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03/2020

UNDERSTANDING THE CROSS-SECTIONAL ASSOCIATION BETWEEN LIFE EXPECTANCY AND HEALTHY LIFE YEARS: THE CroHaM HYPOTHESIS

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Abstract

A central question of interdisciplinary health research is whether the life years gained through increasing life expectancy are primarily spent in good or poor health. Two opposing models have been proposed: "expansion of morbidity" and "compression of morbidity". Existing research based on longitudinal data and time series has supported both approaches, depending on the particular dimension of health under consideration. In this paper we hypothesize that the longitudinal health dimension-specific expansion and compression effects exist equivalently in the cross-sectional association between health and mortality (CroHaM), affecting differences in the number of healthy life years between populations and subpopulations with different levels of life expectancy. The CroHaM hypothesis roots in the observation that most health differentials within and between populations are caused primarily by social factors and it builds on Link and Phelan's "theory of fundamental social causes" (1995). We present empirical support for the hypothesis by analyzing the relationship between life expectancy and healthy life years on the basis of different health dimensions for a sample of female and male Catholic order members and their counterparts in the general populations of Germany and Austria. Finally, we outline that the CroHaM hypothesis may also contribute to a better understanding of differences in life years spent in good or poor health and make suggestions for further testing of the CroHaM hypothesis.

Keywords

Mortality, health, life expectancy, healthy life years, expansion of morbidity, compression of morbidity, CroHaM hypothesis, order members, Cloister Study.

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Acknowledgements

Earlier results and preliminary findings of this study were presented and discussed at the 2014 European Population Conference in Budapest, Hungary (27 June 2014), the 2015 Annual Meeting of the Population Association of America (PAA) in San Diego, USA (30 April 2015), the XXVII REVES Meeting in Singapore (4 June 2015), the German-Austrian-Swiss Demographers' Meeting in Munich, Germany (29 October 2015), and the research seminar of the Luxembourg Institute of Socio-Economic Research (LISER) in Esch/Alzette, Luxembourg (24 February 2016). I thank my colleagues Catherine Bowen, Paola Di Giulio, Ina

Jaschinski, Desiree Krivanek, Christian Wegner-Siegmundt, and Angela Wiedemann who helped to prepare the manuscripts for these presentations. In particular, I thank Christian Wegner-Siegmundt for carrying out most of the analyses presented in this paper, as well as a number of sensitivity tests. Moreover, I am very grateful to Catherine Bowen, Paola Di Giulio and Angela Wiedemann who analyzed the ASCOM data with regard to several research questions which helped to better understand the health and mortality of order members and thus contributed to this paper as well. Most of the work presented here was carried out during ERC project HEMOX, but the work was completed as part of the follow-up ERC project LETHE. Thus, this work was supported by the European Research Council within the European Community's Seventh Framework Programme (FP7/2007–2013), ERC Grant Agreement No. 262663 (HEMOX) and within the EU Framework Programme for Research and Innovation Horizon 2020, ERC Grant Agreement No. 725187 (LETHE).

Understanding the Cross-Sectional Association Between Life Expectancy and Healthy Life Years: The CroHaM Hypothesis

Marc Luy

1. Introduction

The association between health and mortality is one of the central topics of interdisciplinary health research, e.g., in the context of the "compression versus expansion of morbidity" debate which was initiated by the works of Gruenberg (1977) and Fries (1980). The debate concerns the question whether the life years gained by increasing life expectancy (LE) are spent primarily in good health (i.e., compression of morbidity) or in poor health (i.e., expansion of morbidity). Figure 1 illustrates these two opposing approaches. The basis scenario shows a total LE of 70.0 years (total length of the bar) of which 50.0 years are spent in good health (light shaded part of the bar) and 20.0 years are spent in poor health (dark shaded part of the bar). The two bars below show the distribution of life years spent in good and poor health at a moment later in time, when total LE increased to 90.0 years. In the optimistic "compression of morbidity" scenario, all life years gained are spent in good health. In addition, the number of life years spent in poor health are reduced ("compressed") to 10.0 years, resulting in an increase in the total number of life years spent in good health from 70.0 to 80.0. By contrast, in the pessimistic "expansion of morbidity" scenario, the number of life years spent in good health do not increase and all life years gained are spent exclusively in poor health.[1]

Empirical evidence suggests that both effects exist, depending on how health is defined: we find compression of morbidity, e.g., regarding disabilities and limitations, and expansion of morbidity regarding chronic illnesses (Christensen et al. 2009). These observations suggest, in general terms, that the occurrence of compression and expansion effects is linked to the considered health domain's association with mortality: we find compression effects among those health domains which are more severe and thus stronger linked to mortality, whereas we find expansion effects among those health domains which are less

[1] Note that these examples reflect only the extreme variants of the compression and expansion of morbidity scenarios. Several variants between these two are described in the literature as well, e.g., the scenario of "health expansion" which does not reduce the number of life years spent in poor health but adds only life years spent in good health, or the "dynamic equilibrium" scenario which keeps the proportions of life years spent in good and poor health constant as given in the basis scenario. More details about the different variants of health changes within the process of changing LE can be found, e.g., in Crimmins and Beltrán-Sánchez (2011).

Figure 1
Theoretical models of compression and expansion of morbidity

Source: author's own

severe and thus only weakly (or not) associated with mortality. This link between compression and expansion effects on the one hand side and the health-mortality-relationship on the other appears to be plausible. The 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 (Crimmins, Hayward and Saito 1994).

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. In this paper, we hypothesize that the described associations between health and mortality 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). We refer to this translation of the longitudinal compression and expansion effects to the cross-sectional association between health and mortality as "CroHaM hypothesis" (with CroHaM being the abbreviation for cross-sectional association between health and mortality). The theoretical basis of this approach will be outlined in the next section. Then, we describe how we test the CroHaM hypothesis in the quasi-experimental setting of the comparison between Catholic order members and women and men of the general population.

After presenting the results of our empiric analysis, we summarize and discuss the main theoretical aspects and empiric findings of this work, outline the implications for the analysis of differences in life years spent in good or poor health and make suggestions for further tests of the CroHaM hypothesis.

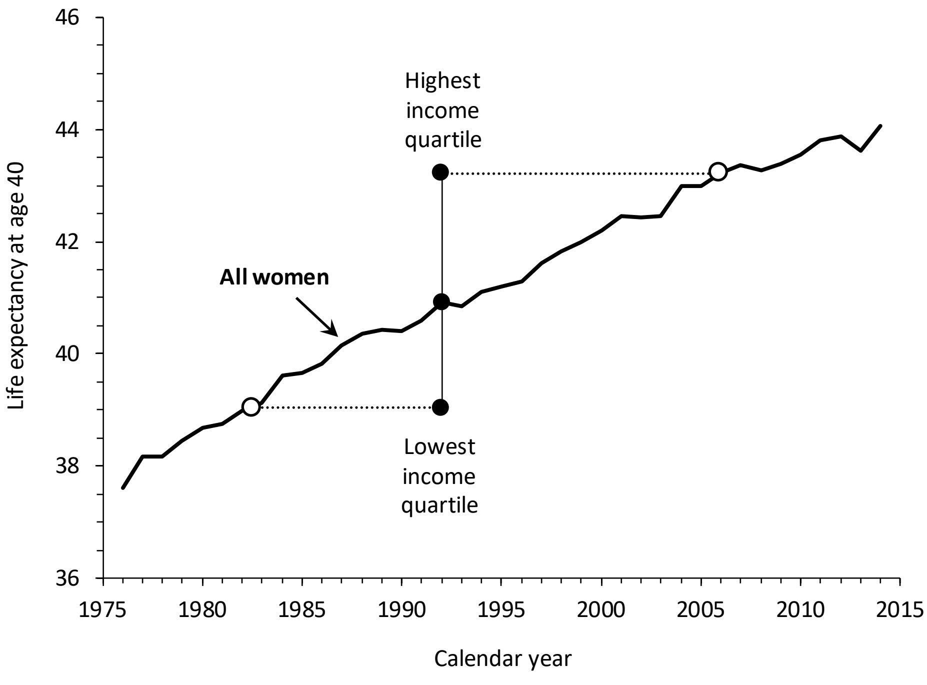
2. Cross-sectional Association between Health and Mortality: The "CroHaM Hypothesis"

