Comparative Population Studies
Vol. 49 (2024): 273-296 (Date of release: 02.09.2024)

Cross-Sectional Association Between Life Expectancy and Unhealthy Life Years: Proof of Concept Tests of the CroHaM Hypothesis*

Marc Luy

Abstract: The recently presented CroHaM hypothesis says (1) that longitudinal health domain-specific expansion and compression effects depend primarily on the health domains' mortality risk and (2) that these effects exist equivalently in the cross-sectional context, affecting differences in healthy life years (HLY) between populations and subpopulations with different levels of life expectancy (LE). We test this hypothesis by analysing the association between LE and unhealthy life years (ULY) at age 50 for a large number of subpopulations. The analyses are carried out for three health domains which are differently related to mortality: poor self-perceived health and strong activity limitation with comparatively high mortality, and chronic morbidity with comparatively low risk of dying. Data on gender- and subpopulation-specific prevalence of these health conditions are taken from the Actual German Health Study 2012 (GEDA). LEs are estimated with the "Longitudinal Survival Method", using data of the German Life Expectancy Survey. ULY are estimated with the "Sullivan Method". Differences in ULY between each subpopulation and the total population and between women and men for each subpopulation are decomposed into the effects caused by differences in health ("health effect") and mortality ("mortality effect") with the "Nusselder/Looman Method". The results confirm the CroHaM hypothesis: we find a positive relationship between LE and ULY only for chronic morbidity, whereas this relationship is negative for poor self-perceived health and strong activity limitation. However, when the mortality effect is controlled for, we find a negative relationship between LE and ULY for all three health domains. The practical relevance of these findings is discussed using the example of the so-called "gender paradox" in health and mortality. We conclude that the CroHaM hypothesis may describe an important determinant of life years spent with and without health impairment, and it may help to better understand and interpret trends and differentials in HLY or ULY based on cross-sectional data.

* This article belongs to a special issue on "Levels and Trends of Health Expectancy: Understanding its Measurement and Estimation Sensitivity".

** This article has an Online Appendix with supplementary material URL: https://www.comparativepopulationstudies.de/index.php/CPoS/article/view/659/417

Federal Institute for Population Research 2024

URL: www.comparativepopulationstudies.de
DOI: https://doi.org/10.12765/CPoS-2024-11
URN: urn:nbn:de:bib-cpos-2024-11en7

Keywords: CroHaM hypothesis • Healthy life years • Health impairment • Life expectancy • Gender paradox · Fundamental cause hypothesis

1 Introduction

This paper is about the verification of the recently presented CroHaM hypothesis on the complex association between life expectancy (LE) and different indicators for healthy life years (HLY) in the cross-sectional context, with CroHaM being the abbreviation for "cross-sectional association between health and mortality" (*Luy* 2021). Empirical studies show that (sub)populations with higher LE do spend more life years in good health than (sub)populations with lower LE only for some indicators of health. For other health indicators, the association between LE and HLY does reverse and the (sub)populations with lower LE spend more life years in good health (*Robine/Michel* 2004; *Zeng et al.* 2017). These contrasting results are still not fully understood and lead to contradictory interpretations and conclusions regarding direction and causes of differences in HLY. Luy's hypothesis not only provides an explanation for these varying results, it also states that HLY estimations based on different health indicators – which reflect different facets of health – must lead to different directions in the association between LE and HLY.

The CroHaM hypothesis connects the cross-sectional association between health and mortality with the longitudinal association between LE and HLY in the context of the "compression versus expansion of morbidity" debate. This debate revolves around three theoretical scenarios: (1) longer lives are associated with more years spent in poor health, i.e., the "expansion of morbidity hypothesis" (*Gruenberg* 1977), (2) longer lives are associated with a delay in the onset of health problems, i.e., the "compression of morbidity hypothesis" (*Fries* 1980), and (3) there is a balanced relationship between health and longevity, i.e., the "dynamic equilibrium hypothesis" (*Manton* 1982). A summary and extensive literature review of these three scenarios can be found in *Payne* (2022). He describes the main idea behind the expansion of morbidity hypothesis as a shift in frailty over successive cohorts, as reductions in mortality – as a consequence of medical advances – let individuals with poor health more likely to survive longer than they would have in the past. In the opposing compression of morbidity framework, the reductions in mortality and improved health behaviours are thought to shift the age of onset of morbidity and disability more quickly than rises in LE, thus compressing life years spent with health impairment towards the end of the life span. The dynamic equilibrium model lies between the pessimistic expansion and optimistic compression scenarios. It hypothesises that advances in medical technology and early diagnosis lead to earlier discovery and treatment of diseases, resulting in declining rates of disability and mortality but an increasing proportion of the population with chronic morbidity (*Payne* 2022: 949-950). Because most HLY indicators are based on broad health indicators that combine different facets of health, the dynamic equilibrium model is usually interpreted as resulting in a constant proportion of life years spent in poor health.

Empirical evidence provided support for each of these approaches, depending on the specific health domain considered (*Christensen et al.* 2009). In particular, existing research suggests a postponement or stagnation of functional limitations and disabilities (*Bardenheier et al.* 2016; *Crimmins* 2015; *Freedman et al.* 2016; *Payne* 2022; *Shen/Payne* 2023), but an increase in morbidity defined by the presence of several biomarkers or physician-assessed health conditions and chronic diseases (*Beltrán-Sánchez et al.* 2016; *Crimmins* 2015; *Crimmins/Beltrán-Sánchez* 2011; *Crimmins et al.* 2019; *Payne* 2022; *Shen/Payne* 2023). These trends were confirmed in recent investigations of trends in HLY in the population of Germany from 2005 to 2019 (*Luy* 2022, 2024b). Using the three health indictors of the "Minimum European Health Module" (MEHM) included in the annual "European Union Statistics on Income and Living Conditions" (EU-SILC), the study found that trends in overall health (self-perceived health) follow the predictions of the compression scenario, whereas trends in chronic morbidity show a decline in line with the expansion scenario, and trends in disability (activity limitation) most closely match the prediction of the dynamic equilibrium model.

Naturally, the "compression versus expansion of morbidity" debate with its hypotheses and empirical investigations refers to longitudinal developments and time trends in health and longevity. *Luy* (2021) assumed that the main cause for the contrasting observations of expansion effects on the one hand and compression effects on the other is the severity of the respective health domains, which is reflected in their risk of dying. He analysed the longitudinal mortality of individuals with health impairment according to the three MEHM health domains and found that people with poor self-perceived health and activity limitations have higher mortality than people with chronic health problems (details about the definition and measurement of these health domains can be found in the data and methods section). He connected this observation with the trends in HLY and concluded that compression effects can be found among those health domains which are more severely and thus more strongly linked to mortality, whereas expansion effects can be found among those health domains which are less severely and thus only weakly associated with mortality. According to *Luy* (2021: 63), "the link between compression and expansion effects on the one hand side and the health-mortality-relationship on the other appears to be plausible" because "[t]he increase in LE is a consequence of reduced mortality which results from – besides reductions in incidence and fatality of specific diseases – a postponement in the onset of these diseases, i.e., a reduction in prevalence. Moreover, the likelihood of suffering longstanding illnesses increases with age, and therefore their prevalence increases with increasing LE".

The central pillar of the CroHaM hypothesis is the assumption that the associations between LE and HLY observed in the longitudinal context hold equivalently in a cross-sectional context regarding differences between populations and subpopulations with different levels of mortality: higher LE is associated with fewer life years spent with health impairments that are more closely related to mortality (such as functional limitations and disabilities), but with more life years spent with health problems that are less closely related to mortality (such as chronic diseases).

Luy (2021) tested his hypothesis by comparing the HLY of male and female Catholic order members with their counterparts of the general population for the three health domains covered by the MEHM: self-perceived health and activity limitations which are closer related to mortality, and chronic morbidity with a less strong link to mortality. An important element of his verification approach is the fact that order members' advantage in LE is larger among men than among women (*Luy* 2002, 2003). In line with the CroHaM hypothesis, he found that order members had the largest advantages when HLY were estimated on the basis of life years spent without activity limitations and in good self-perceived health, and they were smallest or even negative for life years spent without chronic illness. Moreover, all results were stronger among men, indicating the effect of the higher LE surplus of monks against the general population.

