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Ageing populations: new challenges in longevity

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Abstract

Background High-income countries experienced unprecedented gains in life expectancy throughout the twentieth century. However, recent evidence suggests that these gains have slowed, especially at older ages. This paper focuses on recent trends in life expectancy and health in ageing populations in high-income countries.

Methods We analysed mortality and health data from the Human Mortality Database and the Global Burden of Disease. Additionally, we reviewed recent literature to explore changes in life expectancy, health-adjusted life expectancy, physical and cognitive decline, and the impact of ageing on healthcare expenditure in countries with high life expectancies.

Findings Although life expectancy continues to rise in high-income countries, the pace of improvement has slowed, especially among the oldest-old. While health-adjusted life expectancy has generally increased, the proportion of life spent in good health varies across countries, with notable differences in trends in physical and cognitive disabilities. In terms of economic implications, these findings highlight the importance of age and proximity to death as determinants of healthcare expenditures.

Interpretation The deceleration in life expectancy gains, particularly among the oldest populations, raises important questions about future trends in longevity. As physical and cognitive health change in older ages healthcare systems will face new and diverse challenges. Understanding the role of ageing and time-to-death in shaping healthcare costs will be critical for anticipating future needs in high-income countries.

Keywords Mortality, Health economics, Physical health, Cognitive health, Health expectancies

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Introduction

One of the most important accomplishments of the twentieth century was the dramatic gains made in life expectancy[1] in high-income countries. In their seminal paper, "Broken limits to life expectancy," published in *Science* in 2002, Oeppen and Vaupel [1] laid the groundwork for predicting a steady increase in life expectancy. In 2009, Christensen et al. posited that most babies born in 2000 in high-income countries would live to see their 100th birthdays [2]. While life expectancy gains have been remarkable, and continue to improve, there is evidence

[1] Unless otherwise stated, "life expectancy" refers to life expectancy at birth.

now that the pace of mortality improvements in countries with long lifespans is not continuing at the previous rate [3].

Population ageing is inextricably linked to health, functional ability, and healthcare expenditure. Although health-adjusted life expectancy (HALE) has been improving globally for 30 years, the number of years spent in poor health has simultaneously been increasing [4]. Many countries with long lifespans are seeing an increase in the prevalence and incidence of some chronic diseases as populations live longer, diagnostic intensity increases, and survival prognoses after disease onset improves [4, 5]. Some older populations are experiencing less physical disability than in the past, depending on the measure, and others are exhibiting more, though cognitive impairment is clearly declining across cohorts [6, 7]. Although time-to-death has the greatest influence on healthcare expenditure, age also plays a critical role [8].

In 2009 Christensen et al. concluded that if the pace of increase in life expectancy in high-income countries over the past two centuries continues through the 21st century, progress in survival among the oldest would result in unprecedented life expectancies in these countries [2]. This paper also pointed out that in 2009, it was still unclear if increases in life expectancy would be accompanied by a concurrent postponement of functional limitations and disability. Here, we revisit these conclusions and assess how the estimated trajectories in survival, health, and ageing have changed with updated data and literature, and discuss their economic consequences.

Search criteria/methods

This paper updates the conclusions and analyses conducted by Christensen et al. in their 2009 paper, "Ageing populations: the challenges ahead," which posits that people could live longer without severe disability due to modifiable ageing processes. We conducted literature reviews on mortality, health and health expectancies, functional limitations and disability, and healthcare expenditure, and analysed data to calculate improvements in mortality, probabilities of dying at various ages, HALE, disability-adjusted life-years (DALYs), and the proportion of DALYs attributable to disability for select countries. For the literature reviews, we searched relevant repositories, such as PubMed and EconLit, for papers in English with a focus on those published since 2009, though not excluding those published earlier, with search terms that included, but not were not limited to, "physical ageing," "disability," "activities of daily living," "physical ability," "mild cognitive decline," "dementia," "cognitive impairment," "Alzheimer's disease," "Red Herring hypothesis," "Steepening hypothesis," "healthcare expenditure," "social care expenditure/long-term care expenditure," and "informal care giving." For the analyses, we used data from the Human Mortality Database (HMD) for years 1950 to 2020 and Global Burden of Disease (GBD) for years 1990 to 2019. We included literature and analysed data from the following countries and regions: Australia, Canada, Denmark, France, Germany, Hong Kong, Italy, Japan, Sweden, the UK, and the US. The country selection includes all feasible countries from the original study, noting that we analyse unified Germany, as well as East/West regions, and the full UK, as well as England & Wales due to current data availability and political relevance. We added four countries (Australia, Canada, Denmark, and Italy) that share similar characteristics, allowing us to assess whether the original findings hold across a broader, but still comparable, set of high-income countries, and include Hong Kong because of its position as a global leader in longevity. In our analyses of DALYs, we extend our reach to 27 high-income countries.

Mortality

The twentieth century was a time of widespread life expectancy improvements, unprecedented in human history [2]. Gains of about 30 years or more were seen in countries such as Belgium, England and Wales, France, and Iceland. In Italy, women gained 40 years (own calculations based on HMD). "Broken limits to life expectancy" was an appropriate title for an article by Oeppen and Vaupel, alluding not only to the actual increases, but also to the fact that proposed theoretical limits to life expectancy had consistently been broken [1]. The authors, as well as others, documented that the increase in life expectancy in the record holding country and other highly developed countries was almost linear, increasing by about 2.5 years per decade [9, 10]. This fuelled the expectation that life expectancy would continue to increase at the same pace, especially since major events, such as two world wars and the Spanish Flu, had no lasting impact on mortality. A prerequisite for this continued progress was that survival improvements would occur at increasingly higher ages. Christensen et al. showed that, as of 2009, this was the case [2]. For example, in Japan, more than 70% of life expectancy gains could be attributed to declines in mortality at ages 65 and over at the end of the observation period.