The central idea of the CroHaM hypothesis is that the above described longitudinal health domain-specific associations between health and mortality exist equivalently in the cross-sectional context, affecting differences in the number of life years spent in good health between populations and subpopulations with different levels of LE. In other words, the CroHaM hypothesis transfers the longitudinal health domain-specific expansion and compression effects to the cross-sectional context. The theoretical basis behind this transfer is Link and Phelan's "Theory of Fundamental Social Causes" (Link and Phelan, 1995) which was developed to explain the enduring differences in health and longevity by socioeconomic status (SES). It states, in a nutshell, that SES embodies an array of flexibly usable resources that protect health no matter what mechanisms linking SES to health are relevant at any given time. These resources include money, knowledge, prestige, power and beneficial connections, and they operate at both individual and contextual level. On the individual level they are conceptualized as "cause of causes", and on the contextual level they provide so-called "add-ons". Consequently, the theory states, whenever gains are made in the ability to control disease, those who are advantaged with respect to the flexible resources will, on average, benefit more from these gains. Consistent with predictions derived from the fundamental cause explanation are the findings that the SES-mortality association was significantly stronger for highly preventable causes of death, such as lung or colorectal cancer (Singh et al. 2002), than for less preventable causes of death, such as brain or ovarian cancer (Phelan and Link 2005). Further details about the Fundamental Cause Theory can be found in Link and Phelan (2010), Link (2008), Link and Phelan (1996), Phelan et al. (2004), Phelan, Link and Tehranifar (2010).

Although not explicitly stated by Link and Phelan in their works, one can interpret their theory in the way that those who dispose more of the flexibly usable resources are, in a sense, ahead in time compared to those who do not. This time perspective provides an explanation for the differences in LE by SES in both, the longitudinal and the cross-sectional context. We refer to this aspect of the Fundamental Cause Theory as "cross-sectional time effect", implying that cross-sectional differences are an image of longitudinal developments. Figure 2 shows such a longitudinal development, i.e. the trend in period LE at age 40 of women in West Germany from 1975 to 2015 (bold solid line). The graph reveals the already mentioned steady increase in LE, in this case from 37.3 years in 1975 to 43.7 years in 2015 (i.e., an average increase of 1.6 years per decade or almost two months per year). The graph shows also the cross-sectional differences in LE at age 40 between the population subgroups of lowest and highest income quartile in 1992, illustrated with big black dots: western German women of the lowest income quartile had a LE at age 40 of 39.0 years, and those of the highest income quartile had a LE of 43.2 years (Luy et al. 2015). When we relate this difference of 4.2 years to the longitudinal context, we can see that it corresponds to almost 25 years of increases in LE. Women belonging to the lowest income quartile in 1992 had the same level of LE which all western German women reached already in 1982 (39.0 years), and women of the highest income quartile in 1992 had already the LE which was reached by the total female population in 2006 (43.2 years). In other words: compared to the LE of the total population, women of the lowest income quartile lagged 10 years behind, whereas women of the highest income quartile were 14 years ahead in time (illustrated by the big white dots in Figure 2).

The idea of a cross-section time effect implies that varying LE levels of different populations prevailing at the same time root—at least to a large extent—in the same mechanisms as varying levels of LE of the same population prevailing at different times. Consequently, we can assume that the above described health domain-specific compression and

Figure 2
Longitudinal changes in life expectancy and cross-sectional differences by income level, West Germany, women, 1975-2015



Source: author’s own.
Note: Data for all women: own calculations with data from the Statistical Office of Germany; date for income quartiles: Luy et al. (2015).

expansion effects observed in the longitudinal context (e.g., between 1982 and 2006) exist equivalently in the cross-sectional context when we compare the life years spent in good health between populations or subpopulations (e.g., between women of the lowest and highest income quartile in 1992). Note that this hypothesis concerns not only differences between particular SES groups but likewise other kinds of differentials in life years spent in good health—such as differences between women and men, geographical regions or healthy and unhealthy lifestyles—because findings from previous research suggests that SES plays a central role in most of them (Marmot 2005, Bucciardini et al. 2019).

3. Empirical Test of the CroHaM Hypothesis

An empirical test of the CroHaM hypothesis must fulfil two prerequisites:

1. populations or subpopulations with different levels of LE, and
2. health domains with differently strong associations to mortality.

Regarding the first issue, we compare female and male Catholic order members with their counterparts of the general population. Our previous studies revealed that order members live longer than worldly women and men (Luy 2002, Luy 2003). What makes this quasi-experimental setting interesting for testing the CroHaM hypothesis is that the extent of these differences in LE differs between women and men: the advantage of monks against worldly men is larger than the advantage of nuns against worldly women. Luy, Wegner-Siegmundt and Di Giulio (2014) presented evidence that this different extent of order members' LE surplus is likely to root in the different effects of factors related to SES among women and men. Consequently, if the effects stated in the CroHaM exist (i.e., the "CroHaM effects"), they should be stronger in the comparison between monks and men of the general population than in the comparison between nuns and worldly women.

This leads to the second prerequisite, health domains with differently strong associations to mortality. We chose the three domains of the "Minimum European Health" (MEHM) because these are available for a high number of populations and therefore frequently used for empirical analyses. The MEHM domains are:

1. self-perceived health (assessed by the survey question "How is your health in general?" with the answer categories very good/good/satisfactory/not so good/poor),
2. global activity limitation (GALI; "For at least the past 6 months, to what were you limited in activities people usually do due to health problems?", strongly limited/limited/not limited), and
3. chronic health problems ("Do you have any longstanding illness or health problem?", yes/no).

In a first step, we analyzed the mortality risks related to the three MEHM health domains to test whether the second prerequisite of the CroHaM test is fulfilled (Section 3.1). Then, we present the results of the empirical test of the CroHaM hypothesis in Section 3.2.

3.1 Mortality Risks of the MEHM Health Domains

We examined the health-mortality relationship of the three MEHM health domains with data of the German Life Expectancy Survey (LES). The LES is a panel survey that consists of two waves of interviews, restricted to individuals with German citizenship, and it is based on the German National Health Survey. The first wave was carried out between 1984 and 1986 and included a representative random sample of the total West German population. In 1998, the German Federal Institute for Population Research (Bundesinstitut für Bevölkerungsforschung—BiB) carried out a follow-up survey among the individuals interviewed in the 1984/86 National Health Survey. In this second survey, the initial questionnaires were slightly modified—e.g. purely medical details were removed and replaced by questions on general living conditions and family situations—and the number of respondents was restricted to those born between 1914 and 1952. The LES contains demographic indicators as well as information about economic and social status, social networks, health behaviors, life attitudes and a variety of health indicators (more details can be found in Gärtner 2001). Most importantly for this analysis, also the survival status of non-respondents was collected with the second survey.

The western German LES sample includes a total of 4,139 women and 4,335 men. Of those, 285 women (6.9 percent) and 613 men (14.1 percent) died between the two survey waves. For 998 women (24.1 percent) and 885 men (20.4 percent) the survival status in 1998 is unknown. 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, regardless of whether individuals with unknown survival status in 1998 are included or not (Luy and Di Giulio 2005, Salzmann and Bohk 2008). As suggested by Luy and Di Giulio (2005) we excluded the individuals with unknown survival status from the analysis. This selection of the LES sample leads to mortality levels and patterns close to those of the total German population (see Luy et al. 2015).