If the CroHaM hypothesis were true, it would provide an important aspect for better understanding differentials in HLY which are usually investigated on the basis of cross-sectional data. Therefore, the aim of this paper is to provide two proof of concept tests that are closer to the conventional investigations of differentials in HLY than *Luy*'s (2021) quasi-experiment with religious people. First, we will analyse the relationship between LE and HLY for different health domains among a large number of subpopulations with higher and lower LE levels compared to the total population, separately for men and women. Second, we will examine the LE-HLY relationship for gender differences within these subpopulations. This additional examination increases the number of verification scenarios and extends the original test of the CroHaM hypothesis by *Luy* (2021) to include the gender differences in the general population. In contrast to *Luy* (2021), we base our analyses on unhealthy life years (ULY) because both phenomena considered here – the expansion respective compression effects (*Jagger* 2000) and the so-called "gender paradox" in health and longevity (*Di Lego et al.* 2020) – refer primarily to the lifetime spent with health impairments.

The CroHaM hypothesis leads to two specific expectations for our proof of concept tests:

1. We find a positive relationship between LE and ULY across subpopulations and their gender differences only among those health domains with a weak link to mortality (hypothesis 1), and

2. This relationship reverses when the "mortality effect" inherent in the ULY – i.e., the fact that a higher total number of life years increases also the number of life years spent with health impairments – is controlled for (hypothesis 2).

Before presenting the results, we will summarise the theoretical basis of the hypothesis in the next section, since it is still young and not yet widely known. This is followed by a description of the data and methods used in our study. The paper ends with a discussion of the test results and the conclusions on the significance of the CroHaM hypothesis.

2 Theoretical basis of the CroHaM hypothesis

The transition of the above mentioned longitudinal links between severity of health domains and respective expansion and compression effects to the cross-sectional context builds, as second pillar of the CroHaM hypothesis, on *Link* and *Phelan*'s (1995) "theory of fundamental social causes of disease" and is rooted in the observation that most health differentials within and between populations are caused primarily by social factors (*Bucciardini et al.* 2019; *Marmot* 2005), including gender differences in health and longevity (*Vallin* 1995). Notably, empirical evidence shows that socio-economic status (SES) is not only one of the strongest determinants of morbidity and mortality (*Mirowsky/Ross* 2003). Its association with health and longevity has also persisted over centuries, despite essential changes in the diseases and risk factors which have been assumed to be its central drivers (*Antonovsky* 1967).

The fundamental cause theory provides an explanation for this phenomenon. It states, in a nutshell, that the enduring association between SES and health results because SES embodies an array of flexibly usable resources – such as money, knowledge, prestige, power, and beneficial social connections – that protect health no matter what mechanisms are relevant at any given time (*Link/Phelan* 1995). These flexible resources operate at both individual and contextual levels. At the individual level, they can be conceptualised as "cause of causes" or "risk of risks" that shape individual health behaviours by influencing whether people know about, have access to, can afford and are motivated to engage in health-enhancing lifestyles to avoid risks and adopt protective strategies. Examples include knowing about and asking for beneficial health procedures, quitting smoking, getting flu shots, wearing seat belts and driving a car with airbags, eating fruits and vegetables, exercising regularly and taking restful vacations. At the contextual level, flexible resources provide "add on" benefits through shaping access to advantaged neighbourhoods, high-status occupations and social networks that vary significantly in associated profiles of risk and protective factors (more details can be found in *Phelan et al.* 2004, 2010). Consequently, the theory states, whenever gains are made in the ability to control disease, people who are advantaged with respect to these resources will, on average, benefit more from new knowledge and health-enhancing capabilities (*Phelan/Link* 2005).

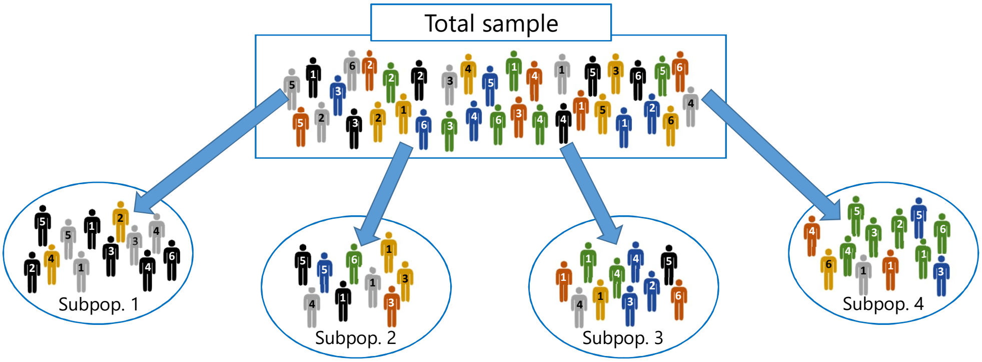
As outlined by *Luy* (2021), *Link* and *Phelan*'s fundamental cause approach includes also a "cross-sectional time effect" which constitutes the basis of the CroHaM hypothesis: individuals who dispose more of the flexible resources are – compared to those with fewer resources – in a certain way ahead in time with regard to access and benefit from increasing knowledge and health-enhancing capabilities. From this new interpretation of the theory of fundamental causes follows that differences in period LE represent a cross-sectional image of longitudinal developments. Thus, varying LE levels of different populations prevailing at the same time can be assumed to root – at least to some extent – in the same mechanisms as varying levels of LE of the same population prevailing at different times. This leads to *Luy*'s central hypothesis: associations between levels of health and mortality which are prevalent in the longitudinal perspective exist equivalently in the cross-sectional context. In the longitudinal respective time trend perspective, the association between health and mortality explains the varying expansion and compression effects according to different health indicators. In the cross-sectional perspective, the association between health and mortality affects the comparison of populations with different levels of LE, and consequently affect cross-sectional differences in the number of HLY between them.

3 Data and methods

Our test of the CroHaM hypothesis requires a set of subpopulations with data that allow the estimation of LE and ULY. These are not available from one data source, so various survey and mortality data had to be used and linked for the analyses. The analytic strategy was to analyse the association between LE and ULY in as many subpopulations as possible. We estimate LE and ULY at age 50 for the year 2012 for 30 subgroups of the German population. Starting at age 50 was chosen because the prevalence of health impairments is too low for the translation into life years spent with poor health below age 50. This holds in particular for our definition of poor health in the indicator for activity limitation (see below). The choice of the calendar year 2012 results from the selected survey for the health data. The decisive selection criterion was the high number of subpopulations for which an estimation of HLY could be carried out. The subpopulations of this study are defined by education level (low, medium, high) according to the ISCED-97 scale (*UNESCO* 1996), net equivalent income (1st, 2nd, 3rd, 4th quartile), net household income (1st, 2nd, 3rd, 4th quartile), work status (manual workers, employees, public servants, self-employed workers), marital status (single, married, divorced, widowed), living arrangement (living alone, living together with other people), smoking (never smokers, ever smokers), alcohol consumption (never, rarely, frequently), and body weight measured by BMI (underweight, normal weight, overweight, obese). The joint analysis of these subpopulations leads to certain overlaps. Some subpopulations will – to some extent – include the same individuals. This overlap of individuals across the subpopulations is however no limitation of the study but rather intended. The analysis of the association between LE and ULY requires a set of subpopulations that differ in LE, but they do not have to be exclusive in terms of the composition of their members.

We illustrate our approach to create the subgroups with a hypothetical survey sample in Figure 1. The rectangular box at the top of the graph contains the entire sample of 36 fictive individuals. The different colours of the individuals represent the different levels of their LE. Each LE group contains six individuals, which are numbered with the digits 1 to 6. The oval areas at the bottom of the graph contain four subpopulations drawn from the total sample, e.g., low education (subpop. 1), employees (subpop. 2), married (subpop. 3) and never smokers (subpop. 4). From the colours of the respective members of the subgroups, it can be concluded that subpopulation 1 has the lowest LE (predominantly black individuals) and subpopulation 4 the highest (predominantly green individuals). The LE of subpopulations 2 and 3 most likely lies in between. In this way, we obtain subpopulations with different, partly overlapping compositions, and consequently different LE. The additional estimation of the subpopulations' ULY enables us to analyse the statistical association between the subpopulations LE and ULY.