Life expectancy has continued to increase in the twenty-first century, though not at the previous pace. Instead of the increase of about 0.25 years annually observed for 1840–2000 [1], record life expectancy rose by 0.16 years per year between 2000 and 2019. The main reason for this is that the rates of mortality improvement have not been as high and have not advanced to higher ages, which are both required to sustain the documented pace. According to a simplified model by Vaupel, mortality needs to drop by about 2.5% annually across all ages to yield 2.5 years of life expectancy gain per decade [11].

Table 1 demonstrates that mortality improvements in selected high-income countries were only close to that level for men aged 80–84. The higher the age-group, the lower the observed improvements, suggesting the end of the decades-long trend of rapid mortality declines reaching ever higher ages [2]. However, it should be noted that although improvements are below 2.5%, mortality has improved faster in the last two decades than in the previous two decades in Denmark, France, Sweden, the UK, and the US. Additionally, Hong Kong, which has been the record holder since 2016, has seen mortality drop by 1.3% to 1.4%, even in the age-group 90–94. It remains to be seen whether Hong Kong represents an example of a new trailblazer, whether it is a short-lived phenomenon, or whether data quality issues might explain at least parts of its recent success.

Table 1 Average annual percent of improvement in mortality for women and men in seven selected countries comparing 1980–2000 to 2000–2019 at ages 80–84, 85–89, 90–94, 95–99. Data are from the HMD

	Women		Men	
	1980 vs. 2000	**2000 vs. 2019**	**1980 vs. 2000**	**2000 vs. 2019**
Age 80–84				
Denmark	0.94	1.62	0.70	2.14
England & Wales	1.35	1.78	1.53	2.23
France	2.49	1.88	1.87	2.22
Hong Kong	–	3.19	–	2.94
Japan	3.49	2.03	1.98	1.78
Sweden	1.57	1.69	1.42	2.12
USA	0.51	1.40	0.87	1.81
Age 85–89				
Denmark	0.75	1.05	0.52	1.33
England & Wales	1.15	1.24	1.18	1.61
France	1.72	1.69	1.25	1.62
Hong Kong	–	2.54	–	2.18
Japan	3.09	1.61	1.82	1.18
Sweden	1.10	1.33	0.77	1.60
USA	0.25	1.08	0.39	1.56
Age 90–94				
Denmark	0.96	0.68	0.46	0.57
England & Wales	0.79	0.85	0.68	1.03
France	1.27	1.22	0.81	1.10
Hong Kong	–	1.33	–	1.43
Japan	2.71	0.94	1.63	0.67
Sweden	0.65	0.93	0.65	0.91
USA	−0.06	0.82	−0.06	1.06
Age 95–99				
Denmark	0.26	0.42	0.40	0.41
England & Wales	0.29	0.40	0.17	0.57
France	0.83	0.75	0.41	0.58
Hong Kong	–	0.04	–	0.15
Japan	2.27	0.33	1.20	0.21
Sweden	0.26	0.65	−0.35	0.82
USA	−0.39	0.56	−0.35	0.57

Figure 1 illustrates the probability of dying at ages 80 (panel a) and 90 (panel b). The observed decline over 70 years demonstrates continuous improvements in survival rates at higher ages, consistent with the findings of Christensen et al. (2009) [2]. However, in some cases in more recent years, excluding the COVID-19 pandemic period, these improvements have reduced in pace.

Though we exclude the COVID-19 years from our analyses, the COVID-19 pandemic had a profound impact on global mortality patterns in 2020 and the years following the pandemic, with many countries experiencing substantial declines in life expectancy [12, 13]. Some countries saw their largest single-year reductions in life expectancy in decades, with the pandemic particularly affecting older populations and reversing years of mortality improvements across multiple countries. In the coming years we will begin to see whether COVID-19 has long-term impacts on life expectancy around the world.

It is also important to note that, while the probability of survival at older ages has been increasing, there is a persistent socioeconomic gradient in mortality in high-income countries. Improvements in life expectancy and lifespan inequality in Europe and the United States are seen primarily in higher socioeconomic groups, with lower socioeconomic groups experiencing little, if any, improvement, by either measure [14–18]. This phenomenon is seen, too, in countries with high national incomes, social transfers, and healthcare expenditures, such as the Nordic countries [14–16, 19].

Health and health expectancies

Mortality improvements have extended lifespans in high-income countries, but understanding the quality of these additional years of life is crucial. Examining health and health expectancies reveals whether populations are living longer in good health, extending years lived with illness and disability, or neither. This shift in focus reflects broader changes in how health itself is conceptualised and measured at the population level.

The World Health Organization's definition of health as "[a] state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" [20] represents a stark shift from thinking of health solely in clinical terms, as had previously been the case, to multidimensional, biopsychosocial terms [21]. There is no one indicator that fully explains health trends over time, but there are several that explain different dimensions of it. For example, disability is often used to measure population health, as it encapsulates physical or cognitive functioning, as well as the ability to engage in activities within society [22].