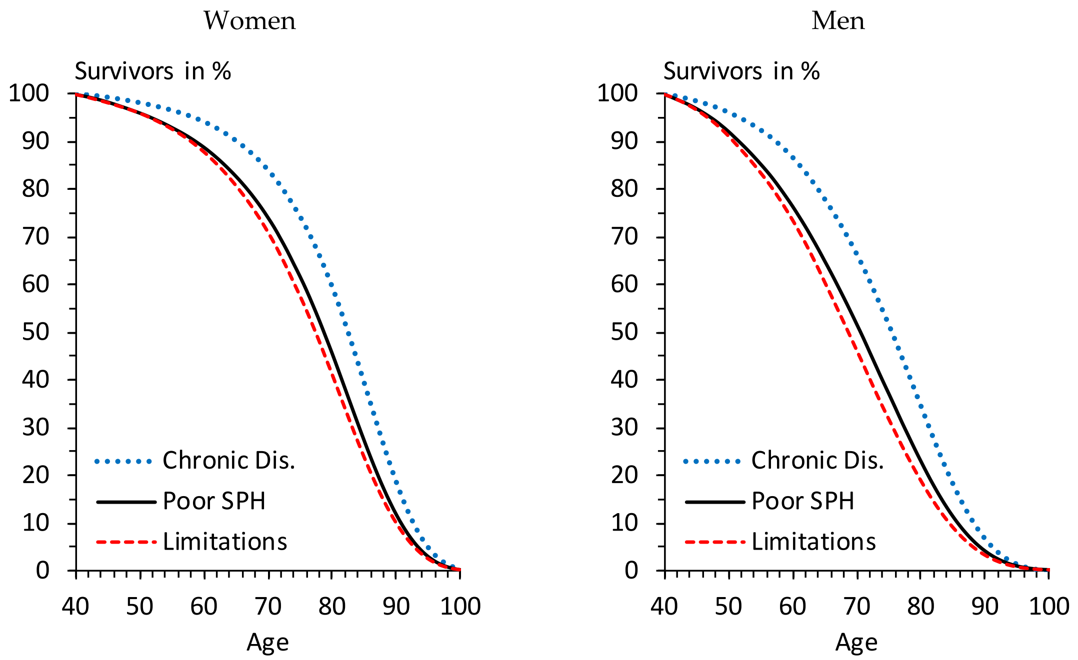
The question on self-perceived health (SPH) was included in the LES as described above (question 47 in LES wave 1). For GALI we used question 48 of LES wave 1 which is not identical to the MEHM question but very similar, being: "Apart from short illnesses: does your health condition limit you in fulfilling everyday tasks, e.g. in household, job or education?" with the answer categories "not at all", "a little", and "substantially".[2] A simple question on chronic diseases as in the MEHM was not included in the LES questionnaire. We approximated the MEHM question on chronic illnesses by defining the presence of chronic health problems as the current prevalence of at least one long-standing illness out of a list of 35 diseases (question 59 of LES wave 1; the list of these 35 diseases in German can be found in Appendix 1).

[2] The exact German wording of the question is: "Von kurzen Erkrankungen einmal angesehen: Behindert Sie Ihr Gesundheitszustand bei der Erfüllung alltäglicher Aufgaben, z.B. Haushalt, Beruf oder Ausbildung?" with the answer categories "Überhaupt nicht", "Ein wenig", and "Erheblich".

We identified for each individual of the LES the presence of health problems according to the MEHM domains at the time of first interview (i.e. presence of chronic diseases, not so good or poor SPH, and substantial limitation in daily activities of life). In addition, we calculated for each individual the exact ages at beginning and end of observation with the corresponding survival time from the date of first interview and the date of second interview respective date of death.[3] The survival times by age were then used to estimate survival functions from age 40 with the "Longitudinal Survival Method" (Luy et al. 2015) for the three subgroups of individuals with health problems according to the MEHM health domains.

Figure 3 shows the three survival functions for individuals who suffer chronic diseases, poor SPH (summarizing "not so good" and "poor" SPH) and activity limitations,

Figure 3
Survival from age 40 of individuals with chronic diseases, poor self-perceived health (SPH) and substantial activity limitations, separated by sex



Life expectancy at age 40
Chronic Dis.: 40.5 years
Poor SPH: 36.7 years
Limitations: 35.6 years

Life expectancy at age 40
Chronic Dis.: 34.0 years
Poor SPH: 29.7 years
Limitations: 28.3 years

Source: own calculations with data from the German Life Expectancy Survey.
Note: survival functions were estimated with the Longitudinal Survival Method (Luy et al. 2015); observation time for mortality follow-up: 1984-1998.

[3] The date of second interview refers to both, LES participants who participated also to wave 2 and those who refused participation to the follow-up survey.

respectively, with the corresponding values for LE, separately for women and men. It becomes apparent that chronic diseases had the weakest link to mortality (dotted lines). The corresponding survival probabilities were distinctly higher than those for poor SPH and activity limitations. The two latter showed only minor differences between them, with individuals suffering poor SPH having had slightly higher survival probabilities than individuals with activity limitations. This holds equivalently for both, women and men.

Among women, LE at age 40 of individuals with chronic diseases was 3.8 years higher than those of individuals with poor SPH and 3.9 years higher than those of individuals with activity limitation. Among men, the corresponding differences were 4.3 and 5.7 years, respectively. Note that the samples underlying the estimated probabilities of dying are to some extent overlapping because some individuals belong to two or all three subgroups. Nonetheless, the postulated differences in mortality exist with a distinctly lower mortality for chronic diseases than for poor SPH and activity limitations.

3.2 Differences in Healthy Life Years between Order Members and the General Population

We tested the CroHaM hypothesis on the basis of life years spent in good health, the so-called "Healthy Life Years" (HLY). "Good health" was defined by good or very good SPH, no global activity limitation, and no chronic health problems, respectively. In line with the CroHaM hypothesis, we expected that direction and extent of differences in HLY between order members and the general population would depend upon the domain of health considered. Based on the findings presented in Section 3.1, we expected to find the largest effects in favor of order members when HLY were estimated for life years without activity limitation (i.e., the MEHM health domain with the strongest association to mortality), somewhat reduced but still positive effects for order members when HLY were estimated for life years in good or very good SPH, and the smallest effects or even disadvantages for order members when HLY were estimated for life years without chronic illness (i.e., the MEHM health domain with the weakest association to mortality). Furthermore, we hypothesized that differences between the monastic and general population would be larger among men than among women, coinciding with the larger differences in LE among monastic versus general population men relative to women. According the CroHaM hypothesis, this expectation applies in both directions, i.e. HLY on basis of health domains with an advantage for order members (consequently with larger advantages for monks compared to nuns) and health domains with a disadvantage for order members (consequently with larger disadvantages for monks).

We estimated HLY at age 50 with the "Sullivan method" which requires life tables and the age-specific prevalence of a specific health state (Sullivan 1971). Health data for Catholic order members stem from the first wave of the Health Survey of the German-Austrian "Cloister Study" (sub-project ASCOM). The survey is based on a self-administered questionnaire and includes Catholic order members aged 50 years and older. The survey was conducted between July and December 2012. In total, 1,158 order members (622 nuns and 536 monks) of 16 different orders from Germany and Austria—with a few members living in Switzerland and Italy—participated to the first survey wave, including 142 religious communities and 69 brothers and sisters who live on their own. The response rate was 68.8 percent (nuns 76.8 percent, monks 63.4 percent). Further information about the survey and details about the data can be found in Wiedemann et al. (2014). For the general populations of Germany and Austria we used data from the EU-SILC 2012 survey, restricted to ages 50 and above (data merged for the two countries, n = 9,169).[4] Both surveys, ASCOM and EU-SILC, include the MEHM with identical wording of questions and answer categories as described in the introduction of this section.