Fig. 1: Graphic illustration of the study's strategy to define the subpopulations from the total survey sample with different levels of life expectancy



Note: the colours of the individuals represent the levels of life expectancy. Assumed order of LE levels from low to high: black, grey, yellow, brown, blue, green.
Source: own illustration

ULY for the subpopulations are estimated for the above mentioned three health domains covered by the MEHM: self-perceived health, limitations in activities of daily living, and chronic morbidity. Data on gender- and subgroup-specific prevalence of these health conditions for age groups 50-54, 50-59, ..., 80+ are taken from the Actual German Health Study 2012 (GEDA), including 10,744 individuals aged 50 years and older (*Robert Koch-Institut* 2014). Self-perceived health reflects the self-assessment of a person's overall health based on the question "How is your health in general?" with the five answer categories "very good", "good", "fair", "poor", and "very poor". Activity limitations are measured with the question "To what extent have you been permanently limited because of illness in your usual daily activities?" with the additional clarification "This means since at least half a year" and the three response options "strongly limited", "limited but not strong", and "not limited". Chronic morbidity is defined as the presence of longstanding health problems based on the question "Do you have one or more longstanding chronic illnesses?" with the addition "Chronic illnesses are longstanding illnesses that require permanent treatment and control, e.g., diabetes or heart diseases" and the two possible responses "yes" and "no" (all questions translated by the author from the German GEDA questionnaire). We define the "unhealthy" state as basis for the estimation of ULY by poor or very poor self-perceived health, strong limitations in activities of daily living, and the presence of longstanding health problems.

LE at age 50 for each subpopulation is estimated with the "Longitudinal Survival Method" (LSM). The LSM is a technique to construct cross-sectional life tables on the basis of cohort-specific survival experiences from longitudinal survey data. The LSM translates these longitudinal survival experiences into a set of cross-sectional age- and gender-specific death rates. These death rates are then applied to a reference life table for a particular calendar year, resulting in period LE estimates for this calendar year (a detailed description with a worked example can be found in *Luy et al.* 2015). The age- and gender-specific death rates for the 30 subpopulations are derived from data of the western sample of the German Life Expectancy Survey (LES). The LES is a panel that consists of two waves of interviews. The first wave was carried out between 1984 and 1986 and includes 8,474 individuals. A follow-up survey was carried out in 1998 together with the collection of information on non-respondents' survival status including deceased. Tests of the quality of the LES mortality data revealed that the reflected survival of the LES sample between 1984 and 1998 is representative for the mortality of the western German population (*Luy/Di Giulio* 2005; *Luy et al.* 2015; *Salzmann/Bohk* 2008). We used the total German population's survival function for 2012 from the *Human Mortality Database* (2016) as reference life table to obtain LE estimates for the same year as for the available health data from the GEDA survey. The estimation of subpopulations' LE on the basis of LES data assumes that the mortality patterns prevalent during the period 1984/86-1998 – or more precisely the relative mortality differences between the subpopulations – are also valid in the calendar year 2012. This assumption is suboptimal. However, it is the only way to estimate LE for the considered subpopulations for the year 2012, because the LES is the only dataset that allows such mortality estimations for the German population.

ULY at age 50 for each subpopulation are estimated with the "Sullivan Method" (*Sullivan* 1971), combining the LE estimates on the basis of the LES with the age- and gender-specific health prevalence values derived from the GEDA survey. Finally, the differences in ULY between each subpopulation and the total population and between women and men for each subpopulation are decomposed into the effects caused by differences in health ("health effect") and mortality ("mortality effect") with the method proposed by *Nusselder* and *Looman* (2004). This method is an extension of the decomposition method for LE developed by *Arriaga* (1984) for application to HLY indicators estimated with the Sullivan method. It quantifies the extent to which differences in the prevalence of good respective poor health and total mortality in each age group contribute to differences in HLY respective ULY between (sub)populations or calendar periods.

4 Results

The test of the CroHaM hypothesis requires a set of subpopulations with different levels of LE to analyse the statistical association with the subpopulations' levels of

ULY. Tables 1 and 2 summarise the estimates for LE at age 50 and ULY at age 50 according to the three MEHM health domains for men and women, respectively. LE at age 50 for the total male population is 29.5 years, of which 3.2 years (10.8 percent) are spent with poor or very poor self-perceived health (SPH), 5.5 years (18.5 percent) are spent with strong activity limitation (LIMIT), and 15.5 years (52.7 percent) are spent with chronic morbidity (CHRON). Across the subpopulations of men, the values for LE(50) range between 23.2 years for widowed individuals and 34.0 years for never smokers. The values for ULY vary for self-perceived health between 1.5 years (4.9 percent) among men of the highest net household income quartile and 5.8 years (20.5 percent) among obese men, for activity limitation between 3.5 years (11.2 percent) among men of the highest net household income quartile and 8.2 years (31.8 percent) among men who never drink alcohol, and for chronic morbidity between 12.6 years (54.2 percent) among widowed men and 18.8 years (66.7 percent) among the obese. Note that the highest and lowest numbers of ULY do not necessarily reflect the highest and lowest proportions of life years spent with health impairments. For instance, the lowest proportion of life years spent with chronic health problems can be found among public servants for whom the ULY value of 13.9 years corresponds to 44.7 percent of their LE at age 50 of 31.1 years.

For the total female population, the estimated LE at age 50 is 34.2 years. Of those, 4.0 years (11.7 percent) are spent with poor or very poor self-perceived health, 6.6 years (19.1 percent) with strong limitation, and 18.9 years (55.1 percent) are spent with chronic illness. Across the female subpopulations, the total number of life years, LE(50), varies between 29.4 years for women with underweight to 39.5 years for self-employed workers. The life years spent with poor or very poor self-perceived health range between 1.4 years (3.9 percent of LE at age 50) for women of the highest net equivalent income quartile and 7.3 years (24.9 percent) for women with underweight, and those spent with strong activity limitations range between 3.9 years (11.1 percent) for frequent alcohol consumers and 10.1 years (34.5 percent) for women with underweight. Noteworthy, underweight women are the subpopulation that shows the lowest number of life years spent with chronic health problems with 16.0 years (54.5 percent), whereas the highest number of ULY for chronic morbidity can be found among obese women with 22.9 years (69.6 percent). The lowest proportion of life years spent with chronic health problems is prevalent among women of the highest net equivalent income quartile whose ULY value is 16.4 years, corresponding to 45.1 percent of their total LE of 36.2 years.

Figure 2 shows the differences between the subpopulations and the total population in LE (x-axes) and ULY (y-axes) for life years spent in poor or very poor self-perceived health, with strong activity limitation, and with chronic morbidity. Men and women are displayed in blue (left side) and red (right side), respectively. Each dot of the graphs represents one subpopulation. Among men, the dots placed furthest to the left on the x-axis represent the subgroup of widowed individuals whose LE lies 6.3 years below the LE of the total sample. This value remains the same in all three figures. What changes are the differences in ULY to the total sample. For SPH and LIMIT, the widowed spend more life years in poor health, with the differences being +1.4 and +0.4 years, respectively. However, for CHRON the difference is negative

Tab. 1: Estimations of life expectancy (LE) and unhealthy life years (ULY) at age 50 for three health indicators, various subpopulations, Germany 2012, men

Group indicator / subpopulation	LE(50)	ULY(50)		
		SPH	LIMIT	CHRON
Total population	29.5	3.2	5.5	15.5
Education according to ISCED-97				
Low (ISCED 1-2)	26.8	4.1	7.8	16.4
Medium (ISCED 3-4)	29.2	3.5	5.8	15.4
High (ISCED 5-6)	32.9	2.5	4.4	16.5
Net equivalent income				
1st quartile	28.2	4.5	7.0	16.2
2nd quartile	29.8	3.3	6.9	16.3
3rd quartile	29.1	2.4	3.8	14.4
4th quartile	30.9	1.9	3.8	14.8
Household net income				
1st quartile	27.1	5.1	7.5	16.0
2nd quartile	29.5	3.8	5.9	16.4
3rd quartile	30.7	3.0	5.7	15.9
4th quartile	31.7	1.5	3.5	15.2
Work status				
Manual workers	27.9	3.5	6.2	15.7
Employees	30.9	3.3	5.6	16.4
Public servants	31.1	2.6	4.9	13.9
Self-employed workers	30.1	2.9	4.6	16.1
Marital status				
Married	29.8	3.2	5.6	15.7
Unmarried	29.7	3.0	4.1	13.6
Divorced	25.0	3.6	4.6	13.3
Widowed	23.2	4.6	5.9	12.6
Living arrangement				
Single-person household	24.9	3.9	5.4	13.4
Multi-person household	29.8	3.1	5.6	15.8
Smoking				
Never	34.0	2.4	4.8	16.5
Ever	28.6	3.7	6.0	15.8
Alcohol consumption				
Never	25.8	5.5	8.2	16.0
Rarely	30.3	3.2	5.8	16.7
Frequently	29.5	2.3	4.3	14.3
Body Mass Index				
Normal weight	29.6	2.4	4.2	13.3
Overweight	29.9	2.5	5.4	15.6
Obese	28.1	5.8	7.9	18.8

Source: own calculations with data from GEDA, LES and HMD; for abbreviations see text.