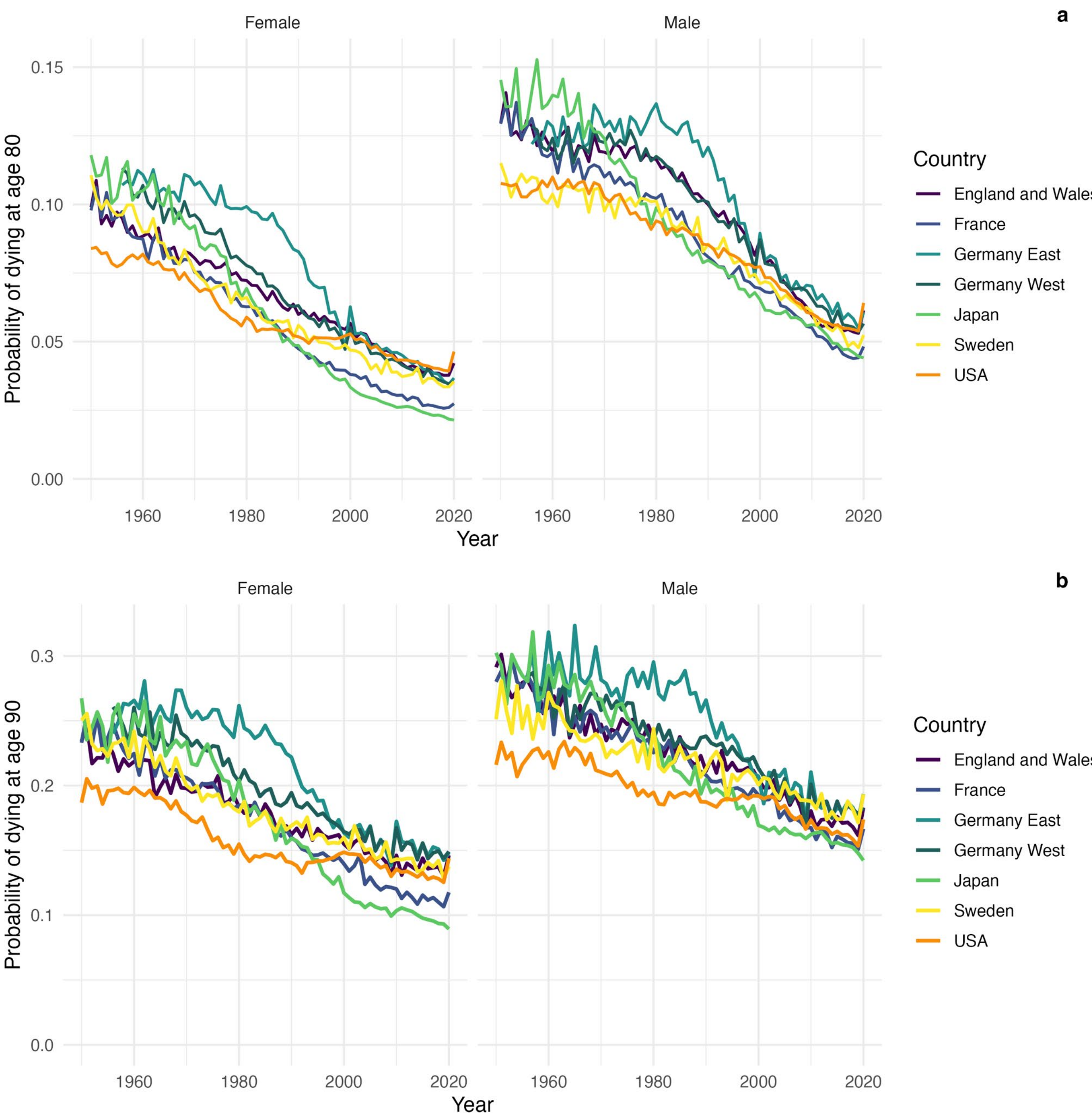

Fig. 1 Probability of dying at ages 80 years (panel **a**) and 90 years (panel **b**) for men and women in selected countries from 1950 to 2020. Data are from the HMD

There are three main theories that explain changes in morbidity and disability in ageing populations. The expansion of morbidity theory predicts an increase in the incidence and prevalence of chronic diseases and disabilities as populations live longer [23, 24]. The compression of morbidity theory hypothesises a reduction and postponement of morbidity to older ages, i.e., compression to the later years of life [25]. The dynamic equilibrium theory posits a reduction in the severity of disease, rather than its prevalence or incidence [26]. These theories can be assessed quantitatively in populations using certain health expectancy measures that estimate the amount of time people are expected to live in good health, and are used to understand how populations are ageing healthwise. Health expectancy measures include disability-free life expectancy – the most commonly used measure of disability – and HALE, which is calculated by the GBD Study group by applying the Sullivan method [27] to a composite disability indicator of 440 health states [5].

In 2019, the GBD group found that HALE had been improving globally for 30 years. At the same time, the number of years spent in poor health had also been increasing [4]. The latter suggests that, in absolute terms, there has been an expansion of morbidity. However, in relative terms, whether compression or expansion of morbidity has been driving this change is still a point of debate. To assess these theories in relative terms, we calculated the health ratio (HR) as proportion of years expected to have been lived in good health at age 65 as the ratio of HALE and remaining life expectancy. This relative indicator reveals whether improvements in health are greater or less than those observed in mortality, though HALE is also influenced by mortality [28]. We selected age 65 to facilitate comparison with previous studies, as it is a widely used cutoff age in health research internationally.