Life tables for Catholic order members were derived from data of the continuously extended nuns' and monks' mortality data base of the Cloister Study collected from order archives, including the life dates of 18,105 order members from German and Austrian religious communities (sub-project COMMS). The use of mortality data from COMMS was necessary because the number of deaths in the ASCOM sample was not sufficient to estimate life tables at the time of this study. The communities participating in COMMS and ASCOM are not identical, but they overlap because some communities participate to both sub-projects of the Cloister Study. Moreover, the ASCOM sub-sample of participants is to some extent health selected and shows lower mortality compared to the total population of the communities participating to the ASCOM study (see Appendix 2).[5] Therefore, we adjusted the COMMS life tables by Cox regression parameters derived from comparisons between the mortality of the COMMS sample and the mortality of ASCOM participants, and between the mortality of ASCOM participants and the total ASCOM sample, referring to deaths of ASCOM participants between waves 1 and 2 (more details can be found in Appendix 3). Life tables of the general populations of Germany and Austria were calculated with data of the Human Mortality Database (HMD).[6] We merged the absolute numbers of person years and deaths by age for Germany and Austria to derive age-specific death rates for both populations combined. All estimates of this study were based on period life tables for the calendar years 1998-2009. The underlying rates for mortality and prevalence were calculated for the age groups 50-54, 55-59, …, 85+.[7]

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[4] Online available at http://www.eurohex.eu.

[5] Appendix 2 shows that mortality of ASCOM participants was significantly lower than mortality of COMMS participants. However, once non-participants were included in the analyses, the differences between the (full) ASCOM sample and the COMMS sample were not statistically significant.

[6] Online available at http://www.mortality.org. Data downloaded on 27 May 2015.

[7] We performed the analyses also with different life tables for the general population by combining the data for Germany and Austria according to the proportions of German and Austrian order members in the ASCOM sample and by averaging LE for Germany and Austria (i.e., weighting both countries by 50:50). Likewise, we tested different variants to combine mortality from the COMMS sub-sample with the health data from the ASCOM sub-sample for order members, including the use of unadjusted and unweighted COMMS life tables and COMMS life tables weighted by the proportions of ASCOM participants from German and Austrian communities. Moreover, we varied the analyses by using the different last open age intervals of life 80+, 85+, 90+ and 95+, using the cross-

We analyzed the differences in HLY between order members and women and men of the general population with three alternative measurements. The first is the simple difference in the absolute number of life years spent in good health. Given that LE among female and male order members is on average higher than among their counterparts of the general population, the difference in LE should lead to a higher absolute number of years spent in a specific health state among nuns and monks, even if order members and the general population have identical health prevalence and age patterns of health. To test the CroHaM hypothesis free of this "longevity effect", we estimated also indicators for HLY which control for or eliminate the effect of different absolute numbers of life years. The most simple and intuitive approach is the proportion of life years spent in good health, i.e. HLY divided by LE. In addition, we decomposed the differences in HLY between order members and the general population into the effects caused by differences in health ("health effect") and mortality ("mortality effect") with the method developed by Nusselder and Looman (2004). The estimated health effect reflects the difference in the total number of life years spent in good health net of the effect caused by differences in the total number of life years, i.e. net of the "longevity effect". Thus, both approaches account for the differences in length of life and offer a more comprehensive picture of differences between order members and the general population in health and mortality.

Figure 4 shows the proportion of people in good health by age group for both order members and the general populations of Germany and Austria and for each of the three health domains. Across all health domains, the proportion of people in good health was generally lower in older age groups. Among order members there were noteworthy deviations in the oldest age group (85+). Specifically, the proportion of monastic women with no activity limitations and the proportion of both monastic women and men with no chronic health problems was higher amongst the 85+ age group relative to the age group 80-84. The estimates for LE at age 50 and HLY for each dimension of health at age 50 of order members and the general population are summarized in Table 1.

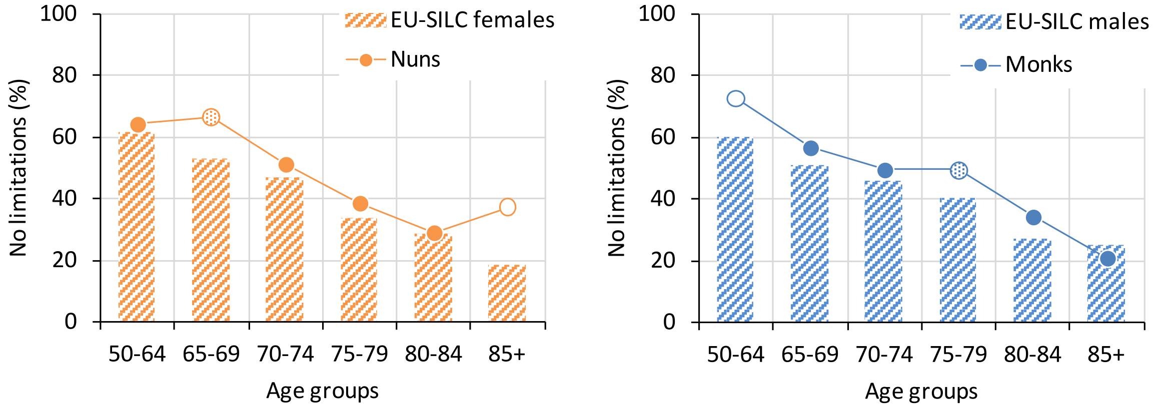
Figure 5(a) shows the differences in HLY at age 50 between nuns and women of the general population, illustrated in bar plots with—from left to right—differences in life years without activity limitations in light shading, life years in good and very good SPH in medium shading, and life years without chronic illness in dark shading. The results are presented in three panels for the alternative measurements of differences in HLY: differences

sectional average length of life (CAL) instead of conventional LE, and using different observation periods (1995-2009, 1998-2009, 2000-2009) for both, order members and general population. Albeit the LE values differ between all these variants, the results were affected only to a minor degree and led to the same conclusions as those presented in this paper. The different estimation variants affected mainly the results for order members because of the low case numbers. Some variants led to larger and others to smaller differences in LE between order members and general population, with corresponding effects on the differences in HLY, in particular regarding the gender-specific effects. Nonetheless, the order of the extent of differences in HLY between order members and general population by definition of health remained the same in all variants.

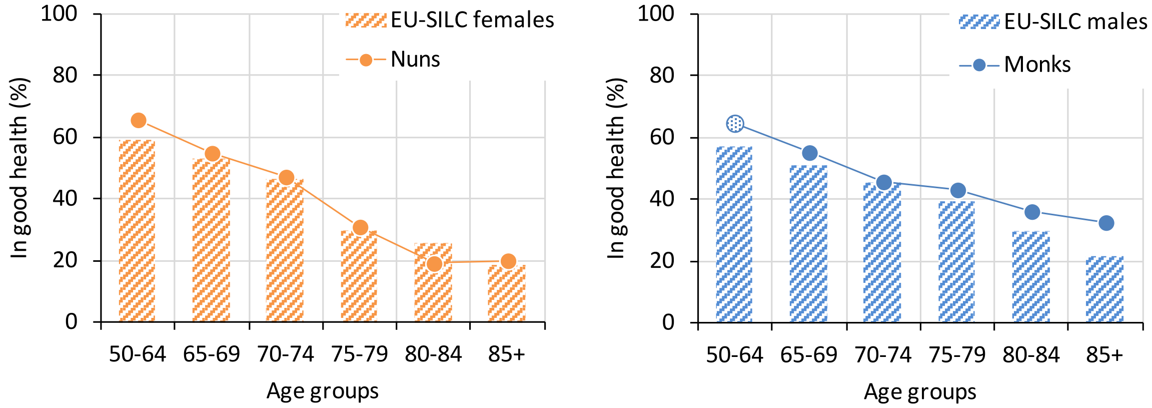
Figure 4

Age-specific prevalence of different health conditions among order members and the total population, Germany and Austria, 2012