Tab. 2: Estimates of life expectancy (LE) and unhealthy life years (ULY) at age 50 for three health indicators, various subpopulations, Germany 2012, women

		ULY(50)		
Group indicator / subpopulation	LE(50)	SPH	LIMIT	CHRON
Total population	34.2	4.0	6.6	18.9
Education according to ISCED-97				
Low (ISCED 1-2)	34.1	5.0	8.2	19.3
Medium (ISCED 3-4)	34.2	3.5	6.3	19.1
High (ISCED 5-6)	37.7	3.2	4.8	18.8
Net equivalent income				
1st quartile	33.7	4.9	7.5	19.6
2nd quartile	34.6	3.7	6.9	19.3
3rd quartile	33.7	3.2	5.4	18.1
4th quartile	36.2	1.4	4.3	16.4
Household net income				
1st quartile	33.1	4.8	7.9	19.8
2nd quartile	34.2	3.4	5.2	18.1
3rd quartile	36.8	4.4	7.0	20.1
4th quartile	36.2	2.4	5.0	17.9
Work status				
Manual workers	33.0	4.6	8.0	19.2
Employees	34.1	4.0	6.1	18.9
Public servants	35.6	4.8	7.1	18.4
Self-employed workers	39.5	1.7	4.6	18.8
Marital status				
Married	34.6	4.0	6.1	18.8
Unmarried	33.1	5.7	5.6	19.7
Divorced	31.2	4.7	6.8	18.9
Widowed	34.3	4.1	8.1	19.1
Living arrangement				
Single-person household	34.3	4.7	8.1	20.2
Multi-person household	34.4	4.2	5.9	18.6
Smoking				
Never	35.2	4.1	6.2	19.6
Ever	32.4	3.5	7.0	16.7
Alcohol consumption				
Never	32.7	6.9	9.3	21.4
Rarely	35.2	2.5	6.1	18.5
Frequently	35.4	2.1	3.9	16.0
Body Mass Index				
Underweight	29.4	7.3	10.1	16.0
Normal weight	35.3	3.1	5.3	16.2
Overweight	33.3	3.2	5.9	19.3
Obese	33.0	6.1	9.0	22.9

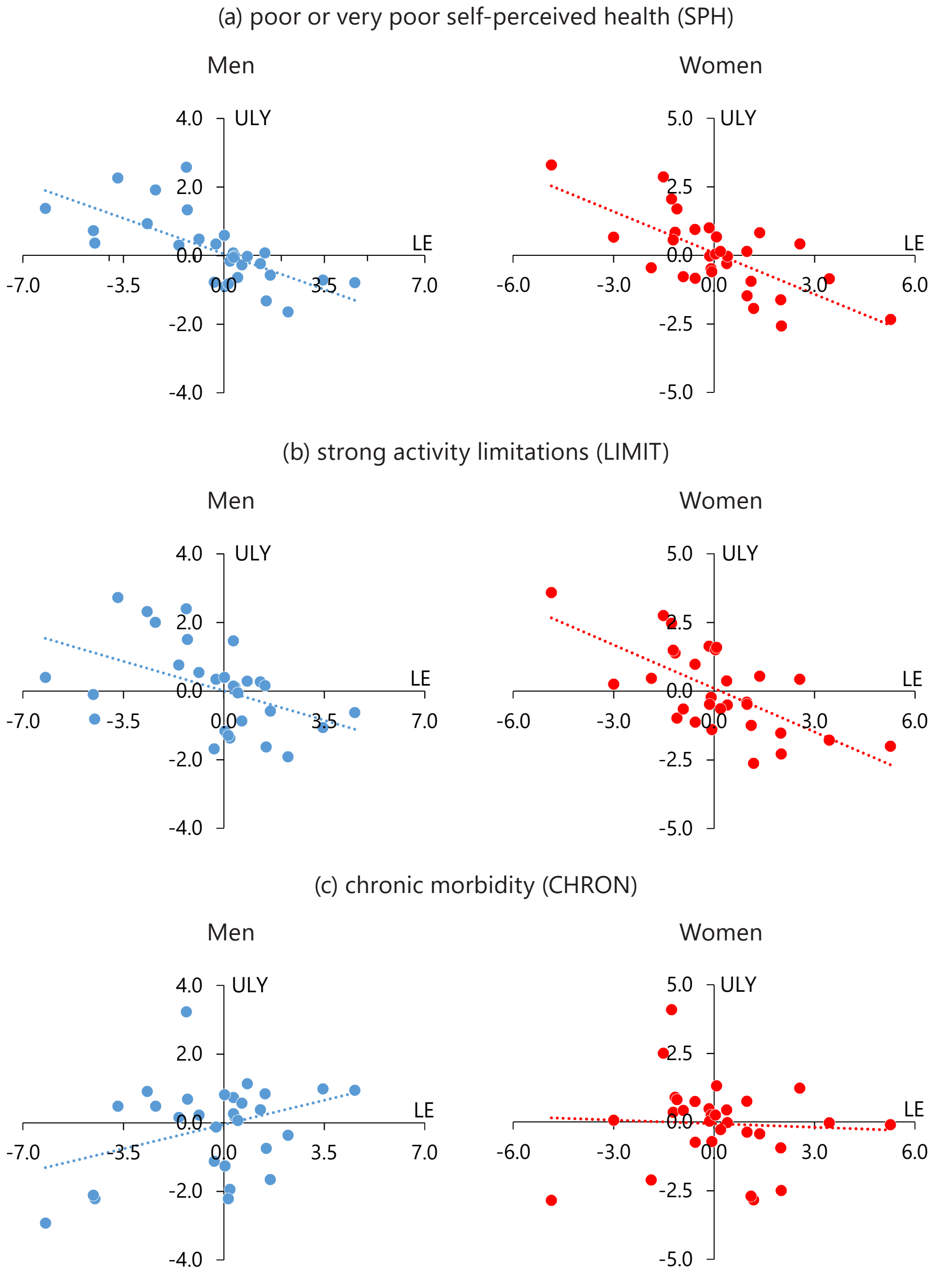
Source: own calculations with data from GEDA, LES and HMD; for abbreviations see text.

(-2.9 years), i.e., widowed men spend less years in poor health compared to the total sample of men. The dots placed furthest to the right of the x-axis refer to male never smokers whose LE is 4.5 higher than the LE of the total sample. The differences in ULY between never smokers and the total sample are -0.8 years for SPH, -0.7 years for LIMIT, and +1.0 years for CHRON. Among women, the dots placed furthest to the left of the x-axis refer to underweight individuals with a difference in LE to the total female sample of -4.8 years, whereas those placed furthest to the right refer to the subpopulation of self-employed workers with a difference in LE to the total sample of women of +5.3 years.

The statistical relationship between LE and ULY across the subpopulations is illustrated by linear regression lines. Figures 2(a) and 2(b) show that these relationships are negative for self-perceived health and global activity limitation, i.e., those health indicators that are more closely linked to mortality. The negative slope of the regression lines indicates that there is a tendency that subpopulations with higher LE spend less years with health impairments, whereas those being disadvantaged in LE spend more life years in poor health condition. This applies in a similar way to both men and women. However, the association between LE and ULY looks different when chronic morbidity is used, i.e., the health indicator that is only weakly linked to mortality (Fig. 2c). Among men, the linear relationship shows a positive direction. This indicates that an advantage in LE is associated, in tendency, with a disadvantage in health, leading to more life years spent with chronic health problems. Among women, this change in the relationship between LE and ULY is less clear. Nonetheless, a difference between the health domains self-perceived health and global activity limitation on the one hand, and chronic morbidity on the other, is apparent as well. These results support Luy's assumption that the cross-sectional association between LE and ULY reflects the longitudinal association and that the mortality risk associated with the health domains plays an important role: higher LE is – in general – associated with a lower number of life years spent in poor health for SPH and LIMIT, but – in tendence – with a higher number of impaired life years for CHRON. This is analysed in more detail in the next step by means of decomposition analysis.