Figure 2, panel a presents trends for HALE at age 65 for 10 selected countries from 1990 to 2019. As in Wang et al., we observed a general improvement in health [4], but

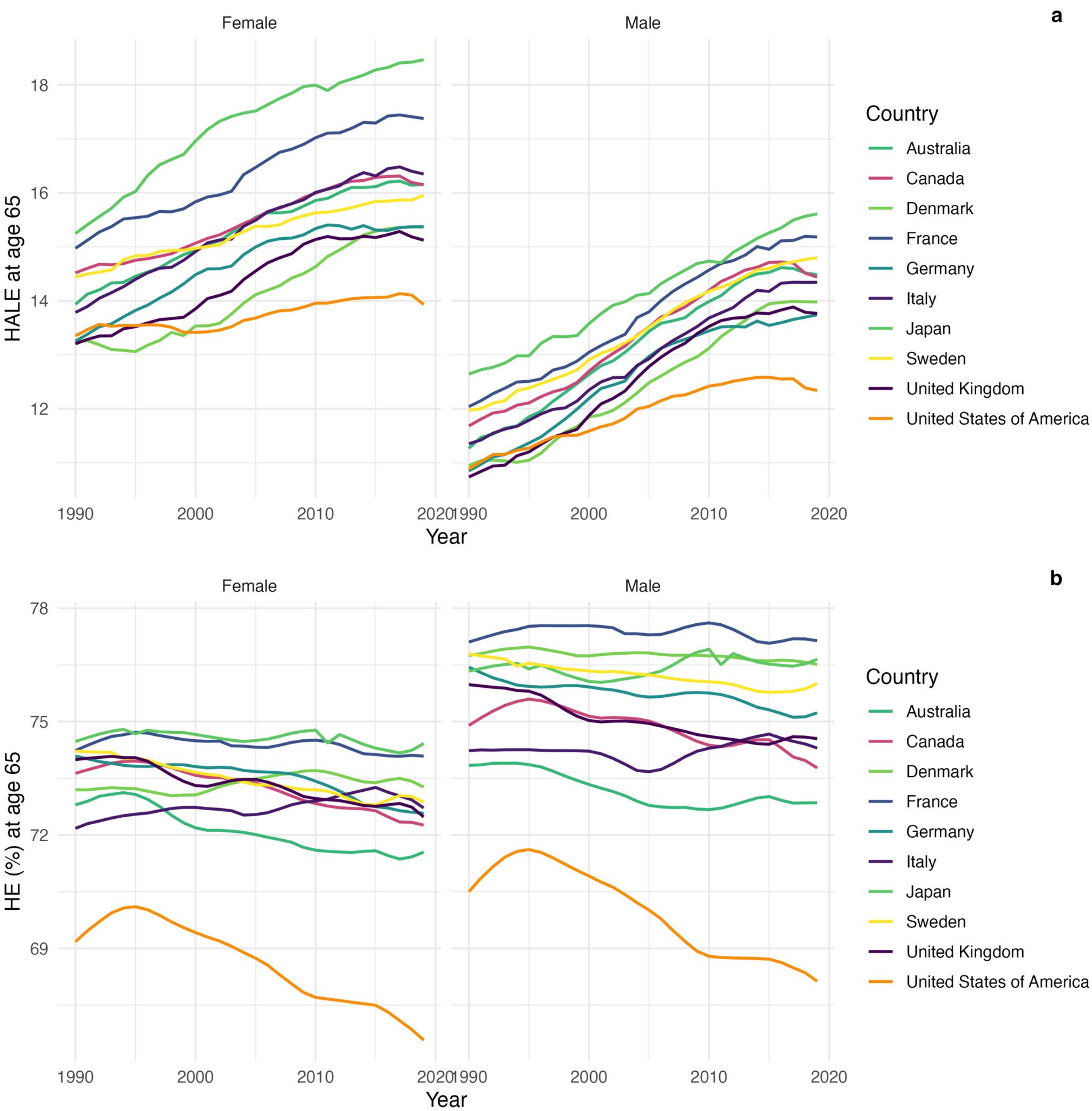

Fig. 2 Health-adjusted life expectancy (HALE) at age 65 (panel **a**) and proportion of years expected to be lived in good health, computed as ratio between HALE and life expectancy at age 65 (panel **b**), for selected countries, years 1990–2019. Data are from the GBD

this changes when we take the proportion of years that were expected to be lived in good health into account, depicted in Fig. 2, panel b. For most countries and both sexes, we observed a constant or decreasing trend, translating to the dynamic equilibrium and expansion of morbidity theories, respectively. Women in Italy and men in Japan are the exceptions and show an improvement in the proportion of years expected to have been lived in good health.

One should take caution when comparing HALE with disability-free life expectancy trends at age 65, as different indicators and surveys for the same population could yield conflicting results [29]. Specifically, HALE weights years lived by health status using disability weights, while disability-free life expectancy counts only years lived without disability based on health prevalence or health state transitions. However, this comparison does allow for contextualizing results obtained via surveys around the world with the harmonised data of the GBD team. Furthermore, the interpretation of changes in HALE and HR over time requires caution, as differences over time may not be statistically significant due to uncertainty around the estimates [30].

In Italy, we observed compression of disability between 2004 and 2019 for both men and women, consistent with prior research [31, 32]. In Japan, consistent with our results, studies have found expansion of disability between 1995 and 2004 [33], although we observed compression after this period. Our results suggest dynamic equilibrium in both France and Denmark, consistent with the literature for France from the early 2000s [34], though in Denmark, studies find a compression of disability until 2011 [35]. For the other selected countries, we observed an expansion of disability in the US, UK, Australia, and Germany (among men). Expansion of disability is typically characterised by a reduction of over 1.5% in the proportion of years expected to have been lived in good health from 1990 to 2020. Our results are in line with the literature for the UK, where expansion of disability was observed at age 65 and older in the first decade of the 2000s [36]. In the US, expansion of disability was observed in a study that utilised similar methodological approaches and data [37], while studies using different data sources observed dynamic equilibrium [38, 39]. In Sweden, we observed expansion of disability, though studies have found both compression and expansion, depending on the age of observation (i.e., 65 or 77), and which survey was being analysed [40]. Contrary to our results, studies find dynamic equilibrium in Canada [41] rather than expansion of disability. Similarly for Australia, where we observed a small expansion of disability, the literature suggests compression of disability [42, 43]. In Germany, studies observe compression of disability, but only analyse severe disability-free life expectancy in one region, reflecting the complexity of retrieving time-trends in disability-free life expectancy data [44].