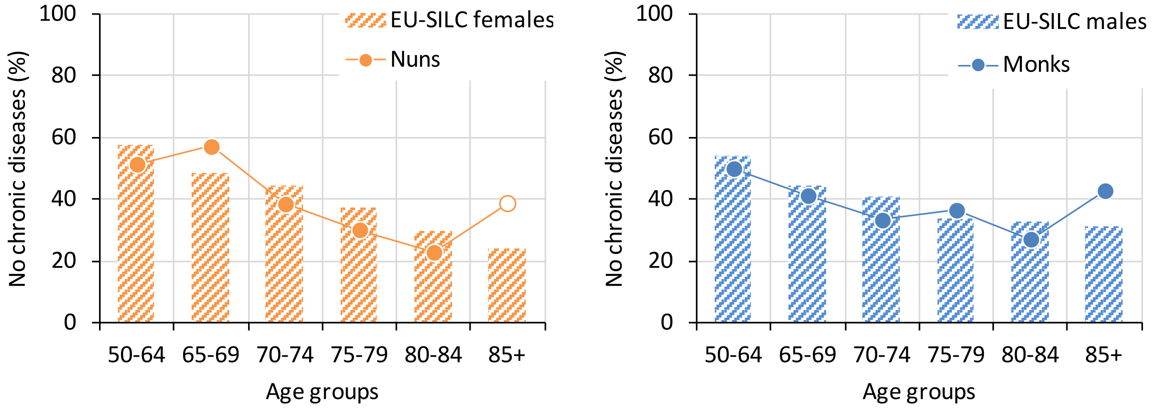
(a) global activity limitation



(b) general perceived health



(c) chronic health problems



Source: own calculations with data of the Cloister Study and EU-SILC 2012.
Note: white circles indicate statistically significant differences with p<0.05, dotted circles with p<0.1.

in the absolute number of life years shown in three bars on the left hand side, differences in the net health effect (in years) in the three bars in the middle, and differences in the proportion of life years spent in good health in the three bars on the right hand side. The dashed line in the left panel reflects the difference in the total number of life years (LE) between nuns and women of the general population

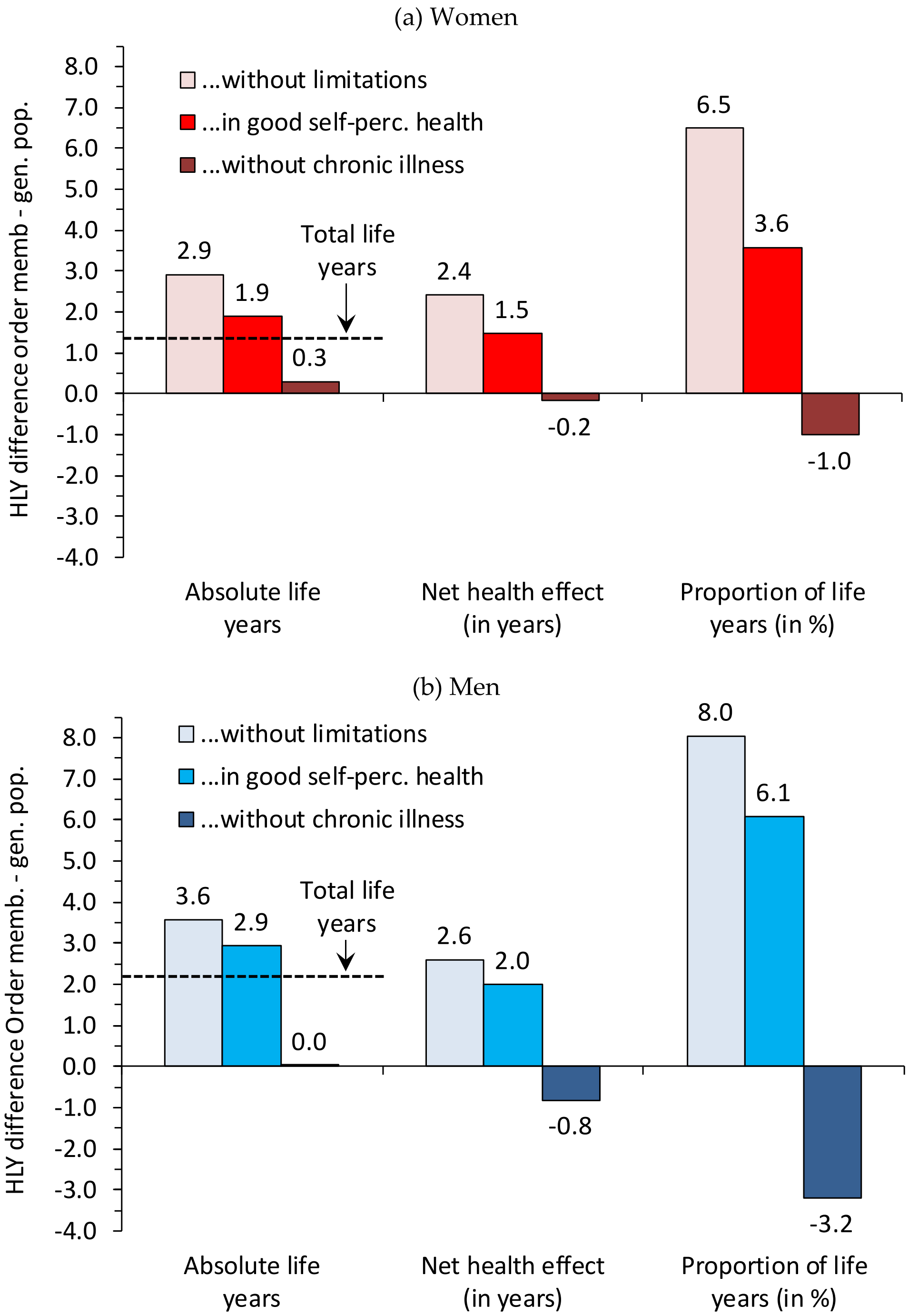
According to the used life tables, nuns had a 1.4 years higher LE at age 50 than women of the general population. Nuns had also a higher absolute number of life years spent in good health. The largest advantage of nuns was found when HLY were estimated on the basis of life years without activity limitation (+2.9 years), followed by their advantage in life years spent in good SPH (+1.9 years). In both cases, the advantage of nuns in HLY was larger than the advantage in total LE. Nuns had also a higher number of life years spent without chronic illness, albeit this advantage was smaller (+0.3 years) than the difference in the total number of life years.

Table 1
Life expectancy (LE) at age 50 and Healthy Life Years (HLY) at age 50 based on life years spent without global activity limitation, in good general health, and without chronic health problems, Catholic order members and total population by gender, Germany and Austria, 2012

	Total life years (LE)	Life years without limitation	Years in good general health	Life years without chronic illness
Female order members				
Absolute life years	34.6	18.9	17.3	15.8
Proportion of life years	---	54.8	50.1	45.6
Total population women				
Absolute life years	33.2	16.0	15.4	15.5
Proportion of life years	---	48.3	46.5	46.6
Male order members				
Absolute life years	30.7	18.0	16.8	13.1
Proportion of life years	---	58.5	54.9	42.7
Total population men				
Absolute life years	28.5	14.4	13.9	13.1
Proportion of life years	---	50.5	48.8	45.9

Source: own calculations with data of the Cloister Study, EU-SILC 2012, COMMS and HMD.
Note: decimals of proportions are based on exact values for LE and HLY, the values in this table may be affected by rounding.