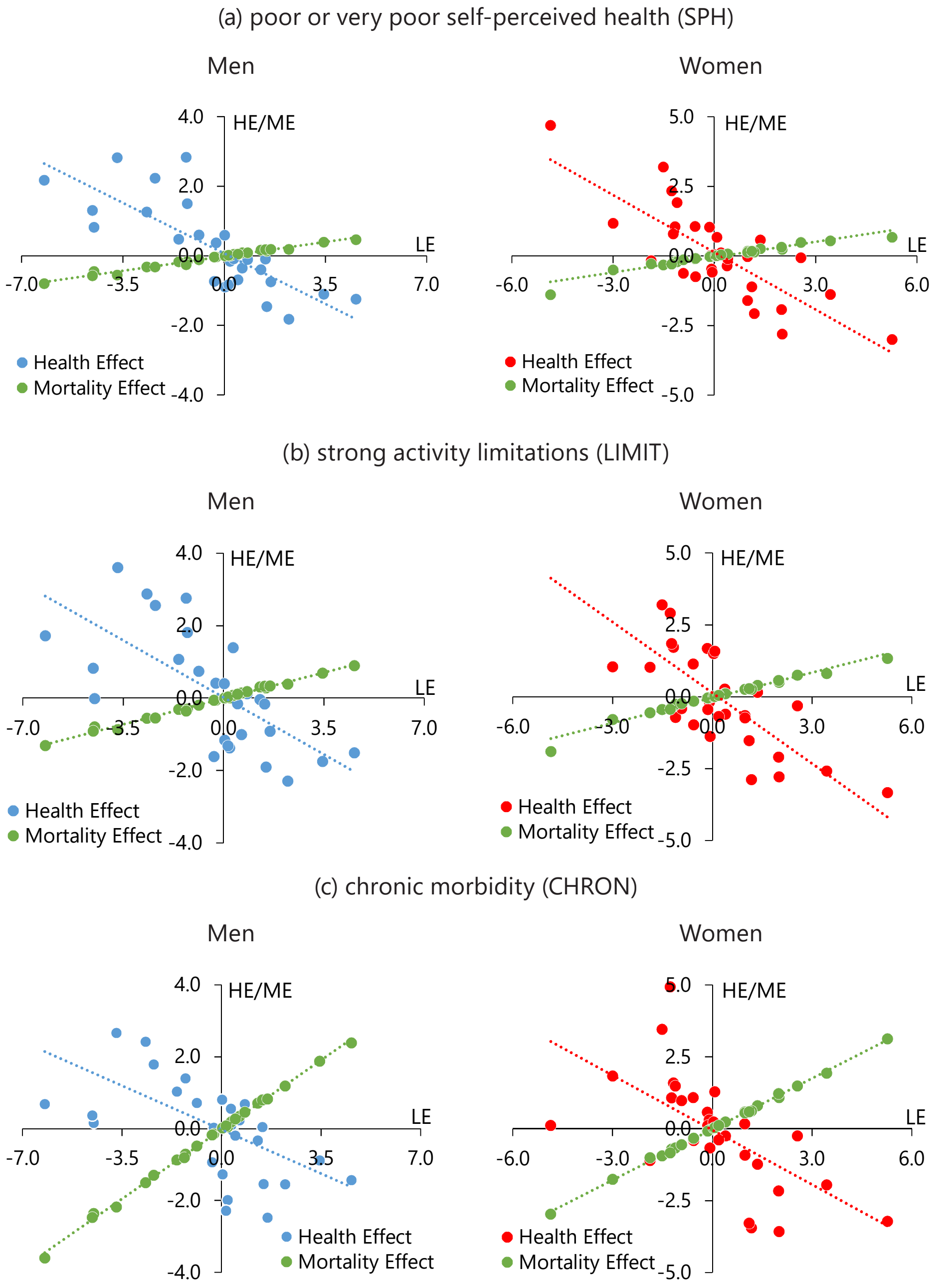
Figure 3 illustrates the relationship between LE and ULY in an identical manner, but the ULY differences between total population and subpopulations are decomposed into years caused by the health effect (blue dots for men, red dots for women) and those caused by the mortality effect (green dots). The detailed results of the decomposition analyses can be found in the Appendix (Table A1 for men and Table A2 for women). Note that health effects and mortality effects add up to the differences in ULY shown in Figure 2. The decomposition yields the same results for each of the three health dimensions and for both sexes. The mortality effect shows a positive association with LE, i.e., the higher LE the higher the mortality effect. This effect is strongest for chronic morbidity and weakest for self-perceived health (see green dots with corresponding regression lines in Figs. 3a-c), i.e., the extent of the mortality effect corresponds to the number of ULY. In other words: the larger the absolute difference in ULY between the subpopulations and the total sample, the larger the mortality effect. When the life years spent with health impairments

Fig. 2: Differences between various subpopulations and the total population in life expectancy (LE) and unhealthy life years (ULY) at age 50 for three health indicators, by gender, Germany 2012



Source: own calculations with data from GEDA, LES and HMD; for abbreviations see text.

Fig. 3: Differences between various subpopulations and the total population in life expectancy (LE) and unhealthy life years (ULY) at age 50 decomposed into health effect (HE) and mortality effect (ME) for three health indicators, by gender, Germany 2012



Source: own calculations with data from GEDA, LES and HMD; for abbreviations see text.

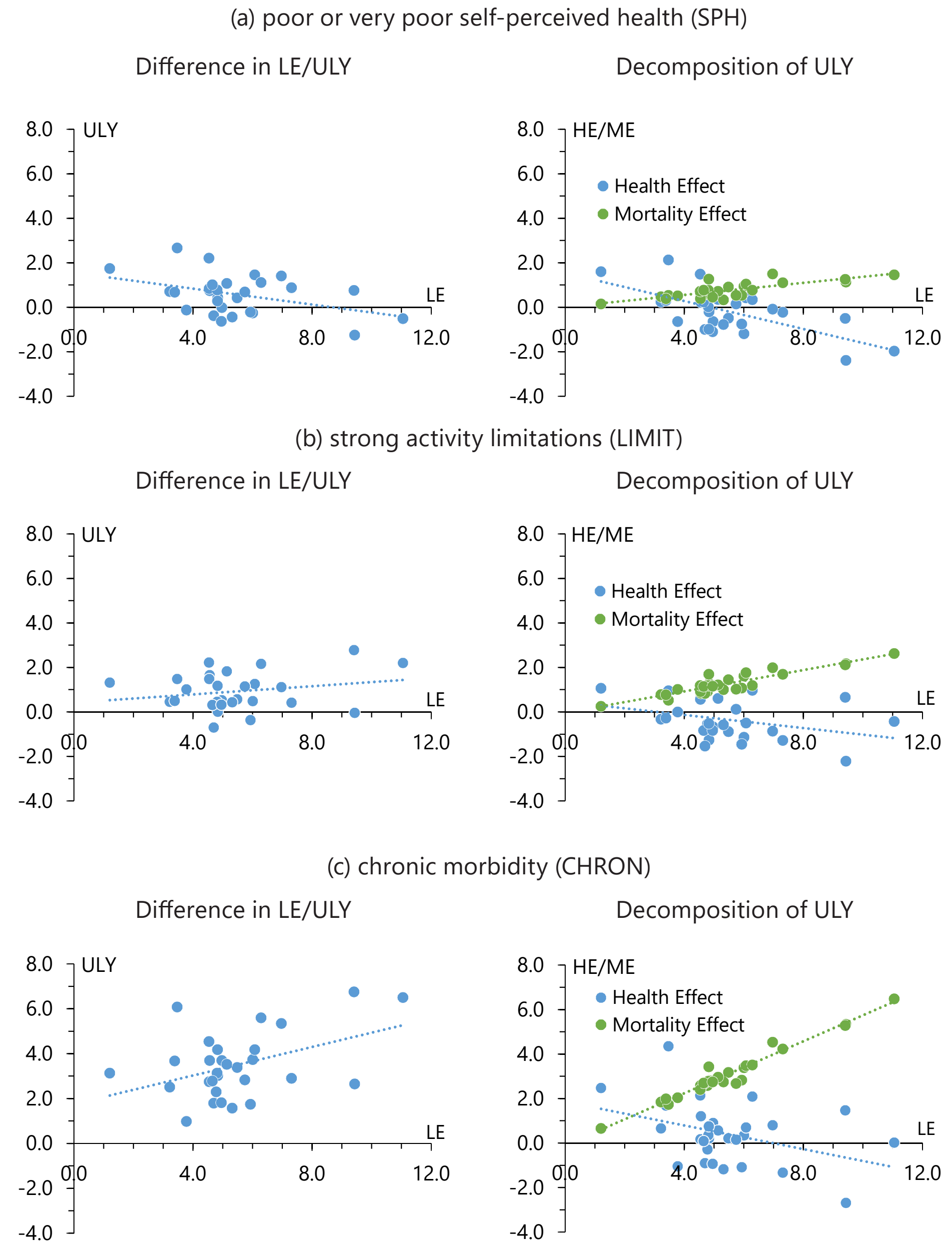
are reduced to the pure health effect, the relationship with LE is negative for all three health domains: the higher the LE, the lower the health effect. This means that subpopulations with lower mortality (higher LE) are on average in better health compared to subpopulations with higher mortality (lower LE). This reveals that comparisons of the total number of life years spent with health impairments (ULY) are biased by the mortality effect because a higher total number of life years (LE) increases the total number of ULY. This happens because gains in LE in modern societies occur almost exclusively in the highest age groups, and these are the age groups in which the risk of onset increases for almost all kinds of health problems. This holds true in particular for chronic diseases or – more general and in line with the CroHaM hypothesis – for health impairments with a low risk of dying.