Until recently, researchers have mainly focused on the average measures of health and ignored the variability within populations. Exploring variability adds nuance to the discussion on compression and expansion of morbidity and disability [45]. This area of study is gaining traction, for example, Permanyer et al., used GBD data to reveal a global increase in healthy lifespan inequality at age 65 over the past 30 years, even where there is general HALE improvement [46].

Functional limitations and disability

Given the complex patterns observed in health expectancy trends, understanding the specific components of health is essential. Physical disability, which affects a person's capacity to perform basic and instrumental tasks, and cognitive disability, encompassing the spectrum from normal age-related cognitive decline to dementia, represent two dimensions that influence whether extended lifespans translate into years of good health or years lived with functional limitations. Both forms of disability affect individual quality of life, family caregiving responsibilities, and healthcare system resources. The evidence reveals complex trends across different countries and time periods, with some encouraging signs of improvement alongside persistent challenges in measuring and addressing physical and cognitive disability. These evolving patterns help explain the heterogeneous health expectancy trends, and provide insight into whether mortality improvements are accompanied by functional improvements or simply longer periods of living with impairment.

Physical disability

Physical disability refers to the reduction of a person's capacity to function physically, and is generally estimated via self-reported ability to complete certain actions. These actions include basic activities of daily living (ADLs) and instrumental activities of daily living (IADLs). ADLs were first conceptualised in the 1950s and 60s as a way to measure functional independence in older adults, and include the ability to perform daily activities, such as feeding, dressing, and maintaining basic hygiene [47]. IADLs were developed later in the late 1960s, to measure the ability to perform more complex activities, such as shopping, housekeeping, and managing finances [48].

Estimates of physical disability measures vary. Across Europe, the prevalence of disability for ADLs among those aged 65 and older is estimated to be 8.4%, with country estimates ranging from 3.3% in Denmark to 15.3% in Belgium. For IADLs, the prevalence of disability is around a quarter across Europe, ranging from 11.8%

in Sweden to 38.8% in Latvia. Among those over the age of 85, it is estimated that around half have a disability in at least one IADL [49, 50]. In the US, it is estimated that 10% of men and 13.4% of women over the age of 50 have two or more limitations with ADLs and/or IADLs [51].

Trends in physical disability

The ADL index is sensitive to changes in meaningful self-care functions, allowing it to be analysed longitudinally as a measure of change on the population level [52]. Research from previous decades showed ADL disability to be in decline [2, 53], but more recent studies find the opposite for some populations. In the US, ADL disabilities were found to have increased 9% from 2000 to 2005, although with no change to functional limitation rates [6]. Since the early 2000s, Denmark and Sweden have both seen a decrease in ADL and IADL disabilities, and Italy and Spain saw a decrease in IADL disabilities [54, 55]. A comparison of changes in ADLs across Northern, Central, and Southern Europe suggest there were no changes over time in any regions before age 70 [54]. On the other hand, a comparison across birth cohorts found evidence for increased disabilities in more recent cohorts in Northern and Western Europe, among men in Eastern Europe, and no changes in Southern Europe [56]. Over time, there has been an improvement in grip strength, walking speed, and balance in Japan among older adults [57, 58], but evidence that grip strength across high- and upper-middle-income countries generally has declined over time [59].

Measuring ADLs and IADLs is not without its challenges. There can be inconsistencies in disability estimates, even within the same populations [60]. Several explanations account for this, including which ADL items are being measured, sample design, and survey methodology. These measurement challenges underscore the importance of interpreting ADL and IADL data with careful attention to methodological context.

Cognitive disability

Cognitive ageing versus pathological brain ageing

While cognitive decline is evident from middle age, it must be distinguished from pathological brain ageing later in life, which is influenced by genetics and several critical stages in a person's life, including the prenatal period, childhood and adolescence, and adulthood [61]. An intermediate stage between normal age-specific cognitive function and dementia is mild cognitive impairment, which refers to a syndrome in which cognitive performance is impaired beyond the level expected for the person's age and level of education. However, this impairment is not sufficient to diagnose dementia [62]. Mild cognitive impairment has serious consequences, it negatively affects the quality of life of older people by reducing their autonomy, activities, and social participation [63], and about 18% develop dementia each year [64]. Despite its importance as a risk factor for dementia, estimates of the prevalence of mild cognitive impairment vary widely, from 1% to 87%, due to differences in diagnostic criteria, assessment tools, and study populations [62].

Among the oldest old in Europe, dementia is one of the most common syndromes, comprising a series of neurodegenerative and vascular brain pathologies, mainly irreversible. The prevalence of dementia increases exponentially with age, doubling approximately every five years up to the ages of 75–79, with a slower increase thereafter. In a meta-study over the period 2008–2018, the prevalence rose to 21.9% in the 85–89 age group and 40.8% in the 90 + age group [65], with women having a higher prevalence than men [65, 66]. Incidence rates also increase exponentially with age, ranging from 42.2 per 1,000 person-years in the UK based on the CFAS II Study, to 97 in the Rotterdam Study at ages 85–89 [7].