Figure 5
Difference in Healthy Life Years (HLY) at age 50 between order members and the general population for different domains of health and different indicators of HLY



Source: author's own.
Note: estimates are based on health data for the year 2012 and period life tables for the calendar years 1998-2009 (for details see text).

The corresponding results for HLY measures free of the longevity effect showed the same basic pattern of differences between nuns and women of the general population. Nuns had an advantage when HLY were defined as life years without activity limitation or life years spent in good SPH. The net health effect provided slightly smaller advantages of nuns compared to the differences in the total number of life years, but even when the longevity effect was excluded the nuns' advantage in HLY was larger than their advantage in total LE (+2.4 years for life years without activity limitation and +1.5 years for life years spent in good SPH). These results were confirmed when HLY were defined as proportion of life years spent in good health (+6.5 percentage points for HLY based on life years without activity limitation, and +3.6 percentage points for HLY based on life years in good SPH). The major difference of the results for the net health effects and for proportions of life years spent in good health compared to those for the total number of HLY was that the nuns' small advantage in life years without chronic illness turned into a small disadvantage. The nuns' number of life years without chronic illness net of the mortality effect were 0.2 years (net health effect) respective one percentage point (proportion of HLY) lower than those of women of the general population.

Figure 5(b) for men shows the same patterns of differences in HLY between order members and the general population as those described for women. Yet, all differences in HLY were larger in line with the monks' larger surplus in total LE (+2.2 years). The advantage of monks in life years spent without activity limitation compared to men of the general population was 3.6 absolute life years, 2.6 years net of the mortality effect, and 8.0 percentage points in the proportion of life years spent in good health. The corresponding differences in life years spent in good SPH were 2.9 years, 2.0 years and 6.1 percentage points, respectively. Regarding life years spent without chronic illness, we found basically no differences between monks and men of the general population in the total number of life years (+0.03 years), and a disadvantage of monks in the net health effect (-0.8 years) and in differences in the proportion of life years spent in good health (-3.2 percentage points).

4. Summary and Conclusions

The aim of this paper was to introduce the CroHaM hypothesis, with CroHaM being the abbreviation for "cross-sectional association between health and mortality". The association between health and mortality is usually connected to the longitudinal perspective, most intensively investigated in the context of the "compression versus expansion of morbidity" debate. In the cross-sectional perspective, however, health and mortality are treated as rather independent variables which are combined to a "Healthy Life Years" indicator (HLY). With information about mortality we construct a survival function to derive the total number of life years, i.e. life expectancy (LE), and the information about health is then used to separate these life years into those spent in good and in poor health. The central idea of the CroHaM hypothesis is that the well-established "health domain-specific" associations between health and mortality—which lead to compression effects for health impairments that are more closely related to mortality (such as functional limitations and disabilities), but to expansion effects for health problems that are less closely related to mortality (such as chronic diseases)—hold equivalently in the cross-sectional context regarding differences between populations and subpopulations with different levels of mortality.

We tested the CroHaM hypothesis by analyzing the association between differences in LE and differences in HLY in a quasi-experimental setting separately for women and men. Namely, we used the proportion of older people in "good health" according to different health indicators (i.e., the MEHM indicators global activity limitations, self-perceived health and chronic conditions) to calculate HLY for a sample of female and male Catholic order members in Germany and Austria and their counterparts in the general population. Catholic order members are a specific sub-population with higher LE relative to the general population. By comparing HLY of Catholic order members and their counterparts in the general population, we tested whether a difference in average LE between two populations living under the same historical conditions (e.g., major world events, economic conditions, medical standards) is related to differences in life years spent in good health across different domains of health which are differently associated to mortality.

What made this quasi-experiment particularly interesting is the fact the order members' advantage in LE is larger among men than among women. Consequently, we expected that the CroHaM effects were stronger in differences between monks and men of the general population compared to differences between nuns and women of the general population. This expectation was valid for both directions of the health-mortality relationship: health domains with stronger associations to mortality on the one hand side (i.e., health domains for which higher LE should lead—in line with the "compression effect"—to more HLY) and health domains with weaker associations to mortality on the other (i.e., health domains for which higher LE should lead—in line with the "expansion effect"—to fewer HLY).

In a first step, we analyzed the mortality of individuals who stated health problems according to the MEHM domains over 14 years with data of the German Life Expectancy Survey (LES). We found the highest mortality among individuals who stated to suffer substantive health-related limitations in daily activities of living and among those who rated their health as poor or very poor. The lowest mortality was prevalent for individuals suffering chronic illnesses. In a second step, we compared the HLY of nuns and monks with their counterparts of the general population for the three MEHM health domains. The results provided strong support for the CroHaM hypothesis. All three measurements for differences in HLY between Catholic order members and the general population showed the same basic pattern: order members had the largest advantages when HLY were estimated on the basis of life years spent without chronic illness, followed by advantages in life years spent in good SPH, and they were smallest (or even negative) for life years spent without chronic illness. Thus, the extent of order members' advantages in HLY was positively associated with the health domains' association to mortality: the stronger this association, the bigger the advantage (and vice versa). Also in line with the CroHaM hypothesis, all these results were larger among men, indicating the effect of the higher LE surplus of monks against the general population.

We carried out a series of analyses with alternative approaches for estimating LE and HLY for order members and the general population to test whether the results are sensitive to these estimation issues. It turned out that all analytic variants arrived at similar results which led to the same conclusions. Nonetheless, further tests of the CroHaM hypothesis should be carried out to evaluate its general relevance in the analysis of HLY. Although preliminary analyses of the ASCOM data suggests that nuns and monks are not systematically different from their counterparts of the general population, they might be considered too selective to provide insights of general value. Therefore, future research should test the hypothesis on the basis of other sub-populations with different levels of LE, e.g., subgroups by education level, occupation or geographical region.

To conclude, the results presented in this paper indicate that the postulated CroHaM effect exists and affects the absolute and relative number of HLY of sub-populations or populations with different levels of LE in the cross-sectional context. These insights might be an important factor for better understanding still unexplained phenomena such as the "gender paradox" in health. For instance, the CroHaM hypothesis might be the causal basis of Luy's and Minagawa's "longevity hypothesis", stating that women spent less years in good health than men not *in spite of* living longer, but *because* they live longer (Luy and Minagawa, 2014). The relevance of the CroHaM hypothesis is not restricted to the gender paradox in health, however. If the hypothesized cross-sectional relationship between health and mortality exists, the CroHaM effects would affect all comparisons of populations with different levels of LE. Therefore, once the CroHaM hypothesis is confirmed in other empirical tests, the CroHaM effect should be controlled for in the analyses of differences in HLY to reduce the risk of misleading interpretations.