Remarkably, the magnitude of the health effect, characterised by the slope of the regression lines, appears to be nearly identical in all six graphs of Figure 3. Most importantly, a comparison of the regression lines for the LE-ULY relationship in Figure 2 and for the LE-health effect relationship in Figure 3 reveals that the association between LE and life years spent with health impairments becomes notably stronger once the mortality effect is controlled for. All these findings confirm the core of the CroHaM hypothesis that the extent of the mortality risk associated with a health domain is the main cause of the domain-specific cross-sectional compression and expansion effects which are reflected in the association between LE and ULY.

Figure 4 shows the same relationships for the gender differences in total life years and life years spent with health impairments within the subpopulations. Those for the LE-ULY relationship are displayed in the left-hand graphs of Figures 4(a)-4(c), and those for the LE-health effect respective mortality effect relationship are shown in the right-hand graphs. As to be expected, women outlive men in each of the subpopulations. Consequently, all values for the gender difference in LE are positive, ranging from a 1.2 years difference among never smokers (dots placed furthest to the left on the x-axis) to a difference of 11.0 years among widowed people (dots placed most on the right). The gender gaps in ULY are smaller, ranging by 3.9 years for self-perceived health (-1.2 years among self-employed workers, 2.7 years among the never married), by 3.5 years for activity limitation (-0.7 years in the second lowest net household income quartile, 2.8 years among individuals who live alone), and by 5.8 years for chronic morbidity (1.0 years among ever smokers, 6.8 years among individuals who live alone). Figures 4(a) and 4(b) show that most values for the gender differences in life years spent with poor or very poor self-perceived health and those spent with strong activity limitation are positive. This indicates that among most subpopulations, women also have a higher number of ULY. For the gender differences in life years spent with chronic morbidity (Fig. 4c), all values are positive, suggesting a general and larger disadvantage of women in chronic diseases than in the other two health domains.

With respect to the relationships between the extents of gender differences in LE and gender differences in ULY for the three health domains, the regression lines show essentially the same picture as for the LE-ULY relationships of the differences between total population and subpopulations shown in Figure 2. For self-perceived health, there is a tendency for an increased surplus in female LE to be associated with

Fig. 4: Gender differences (women – men) in life expectancy (LE) versus unhealthy life years (ULY) at age 50 for three health indicators in absolute years (left pane) and ULY differences decomposed into health effect (HE) and mortality effect (ME) (right pane), various subpopulations, Germany 2012



Source: own calculations with data from GEDA, LES and HMD; for abbreviations see text.

a lower disadvantage in ULY (Fig. 4a). At high levels of the female advantage in LE, the disadvantage in ULY seems to vanish or even turn into an advantage for women, i.e., a lower number of ULY compared to men. The opposite holds true for chronic health problems where the regression line suggests that a higher female advantage in LE is associated with a higher number of ULY among women compared to men (Fig. 4c). Regarding activity limitations, the LE-ULY relationship lies somewhere in between with the regression line being close and almost parallel to the zero line (Fig. 4b).

The decomposition of gender differences in ULY into the mortality effect and the health effect yields the same result as the decomposition analyses for the differences between male and female total and subpopulations shown in Figure 3. The higher LE of women leads to a higher number of ULY compared to men, regardless of the health domain considered. The larger the female surplus in LE, the larger the female surplus in ULY (see green lines for the mortality effect in Fig. 4a-4c). Once the mortality effect is controlled for, the gender differences in the remaining health effects show an opposite association with gender differences in LE, i.e., the female disadvantage in ULY decreases with the extent of the female advantage in LE and turns into a female advantage in ULY at some level of LE surplus. This holds true even for gender differences in life years spent with chronic morbidity (Fig. 4c), where the absolute numbers of LE and ULY suggested a general female disadvantage in ULY which increases with the extent of the female advantage in LE. Thus, also in the analyses of gender differences, the regression lines for the health effects of the three health domains show a similar slope. There are only variations with respect to the intersection of the linear regression lines with the zero line. This means that also the results for the gender differences in LE and ULY across the 30 subpopulations provide support for the CroHaM hypothesis.

5 Discussion and conclusions

The aim of this paper is to test the CroHaM hypothesis which states that the health domain-specific expansion and compression effects found in longitudinal analyses and time trends hold equivalently in the cross-sectional context with regard to differences between populations and subpopulations (*Luy* 2021). According to this hypothesis, higher LE is associated with fewer life years spent with health impairments that are more closely related to mortality (such as self-perceived health and activity limitation), but with more life years spent with health problems that are less closely related to mortality (such as chronic diseases). We tested the CroHaM hypothesis by analysing the association between LE and ULY across 30 subgroups of the total population of Germany. In line with the formulated expectations, we find a positive relationship between LE and ULY only for chronic morbidity, whereas this relationship is negative for self-perceived health and global activity limitation (H1 confirmed). However, when the mortality effect is controlled for, we find a negative relationship between LE and ULY (reduced to the pure health effect) for all three analysed health domains (H2 confirmed). This holds true for both test settings, the variations in LE and ULY between the male and female subpopulations and for the variations in gender differences in LE and ULY among the subpopulations. Thus, the presented results confirm the CroHaM hypothesis: the longitudinal health domain-specific expansion and compression effects exist equivalently in a cross-sectional context, affecting differences in ULY between subpopulations with higher and lower levels of LE.

We assessed the robustness of these results in a series of sensitivity analyses: we used the "Cross-sectional Average Length of life" (CAL) as introduced by *Brouard* (1986) and *Guillot* (2003) instead of conventional LE as measure for longevity, we used smoothed instead of unsmoothed values for the age-specific prevalence of the three health indicators, and we smoothed the age-specific prevalence values by applying different smoothing techniques (splines and logit models with prevalence values of the GEDA sample as standard). None of these analyses led to different results and interpretations (data not shown but available on request). An issue worth mentioning is that the 30 subpopulations of this study are not independent of each other but overlap to varying degrees, i.e., some individuals are members of the same subpopulations. For instance, one person might belong to the subgroups of low education, second net equivalent income quartile, third net household income quartile, manual workers, married, multi-person household, ever smoker, frequent alcohol consumption and overweight. Another one might be a member of the subpopulations high education, third net equivalent income quartile, third net household income quartile, public servants, married, multi-person household, ever smoker, rare alcohol consumption and overweight. Thus, these two fictive individuals share memberships in the subpopulations of the group indicators net household income, marital status, living arrangement, smoking and body mass index, but not of the other group indicators education, net equivalent income, work status and alcohol consumption. As illustrated in Figure 1, one could think of the sampling of our 30 subpopulations as drawing with replacement from the total population. The procedure results in 30 subpopulations which are differently composed and have different levels of LE and ULY. This is the decisive characteristic of the subpopulations for our experiment designed to test the CroHaM hypothesis and therefore, their partly overlapping must not be seen as a limitation.