Trends in prevalence and incidence of cognitive impairment and dementia among the oldest old

Given the life-course risks of pathological brain changes, secular improvements in living conditions and education over successive cohorts should lead to better cognitive functioning [61]. Cohort studies have shown that there is an improvement that extends to the oldest old. Comparing the Danish 1905 and 1915 cohorts of nonagenarians, the later cohort scored better in terms of cognitive tests, physical functioning, and quality of life [67, 68]. In the US, the prevalence of cognitive impairment without dementia decreased among the 85-year old between 2000 and 2012, albeit with overlapping 95% confidence intervals [69].

At the beginning of the new millennium there was conflicting evidence about trends in age-specific dementia prevalence and incidence. With the arrival of new data from population-based studies, it became clear that trends were either stable or declining [2]. From the 1980s to the 2010s, the age-specific prevalence of dementia appears to be stable or declining for those aged 65 and above [70] with the CFAS I and II Studies showing a 23% decline in prevalence over two decades in the UK, and the Health and Retirement Study, a 26% decline over 12 years in the US population. In these two studies, the decline in the prevalence of dementia extended up to ages 85 and above, albeit only statistically significant in CFAS I and II for men. The tendency for this gender specific decline at ages 85 and above was confirmed in a German study based on health claims data for the first decade of 2000 [71], while other studies reported stable or inconclusive trends in dementia prevalence.

Age-specific dementia incidence appears to be declining across all cohorts and time periods in both population-based surveys and secondary evidence from medical records and health and insurance administrative databases [70]. In a meta-analysis, this decline was 13% per decade between 1988 and 2015, with a slightly higher decline in women [7].

Life expectancy and mortality of dementia patients

While the mortality of people with dementia is about 2.6 to 3 times higher [72, 73] than that of people without dementia, the average survival of people with dementia aged 85 and over is still about 3.8 years [74], with women living longer with severe dementia than men. This results in a huge economic burden, much of which is borne by families providing informal care [75]. Previously, little was known about dementia mortality trends, and the latest data are still inconclusive. A decline in dementia mortality similar to that without dementia has been observed in a number of studies [76], but there are also reports of increases in dementia mortality among women [71] and mortality with cognitive impairment [77].

Healthcare expenditure

The relationship between ageing populations and healthcare costs has been a subject of considerable debate, with researchers examining whether age itself or proximity to death drives healthcare spending. As mortality rates have declined, understanding the economic implications of extended lifespans becomes increasingly important for healthcare policy. This distinction has consequences for how societies prepare for and manage the fiscal challenges of ageing. Understanding these economic dynamics is crucial as healthcare systems worldwide grapple with unprecedented demographic shifts and their associated financial pressures.

Age and time-to-death as drivers for healthcare expenditure

It is well established that time-to-death affects healthcare expenditure more than age [78]. Some health economists reject age as a contributor to healthcare expenditure all together, or view it as a red herring, giving name to the red herring hypothesis that posits that time-to-death, and not age, is the primary influence of healthcare expenditure [79, 80]. In its pure form, this is equivalent to the compression of morbidity theory [25, 81].

Research shows that healthcare expenditure increases exponentially with proximity to death for the simple reason that dying is associated with receiving a large quantity of treatment. In their formulation of the red herring hypothesis, Zweifel et al. refer to a Medicare study that found that 5.1% of Medicare beneficiaries who died in 1988 accounted for 29.1% of total Medicare payments for that year [82]. However, more recent data from a range of countries suggests the proportion of healthcare expenditure utilised in the last year of life is lower, between 8.5% and 11.2% [83]. In the Netherlands, researchers calculated ratios of disease-specific hospital-care expenditure for surviving patients to deceased patients in their last year of life for 93 diseases and found around half to be greater than 10, the largest being 295, for lung cancer [84].

Even when controlling for time-to-death, age affects healthcare expenditure both directly and indirectly, as studies show that time-to-death effects and age interact with each other, albeit in different directions in different studies [8, 85, 86]. This could be because chronic disease management is more successful for younger patients than for older patients over the age of 75 [8], and also that the use of medical technology tends to be costlier for older patients than for younger ones [87]. Additionally, age-steepening, i.e., when healthcare expenditure grows at a higher rate over time for the old compared to the young, has been observed in several populations [8, 88, 89].

Heterogeneity in studies on healthcare expenditure should be considered, as different types of hospital care will yield different expenditures. Many studies only include expenditures for hospital services, either only inpatient services or both inpatient and outpatient services, while others investigate subcategories of expenditures. Time-to-death has a strong impact on healthcare expenditure from hospital services in most studies [84–86, 90–93], Carreras et al. being an exception [94]. When tested, studies find age effects, often referred to as age steepening, to be statistically significant [8, 88, 89, 93], Felder and Werblow being the exception [95]. The second largest healthcare expenditure subcategory is long-term personal care which is much more sensitive to direct age effects and little to time-to-death [90, 96–98]. Results are more diverse for other subcategories, such as primary care [99], prescription drugs [100], and diagnostic services [94].

Modelling healthcare expenditure

Early forecasts of official healthcare expenditure used methods that adjusted for time-to-death [101]. A more sophisticated approach to assess the aggregate impact of time-to-death on healthcare expenditure is to quantify by how much healthcare expenditure forecasts will reduce when adjusting for time-to-death, as opposed to using naïve forecasts that use constant age-specific healthcare expenditures. This method yields great variation in the results, from only a 7% reduction when adjusting for time-to-death for inpatient care expenditures in Scotland, to 50% for public health care expenditures in Denmark [102]. The latter is three times higher than what was reported in an earlier study on Danish healthcare expenditure [103].