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Appendix

Appendix 1

List of 35 longstanding illnesses from question 59 of LES wave 1 (in German)[8]

- Durchblutungsstörungen am Herzen, Angina pectoris
- Herzinfarkt
- Herzschwäche (Herzinsuffizienz, „Herzasthma“)
- Durchblutungsstörungen am Gehirn
- Zuckerkrankheit, Diabetes
- Schlaganfall
- Krampfadern, Thrombose, Venenentzündung
- Durchblutungsstörungen in den Beinen (außer Krampfadern)
- Bluthochdruck, Hypertonie
- Starkes Übergewicht, Fettsucht
- Gicht, Harnsäureerhöhung
- Erhöhtes Cholesterin, erhöhte Blutfette
- Zu niedriger Blutdruck
- Gelenkrheumatismus, chronische Gelenkentzündung, Arthritis, Arthrose
- Hexenschuss, Ischias
- Bandscheibenschaden
- Lungenasthma, Bronchialasthma
- Lungentuberkulose
- Chronische Bronchitis, d.h. Husten mit morgendlichem Auswurf an den meisten Tagen, mindestens 3 Monate lang
- Leberentzündung, akute oder chronische Hepatitis, Fettleber
- Leberverhärtung, Leberzirrhose
- Gallenblasenentzündung oder Gallensteine
- Magen-, Zwölffingerdarmgeschwür, Ulcus
- Magenschleimhautentzündung
- Kropf, andere Schilddrüsenkrankheit
- Entzündung oder Steine der Blase, der Niere, der Harnwege
- Verdauungsbeschwerden, Verstopfung
- Heuschnupfen
- Andere Allergien
- Körperbehinderungen der oberen Gliedmaßen oder Schulter (z.B. Lähmungen, Fehlen von Gliedmaßen oder Teilen, Fehlbildungen, Gelenkversteifungen)
- Körperbehinderungen der unteren Gliedmaßen oder Hüfte (z.B. Lähmungen, Fehlen von Gliedmaßen oder Teilen, Fehlbildungen, Gelenkversteifungen)

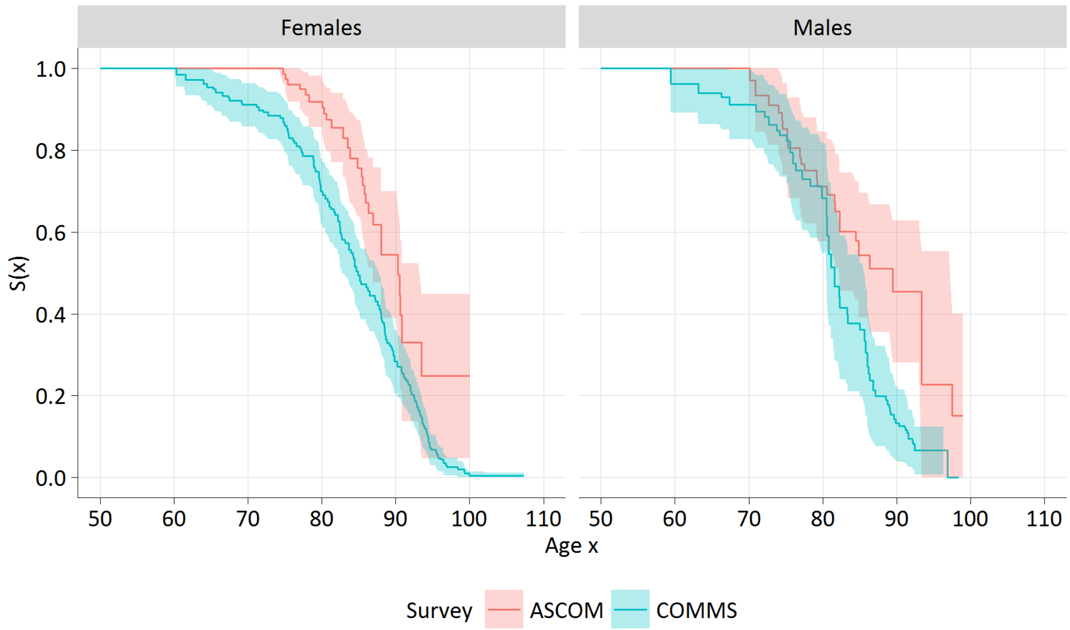
[8] Exact German wording of the question: „Haben oder hatten Sie jemals eine dieser Krankheiten?“

- Körperbehinderungen der Wirbelsäule (z.B. Verkrümmungen, Versteifungen oder Fehlbildungen, nicht Muskelverspannungen)
- Krebskrankheiten
- Sonstige Krankheiten oder Behinderungen, die länger als drei Monate gedauert haben
- Für Männer: Vergrößerte Vorsteherdrüse, Prostata

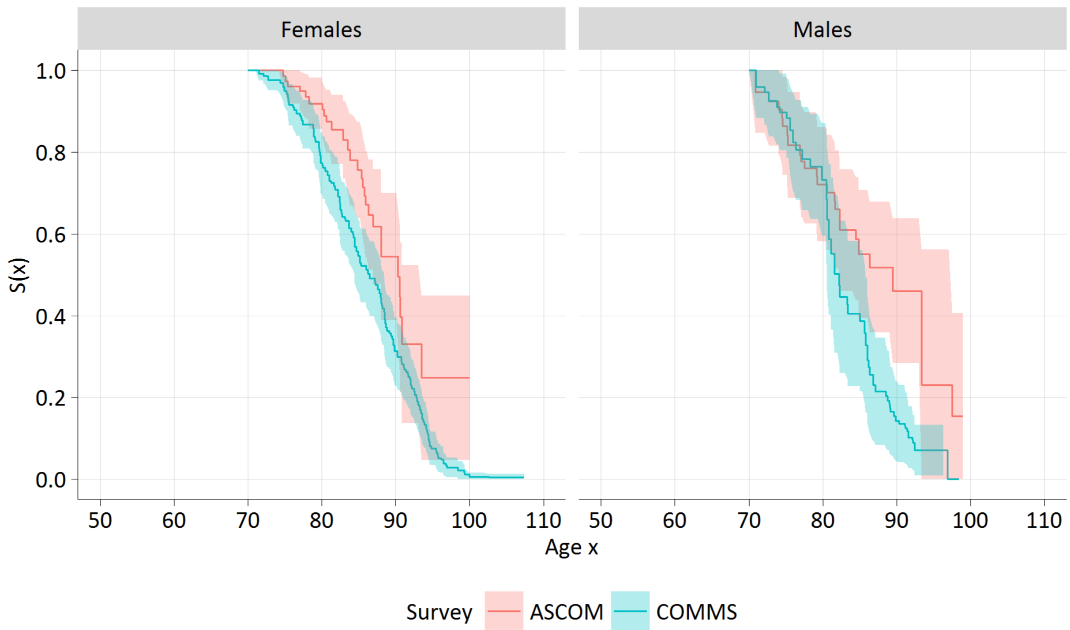
Appendix 2

Kaplan Meier survival function for the COMMS sample of the Cloister Study in comparison to the ASCOM sub-sample of survey participants and to the full ASCOM sample

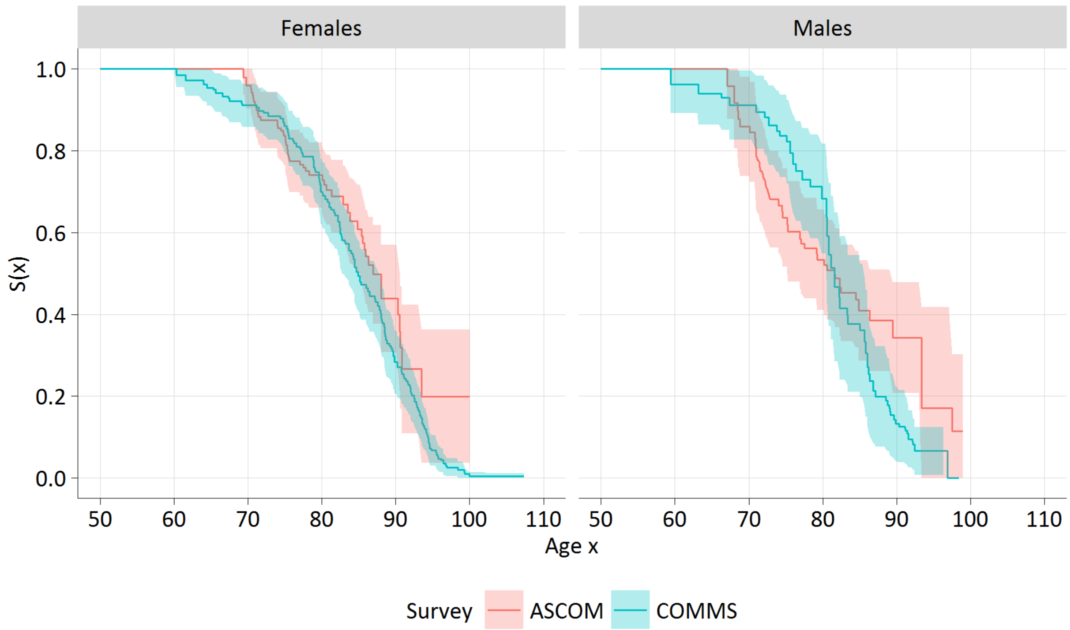
(a) Survival time by age (from age 50), ASCOM participants only