Another limitation of this study could be seen in the reduction to subpopulations from one country. The advantage of this restriction is, however, that typical problems in international comparative analyses or studies that combine data on self-assessments of health from different countries are eliminated, such as social and cultural differences between countries, different languages, different health systems, different surveying techniques, variations in the survey questions etc. (see e.g. *Luy et al.* 2023). In addition, it is difficult to find data that allow the estimation of LE and ULY for such a high number of subpopulations as done in this study. Nonetheless, additional tests of the CroHaM hypothesis with data from other countries would be valuable and should be a target of future research. This would be important because the CroHaM hypothesis is independent of a specific country context. This means that the postulated cross-sectional association between health and mortality which is reflected in the association between LE and ULY is supposed to be independent of the characteristics of a specific society and the levels of LE and ULY. Such factors might affect the extent of the LE-ULY relationship, but – according to the CroHaM hypothesis – not its general existence and directions. Nonetheless, it is important to emphasise that the described associations between LE and ULY might not apply to two specific subpopulations. For instance, male manual workers are disadvantaged against male public servants in both LE and life years spent with chronic morbidity, i.e., they have a lower LE (27.9 vs. 31.1 years) but a higher number of ULY (15.7 vs. 13.9 years). In such cases, it is important to identify the factors that lead to such a strong health disadvantage for manual workers compared to civil servants that more than offset the overall tendency in the opposite direction. There are also group indicators which show the identical gradients in LE and life years spent with chronic morbidity across their subgroups, e.g., marital status (see Table 1). Thus, individual comparisons that deviate from the general trend do not affect our main conclusion: the LE-ULY relationships found across the 30 subpopulations indicate that the CroHaM effect described by *Luy* (2021) actually exists and influences differences in ULY.

The found confirmation of the CroHaM hypothesis is relevant because it might provide the key to a better understanding of still unexplained phenomena, such as the so-called "gender paradox" in health and longevity (*Di Lego et al.* 2019). The results presented in this paper suggest two factors that might help to disentangle these seemingly paradox gender differences described by *Lorber* and *Moore* (2002: 13) with the memorable sentence "women get sicker, but men die quicker". First, there seems to be no general "gender paradox" that holds true for all kinds of health problems. With regard to self-perceived health and activity limitation, the gender differences in ULY are close to zero with only a weak tendency towards a minor disadvantage for women. Among the three MEHM health domains, a higher number of life years spent with health impairments among women can be found only with regard to the chronic illnesses. Moreover, our analysis of gender differences in LE and ULY across 30 subpopulations reveals that the extent of the disadvantage of women in life years spent with chronic morbidity corresponds, in tendency, to the level of their advantage in LE. However, bringing us to the second factor, this effect reverses when the mortality effect inherent in women's higher LE is controlled for. The decomposition analyses reveal that the health effects, i.e., the gender differences in the absolute number of ULY net of the effect caused by gender differences in mortality, are similar for all three health domains. In other words, the differences between the three health domains in the absolute number of ULY and the different directions of their relationship to LE are caused primarily by the gender differences in LE. This finding suggests that the "longevity hypothesis" introduced by *Luy* and *Minagawa* (2014), saying that "women [do] suffer from worse health than men […] not in spite of living longer, but because they live longer" (*Luy/Minagawa* 2014: 17), is indeed relevant for understanding the complex differences in ULY between women and men. In sum, the CroHaM hypothesis opens the view to a new perspective, namely that gender differences in health and longevity might not be as paradoxical as they appear but instead, they might be well explainable (see *Luy* 2024a for a recent application of the CroHaM hypothesis to the analysis of gender differences in ULY in Germany).

These thoughts about the gender paradox were intended to provide only a glimpse of the new possibilities created by the CroHaM hypothesis for understanding and interpreting differentials in the ULY. Of course, this must not be understood as if this hypothesis could provide an explanation for everything. Levels, trends and differentials in health and longevity are always the consequence of a complicated network of factors, and different factors can play different roles in different contexts. The CroHaM hypothesis adds a new explanatory factor to this network that has not been considered so far in the cross-sectional context. It is definitely only one of many factors, but one that can play an important role in particular contexts as demonstrated in the context of the gender paradox. More tests and applications of the CroHaM hypothesis should be done to test its generalisability. It may actually describe an important determinant of life years spent with and without health impairment and may help to better understand and interpret trends and differentials based on cross-sectional data.

References

Antonovsky, Aaron 1967: Social class, life expectancy and overall mortality. In: The Milbank Memorial Fund Quarterly 45,2: 31-73. https://doi.org/10.2307/3348839

Arriaga, Eduardo E. 1984: Measuring and explaining the change in life expectancies. In: Demography 21,1: 83-96. https://doi.org/10.2307/2061029

Bardenheier, Barbara H. et al. 2016: Compression of disability between two birth cohorts of US adults with diabetes, 1992-2012: a prospective longitudinal analysis. In: The Lancet Diabetes & Endocrinology 4,8: 686-694. https://doi.org/10.1016/S2213-8587(16)30090-0

Beltrán-Sánchez, Hiram; Jiménez, Marcia P.; Subramanian, S. V. 2016: Assessing morbidity compression in two cohorts from the Health and Retirement Study. In: Journal of Epidemiology and Community Health 70,10: 1011-1016. https://doi.org/10.1136/jech-2015-206722

Brouard, Nicolas 1986: Structure et dynamique des populations. La pyramide des années à vivre, aspects nationaux et examples régionaux. In: Espaces, Populations, Sociétés 2,14-15: 157-168. https://doi.org/10.3406/espos.1986.1120

Bucciardini, Raffaella et al. 2019: Health inequalities: a research positioning exercise at the National Institute of Health, Italy. In: European Journal of Public Health 29,5: 943-947. https://doi.org/10.1093/eurpub/ckz115

Christensen, Kaare et al. 2009: Ageing populations: the challenges ahead. In: The Lancet 374,9696: 1196-1208. https://doi.org/10.1016/S0140-6736(09)61460-4

Crimmins, Eileen M. 2015: Lifespan and healthspan: past, present, and promise. In: The Gerontologist 55,6: 901-911. https://doi.org/10.1093/geront/gnv130

Crimmins, Eileen M.; Beltrán-Sánchez, Hiram 2011: Mortality and morbidity trends: is there compression of morbidity? In: The Journals of Gerontology Series B: Psychological Sciences and Social Sciences 66,1: 75-86. https://doi.org/10.1093/geronb/gbq088

Crimmins, Eileen M. et al. 2019: Changing disease prevalence, incidence, and mortality among older cohorts: the Health and Retirement Study. In: The Journals of Gerontology 74,1: S21-S26. https://doi.org/10.1093/gerona/glz075

Di Lego, Vanessa; Lazarevič, Patrick; Luy, Marc 2019: The male-female health-mortality paradox. In: *Gu, Danan; Dupre, Matthew E.* (Eds.): Encyclopedia of Gerontology and Population Aging. Cham: Springer International Publishing: 1-8. https://doi.org/10.1007/978-3-319-69892-2_798-2

Di Lego, Vanessa; Di Giulio, Paola; Luy, Marc 2020: Gender differences in healthy and unhealthy life expectancy. In: *Jagger, Carol et al.* (Eds.): International Handbook of Health Expectancies. Cham: Springer International Publishing: 151-172. https://doi.org/10.1007/978-3-030-37668-0_11

Freedman, Vicki A.; Wolf, Douglas A.; Spillman, Brenda C. 2016: Disability-free life expectancy over 30 years: a growing female disadvantage in the US population. In: American Journal of Public Health 106,6: 1079-1085. https://doi.org/10.2105/AJPH.2016.303089

Fries, James F. 1980: Aging, natural death, and the compression of morbidity. In: New England Journal of Medicine 303,3: 130-135. https://doi.org/10.1056/NEJM198007173030304

Gruenberg, Ernest M. 1977: The failure of success. In: The Milbank Memorial Fund Quarterly 55,1: 3-24. https://doi.org/10.2307/3349592

Guillot, Michel 2003: The cross-sectional average length of life (CAL): A cross-sectional mortality measure that reflects the experience of cohorts. In: Population Studies 57,1: 41-54. https://doi.org/10.1080/0032472032000061712

Human Mortality Database 2016: University of California, Berkeley (USA), and Max Planck Institute for Demographic Research (Germany) [www.mortality.org or www.humanmortality.de, 10.01.2016].