These time-to-death-based projections may, themselves, be naïve. Firstly, time-to-death (postponement of death) is not exogenous [104]. What led to delays in time-to-death, i.e., lower death rates and increased lifespans, must be factored into the projection model. The cheap way is through healthier life styles, which would improve public health on the population level more broadly [105]. The costly way is through complex and enduring technological interventions, and any cost reduction effects of time-to-death would be offset by increased technology costs [87, 106]. Furthermore, the costs of delaying time-to-death would offset the savings associated with the delay [107, 108]. Even without assuming and adding upsurges in per capita healthcare expenditure for the elderly to the predictions – and such predictions have not yet been published – future healthcare expenditure might not be reduced from time-to-death adjustment by much. When the costs of postponing death are factored into the projections, the reduction factor could be zero.

However, supply responses, such as health policies, pull the pendulum in the other direction [90, 109]. Budget caps are possible in tax-based systems and most insurance-based systems. For example, over four out of the past five decades, the cap in Danish total healthcare expenditure has been that the growth of healthcare expenditure would not exceed the GDP growth (the first decade of this century was the politically designed exception).

Age and time-to-death as proxies for health status and morbidity

Recent research on the associations between ageing populations and healthcare expenditure has focused increasingly on the health status and morbidities of individuals as the real drivers of demand for healthcare. Inclusion of such variables in regression models always reduces the size of the time-to-death effects on healthcare expenditure, but these effects are still statistically significant. For example, with Danish data, inclusion of chronic morbidities (dummies for 28 chronic diseases) reduced time-to-death effects on healthcare expenditure by a factor of three to four for those aged 80 + years, and a factor of five for those between ages 60 and 80 [8]. This study also shows age effects on healthcare expenditure through interaction between age and disease management, which has been more successful for those under 75 years than for older patients. On the other hand, a Spanish study that used data from a Clinical Risk Groups patient classification system, a good indicator of health status, had different findings [94]. The Clinical Risk Groups indicator assigns individuals to one of nine mutually exclusive and exhaustive categories based on their clinical records and prescription codes – from "healthy" to "catastrophic". Adding this health status indicator as eight dummies ("healthy" is baseline) takes away time-to-death effects on healthcare expenditure for all types of services, including acute outpatient, acute inpatient, primary care, pharmaceuticals, diagnostic tests, accidents and emergencies, and integrated care. Overall, many uncertainties and unknown mechanisms remain about future healthcare expenditure associated with ageing populations.

The red herring hypothesis [80, 81] soothed many worries about escalating healthcare expenditure in ageing populations; most healthcare expenditure would only be postponed along with postponement of death. However, the red herring hypothesis suggests that age is an imperfect proxy for health in the context of health expenditures [110]. Kotschy et al. (2025) attribute the limitations of age as a proxy for health to differences in how ageing occurs across people, health domains, and over time [111]. The associated hypothesis about compression of morbidity is challenged by the most recent data in high-income countries. Two indicators, computed by the GBD study group or obtained using their estimates, are presented in Fig. 3 to support this statement: (1) disability-adjusted life years (DALYs), the sum of the years of life lost due to premature death and years lived with disability due to poor health (YLD); and (2) the proportion of DALYs attributable to disability (YLD/DALY). Figure 3 shows an absolute improvement in DALYs (panel a) in all countries analysed from 1990 (orange) to 2019 (blue). However, in relative terms, the proportion of DALYs attributable to disability has increased over time (panel b), suggesting a relative expansion of morbidity for all countries. Healthcare expenditure in the last year of life has diminished to about 10% of annual healthcare expenditure [83] – from about 30% in the 1990s [82]. Finally, although time-to-death remains an important factor in healthcare expenditure, especially for hospital services, so does age directly, especially for long term care, but also indirectly in interaction with time-to-death, with disease management, and with time, i.e., steepening effects.

Conclusions

The landscape of ageing and longevity has evolved in ways that warrant reassessment of earlier projections and assumptions about future demographic trends. The findings from this paper offer new insights into these evolving dynamics in high-income countries that extend beyond those drawn by Christensen et al. in their influential 2009 paper, "Ageing populations: the challenges ahead".

We document that life expectancy has continued to increase, albeit at a slower pace than before. This represents a shift from the trends that informed the conclusions of the original paper. The rapid gains in life

