bobko, I., Badora-Musiał, K., Bochenek, A., Domagała, T., et al. (2021). Poland: Health System Review. *Health Systems in Transition*, *21*(1), 1–234.
- Steckermeier, L. (2021). The value of autonomy for the good life. An empirical investigation of autonomy and life satisfaction in Europe. *Social Indicators Research*, *154*(2), 693–723.
- Toch-Marquardt, M., Menvielle, G., Eikemo, T. A., Kulhanová, I., Kulik, M. C., Bopp, M., et al. (2014). Occupational class inequalities in all-cause and cause-specific mortality among middle-aged men in 14 European populations during the early 2000s. *PLoS ONE*, *9*(9), e108072.
- Tomaselli, V., Fordellone, M., & Vichi, M. (2021). Building well-being composite indicator for micro-territorial areas through PIS-SEM and k-means approach. *Social Indicators Research*, *153*, 407–429. <https://doi.org/10.1007/s11205-020-02454-0>
- Trendafilov, N. T. (2010). Stepwise estimation of common principal components. *Computational Statistics & Data Analysis*, *54*(12), 3446–3457.
- Tur-Sinai, A., Teti, A., Rommel, A., Hlebec, V., & Lamura, G. (2020). How many older informal caregivers are there in Europe? Comparison of estimates of their prevalence from three European surveys. *International Journal of Environmental Research and Public Health*, *17*(24), 9531.
- United Nations. (2022). World population prospects 2022: Summary of results — population division. United Nations. <https://www.un.org/development/desa/pd/content/World-Population-Prospect-2022>
- Vestergaard, L., Nielsen, J., Richter, L., Schmid, D., Bustos, N., Braeye, T., et al. (2020). Excess all-cause mortality during the COVID-19 pandemic in Europe—preliminary pooled estimates from the Euro-MOMO network. *Eurosurveillance*, *25*(26), 2001214. <https://doi.org/10.2807/1560-7917.ES.2020.25.26.2001214>

- Waldron, I., Hughes, M. E., & Brooks, T. L. (1996). Marriage protection and marriage selection-prospective evidence for reciprocal effects of marital status and health. *Social Science & Medicine*, *43*(1), 113–123.
- Weber, A. M., Cislighi, B., Meausoone, V., Abdalla, S., Mejía-Guevara, I., Loftus, P., et al. (2019). Gender norms and health: Insights from global survey data. *The Lancet*, *393*(10189), 2455–2468.
- Weber, D., & Loichinger, E. (2022). Live longer, retire later? Developments of healthy life expectancies and working life expectancies between age 50–59 and age 60–69 in Europe. *European Journal of Ageing*, *19*, 75–93. <https://doi.org/10.1007/s10433-020-00592-5>
- World Health Organization. (2022a). Ageing and health. World Health Organization. <https://www.who.int/news-room/fact-sheets/detail/ageing-and-health>
- World Health Organization. (2022b). World mental health report: Transforming mental health for all. World Health Organization. <https://www.who.int/teams/mental-health-and-substance-use/world-mental-health-report>
- Zick, C. D., & Smith, K. R. (1991). Marital transitions, poverty, and gender differences in mortality. *Journal of Marriage and the Family*, *53*(2), 327–336.
- Zimmer, Z., Zajacova, A., & Grol-Prokopczyk, H. (2020). Trends in pain prevalence among adults aged 50 and older across Europe, 2004 to 2015. *Journal of Aging and Health*, *32*(10), 1419–1432.

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