Jagger, Carol 2000: Compression or expansion of morbidity – what does the future hold? In: Age and Ageing 29,2: 93-94. https://doi.org/10.1093/ageing/29.2.93

Link, Bruce G.; Phelan, Jo 1995: Social conditions as fundamental causes of disease. In: Journal of Health and Social Behavior 35,Extra Issue: 80-94. https://doi.org/10.2307/2626958

Lorber, Judith; Moore, Lisa Jean 2002: Gender and the Social Construction of Illness. The gender lens series. Plymouth, UK: AltaMira Press.

Luy, Marc 2002: Warum Frauen länger leben. Erkenntnisse aus einem Vergleich von Kloster- und Allgemeinbevölkerung. Materialien zur Bevölkerungswissenschaft 106. Wiesbaden: Bundesinstitut für Bevölkerungsforschung.

Luy, Marc 2003: Causes of male excess mortality: insights from cloistered populations. In: Population and Development Review 29,4: 647-676. https://doi.org/10.1111/j.1728-4457.2003.00647.x

Luy, Marc 2021: The cross-sectional association between health and mortality: insights from the Cloister Study. In: *Luy, Marc* (Ed.): The Male-Female Health-Mortality Paradox: Research Report of the ERC Project HEMOX. VID Forschungsbericht 40. Vienna: Verlag der Österreichischen Akademie der Wissenschaften: 61-82.

Luy, Marc 2022: Entwicklung der gesunden Lebensjahre in Deutschland: Kompression versus Expansion der Morbidität und die Bedeutung des Gesundheitsindikators. In*: Edel, Andreas; Thomas, Mahalia* (Eds.): Grünbuch Alternde Gesellschaft II: Altern – nicht nur eine Frage des Alters. Neue Perspektiven auf ein längeres Leben. Population and Policy Discussion Papers 15. Berlin: Newprint Blue: 20-27.

Luy, Marc 2024a: Das Geschlechterparadoxon in der gesundheitlich beeinträchtigten Lebenszeit – Ende eines Mythos? In: Bundesgesundheitsblatt – Gesundheitsforschung – Gesundheitsschutz 67,5: 512-520. https://doi.org/10.1007/s00103-024-03877-7

Luy, Marc 2024b: Gesunde Lebenserwartung: Ein kritischer Blick auf Nutzen und Potenziale des demographischen Gesundheitsindikators. In: Bundesgesundheitsblatt – Gesundheitsforschung – Gesundheitsschutz 67,5: 538-545. https://doi.org/10.1007/s00103-024-03874-w

Luy, Marc; Di Giulio, Paola 2005: Der Einfluss von Verhaltensweisen und Lebensstilen auf die Mortalitätsdifferenzen der Geschlechter. In: *Gärtner, Karla; Grünheid, Evelyn; Luy, Marc* (Eds.): Lebensstile, Lebensphasen, Lebensqualität. Interdisziplinäre Analysen von Gesundheit und Sterblichkeit aus dem Lebenserwartungssurvey des BiB. Schriftenreihe des Bundesinstituts für Bevölkerungsforschung 36. Wiesbaden: VS Verlag für Sozialwissenschaften: 365-392.

Luy, Marc; Minagawa, Yuka 2014: Gender gaps – life expectancy and proportion of life in poor health. In: Health Reports 25,12: 12-19.

Luy, Marc et al. 2015: Life expectancy by education, income and occupation in Germany: Estimations using the Longitudinal Survival Method. In: Comparative Population Studies 40,4: 399-436. http://dx.doi.org/10.12765/CPoS-2015-16en

Luy, Marc; Di Giulio, Paola; Minagawa, Yuka 2023: The impact of interpersonal reporting heterogeneity on cross-country differences in Healthy Life Years in Europe. In: European Journal of Public Health 33,6: 1060-1064. https://doi.org/10.1093/eurpub/ckad142

Manton, Kenneth G. 1982: Changing concepts of morbidity and mortality in the elderly population. In: The Milbank Memorial Fund Quarterly/Health and Society 60,2: 183-244. https://doi.org/10.2307/3349767

Marmot, Michael 2005: Social determinants of health inequalities. In: The Lancet 365,9464: 1099-1104. https://doi.org/10.1016/S0140-6736(05)71146-6

Mirowsky, John; Ross, Catherine E. 2003: Education, Social Status, and Health. New York: Aldine de Gruyter.

Nusselder, Wilma J.; Looman, Caspar W. N. 2004: Decomposition of differences in health expectancy by cause. In: Demography 41,2: 315-334. https://doi.org/10.1353/dem.2004.0017

Payne, Collin F. 2022: Expansion, compression, neither, both? Divergent patterns in healthy, disability-free, and morbidity-free life expectancy across U.S. birth cohorts, 1998-2016. In: Demography 59,3: 949-973. https://doi.org/10.1215/00703370-9938662

Phelan, Jo C. et al. 2004: "Fundamental causes" of social inequalities in mortality: a test of the theory. In: Journal of Health and Social Behavior 45,3: 265-285. https://doi.org/10.1177/002214650404500303

Phelan, Jo C.; Link, Bruce G. 2005: Controlling disease and creating disparities: a fundamental cause perspective. In: The Journals of Gerontology Series B: Psychological Sciences and Social Sciences 60, Special Issue 2: S27-S33. https://doi.org/10.1093/geronb/60.Special_Issue_2.S27

Phelan, Jo C.; Link, Bruce G.; Tehranifar, Parisa 2010: Social conditions as fundamental causes of health inequalities: theory, evidence, and policy implications. In: Journal of Health and Social Behavior 51,1 suppl: S28-S40. https://doi.org/10.1177/0022146510383498

Robert Koch-Institut 2014: Daten und Fakten: Ergebnisse der Studie "Gesundheit in Deutschland aktuell 2012". Berichte zur Gesundheitsberichterstattung des Bundes. Berlin: Robert Koch-Institut.

Robine, Jean-Marie; Michel, Jean-Pierre 2004: Looking forward to a general theory on population aging. In: The Journals of Gerontology Series A: Biological Sciences and Medical Sciences 59,6: M590-M597. https://doi.org/10.1093/gerona/59.6.M590

Salzmann, Thomas; Bohk, Christina 2008: Überprüfung der im Rahmen des „Lebenserwartungssurveys" gemessenen Sterblichkeit auf Bevölkerungsrepräsentativität unter Berücksichtigung rechts- und intervallzensierter Ereignisse mit dem Konzept „Relative Survival". In: Zeitschrift für Bevölkerungswissenschaft 33,2: 121-152. https://doi.org/10.1007/s12523-009-0008-3

Shen, Tianyu; Payne, Collin F. 2023: Disability and morbidity among US birth cohorts, 1998-2018: A multidimensional test of dynamic equilibrium theory. In: SSM – Population Health 24: 101528. https://doi.org/10.1016/j.ssmph.2023.101528

Sullivan, Daniel F. 1971: A single index of mortality and morbidity. In: HSMHA-Health Reports 86,4: 347-354. https://doi.org/10.2307/4594169

UNESCO 1996: International Standard Classification of Education ISCED 1997. Montreal: UNESCO-UIS.

Vallin, Jacques 1995: Can sex differentials in mortality be explained by socio-economic mortality differentials? In: *Lopez, Alan D.; Caselli, Graziella; Valkonen, Tapani* (Eds.): Adult Mortality in Developed Countries: from Description to Explanation. Oxford: Clarendon Press: 179-200.

Zeng, Yi et al. 2017: Survival, disabilities in activities of daily living, and physical and cognitive functioning among the oldest-old in China: a cohort study. In: The Lancet 389,10079: 1619-1629. http://dx.doi.org/10.1016/S0140-6736(17)30548-2

Date of submission: 04.09.2023 *Date of acceptance: 17.06.2024*

Prof. Dr. Marc Luy (✉). Vienna Institute of Demography of the Austrian Academy of Sciences (OeAW). E-mail: Marc.Luy@oeaw.ac.at
URL: https://www.marcluy.eu

Comparative Population Studies

www.comparativepopulationstudies.de

ISSN: 1869-8980 (Print) – 1869-8999 (Internet)

Published by
Federal Institute for Population Research (BiB)
65180 Wiesbaden / Germany

Managing Publisher
Dr. Nikola Sander