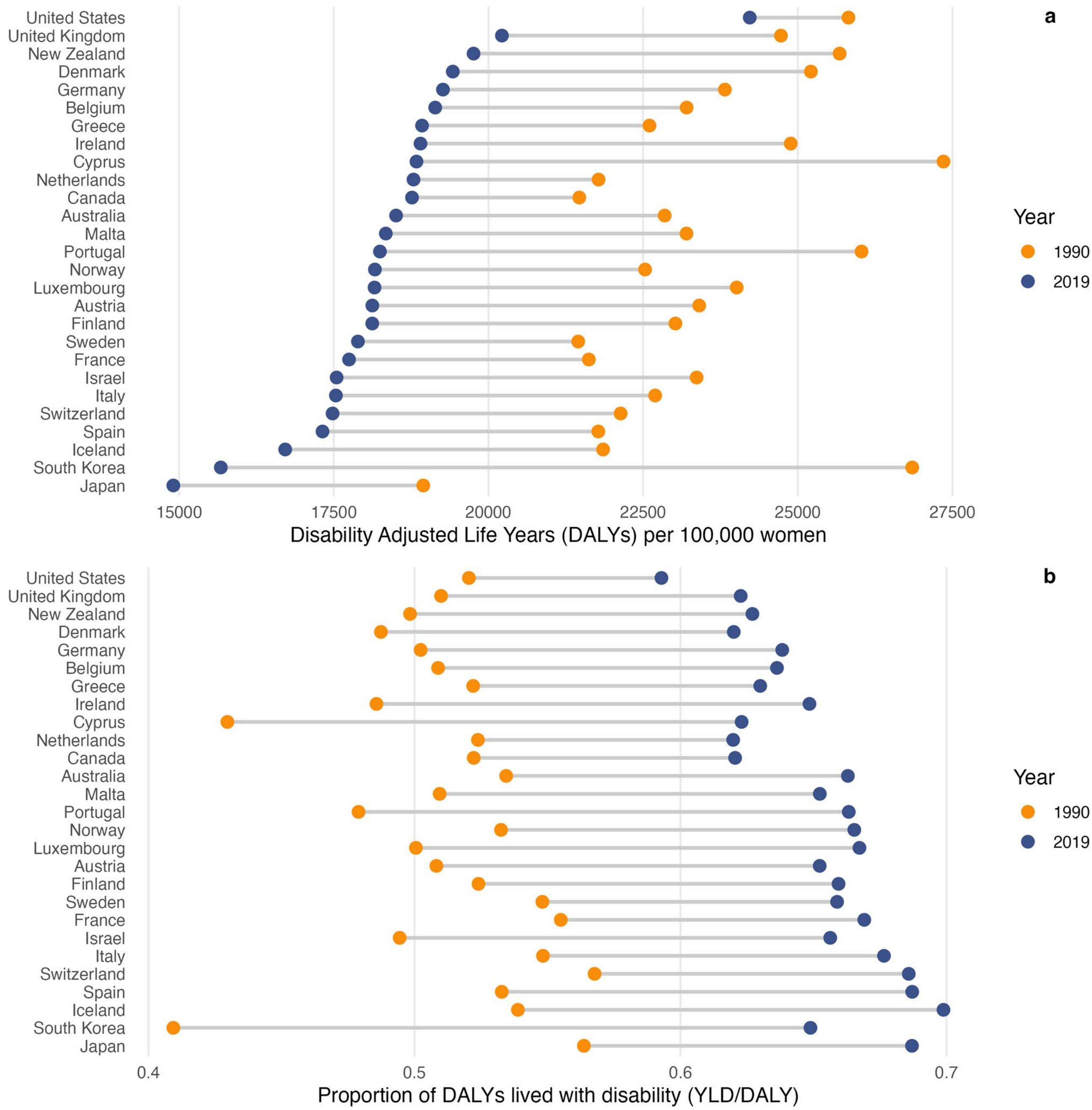

Fig. 3 Disability adjusted life-years (DALYs) (panel **a**), and proportion of DALYs lived with disability (YLD/DALY) for selected countries, 1990 and 2019. Data are from the GBD

expectancy observed during the latter half of the twentieth century are unlikely to continue in the future *if* improvements at older ages do not match the 2.5% necessary to keep the pace of the "broken limits" improvements, although it cannot be ruled out that the lower rate of improvement is a temporary phenomenon. Our expanded analysis across ten countries (compared to the original six countries/regions) reveals heterogeneity in ageing patterns across high-income countries, showing that longevity trends are not uniform.

While HALE has generally improved, the proportion of life spent in good health varies, with no clear consensus on whether high-income countries are experiencing compressions or expansions of morbidity, or dynamic equilibrium.

Our examination of healthcare expenditure patterns in the context of current demographic trends offers new insights into the economic implications of population ageing that reflect more recent healthcare cost dynamics. Contrary to the red herring hypothesis, which downplays the role of chronological age in healthcare spending, both age and time-to-death significantly impact healthcare expenditures, with implications for healthcare policy and planning. This highlights the importance of developing health systems that will be able to manage the complex needs of ageing populations.

We provide updated evidence on the complex relationship between disability trends and longevity, showing that physical and cognitive disabilities are evolving differently across populations – a nuanced picture that wasn't fully captured in Christensen et al. (2009). While some countries show improvements in disability rates, others do not, especially among the oldest-old.

These findings should be interpreted within the context of data limitations inherent in our analysis. Our reliance on HMD data involves potential variations in mortality registration completeness and accuracy across countries and time periods. Similarly, GBD data come with uncertainties reflected in confidence intervals around health expectancy estimates, and both data sources depend on national statistical systems that vary in their data collection methods and coverage.

This paper highlights the interdependent dynamics of ageing, health, and healthcare expenditure in high-income countries. While significant progress has been made in extending life expectancy, challenges remain in ensuring that these additional years are lived in good physical and cognitive health. As we move forward, it will be crucial to balance the goals of extending life with those of improving the quality of life, thereby ensuring that longevity gains translate into broader benefits for society.

Abbreviations

HALE	Health-adjusted life expectancy
HR	Health ratio
DALY	Disability-adjusted life year
YLD	Years lived with disability
ADL	Activities of daily living
IADL	Instrumental activities of daily living
GBD	Global Burden of Disease
HMD	Human Mortality Database

Supplementary Information

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Supplementary Material 1.

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Dedication
This paper is dedicated to Jim Vaupel, whose pioneering work in demography has inspired countless researchers around the world. His relentless pursuit of knowledge and innovative thinking continue to shape our understanding of population dynamics. We honour his legacy and are grateful for his profound contributions to the field.

Authors' contributions
JC was responsible for the administration of the project. CS and RR conducted formal analyses and CS produced all visualisations. All authors contributed to the conceptualisation, writing, reviewing, and editing of the paper.

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Data availability
All data are available via the Human Mortality Database and the Global Burden of Disease.

Declarations

Ethics approval and consent to participate
This study utilised publicly available data from the Human Mortality Database and Global Burden of Disease database. No primary data collection involving human subjects was conducted. As all data were already in the public domain and de-identified, institutional review board approval was not required for this analysis.

Competing interests
The authors declare no competing interests.

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