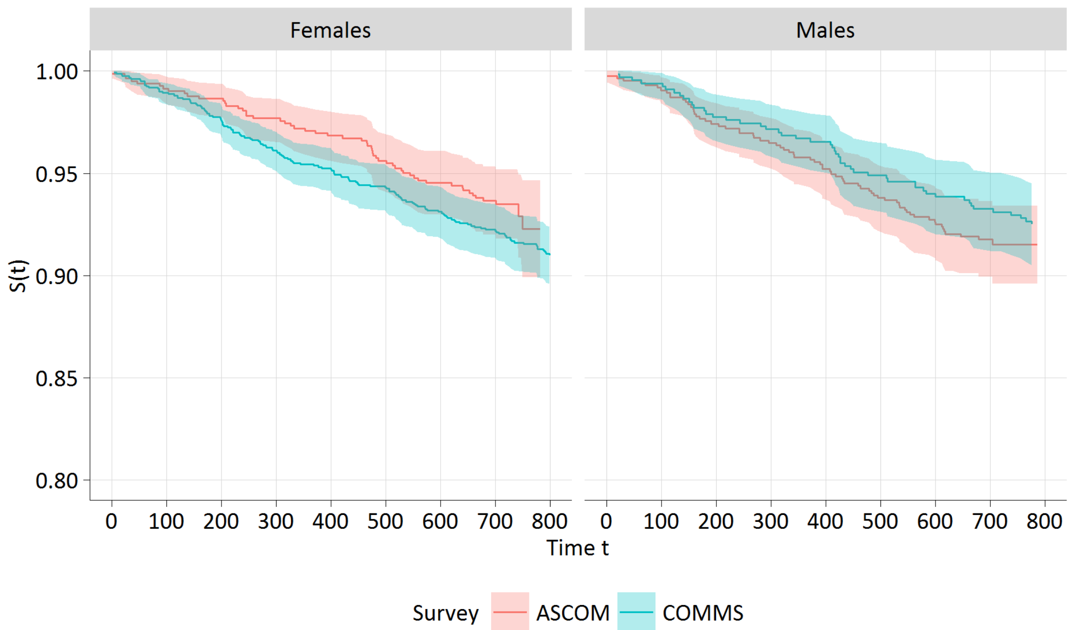
(b) Survival time by age (from age 70), ASCOM participants only



(c) Survival time by age (from age 50), full ASCOM sample
(age of non-participants imputed)



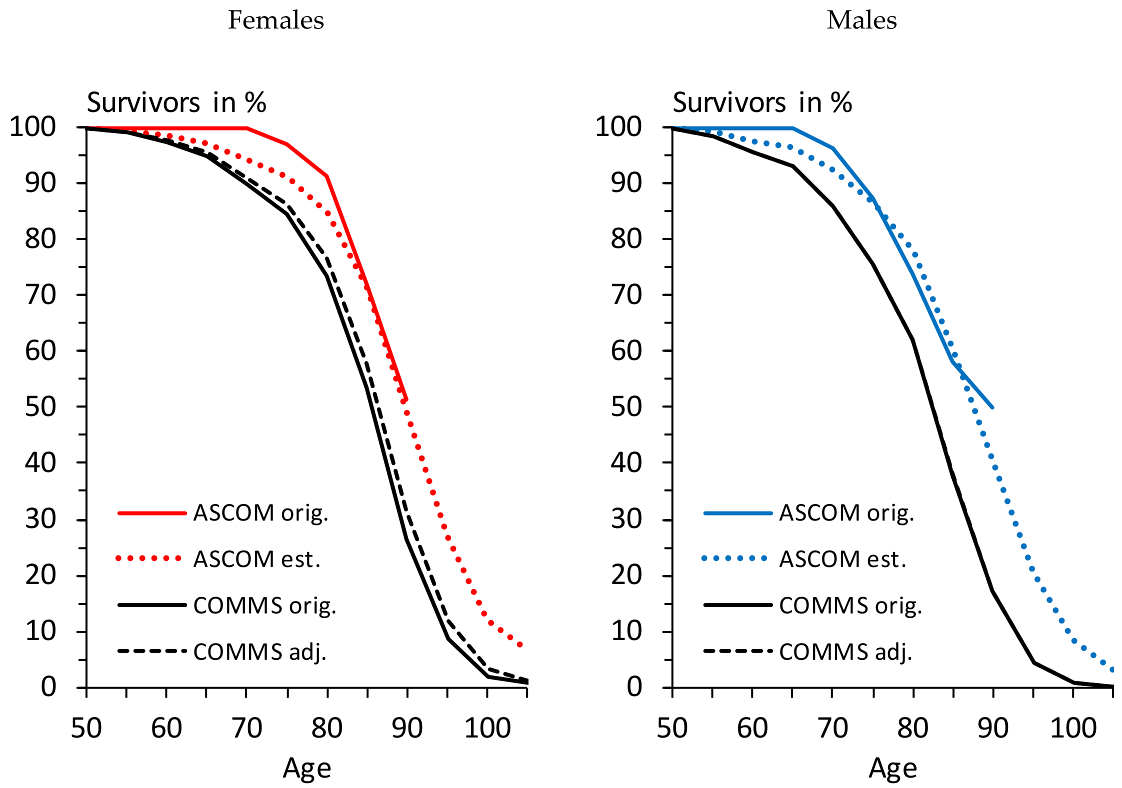
(d) Survival time in days, full ASCOM sample



Notes: the imputation of ages of ASCOM non-participants was necessary because ages are known only for participants; imputation was based on information of ASCOM participants about sex, country and community and information about survival status of non-participants at the time of survey wave 2.

Appendix 3

Survival functions for ASCOM participants and the COMMS sample of the Cloister Study, estimated survival for ASCOM participants on the basis of the COMMS and ASCOM-adjusted survival of the COMMS life table



Notes: "ASCOM orig." refers to the mortality of the participants of the ASCOM survey and "COMMS orig." refers to the mortality of the total COMMS sample. "ASCOM est." is the estimated survival of ASCOM participants derived from the "COMMS orig." survival function, adjusted by Cox regression controlled for age. "COMMS adj." results from adjustment of the "ASCOM est." survival function by Cox regression on the basis of mortality differences between ASCOM participants and the total ASCOM sample (see below). The "COMMS adj." survival function was used as life table for the estimation of healthy life years for Catholic order members.

Cox regression for comparison of mortality of ASCOM participants [1] and the full COMMS sample [2] (basis of "ASCOM est." survival function)

	Females				Males			
Variable	Exp(b)	S.E.	z	p	Exp(b)	S.E.	z	p
[1]	1.00	-	-	-	1.00	-	-	
[2]	1.85	0.220	2.80	0.0051	1.93	0.251	2.62	0.0088
Age	1.13	0.008	14.71	0.0000	1.14	0.013	9.90	0.0000

Cox regression for comparison of mortality of ASCOM participants [1] and full ASCOM sample [3] (basis of "COMMS adj." survival function)

	Females				Males			
Variable	Exp(b)	S.E.	z	p	Exp(b)	S.E.	z	p
[1]	1.00	-	-	-	1.00	-	-	-
[3]	0.62	0.243	-1.97	0.0490	0.52	0.240	-1.97	0.0066