Disability-Free Life Expectancy in England over The Past Decade: Trends Differ across Genders and Levels of Disability

Abstract

There is increasing interest in the use of health expectancy indicators to understand implications of population aging. We assess how disability-free life expectancy (DFLE) has evolved in the past decade in England distinguishing four levels of disability, and explore differences across gender and severity levels.

We use data from the English Longitudinal Study of Ageing to measure disability. Disability is defined following the WHO's International Classification of Functioning, Disability and Health, and classes estimated using latent class analysis. DFLE is calculated at the time of the first wave, 2002, and a decade after, applying Sullivan method.

We identified four distinct classes of disability (no disability, mild, moderate and severe). Changes in DFLE observed between 2002 and 2012 differed across gender and disability classes. Between 2002 and 2012, gains in life expectancy were accompanied by small gains in years with any disability level in men, while for women only years with mild disability increased.

A dynamic equilibrium of disability for women and an expansion for men were found. Our findings highlight the importance of distinguishing severe and milder disability levels, because their trends seem to be divergent; and to consider both proportional and absolute changes in health expectancy to quantify the burden of disability.

Key words*:* disability free life expectancy – expansion – compression – dynamic equilibrium – England

Introduction

Life expectancy has been used as an indicator of population health for a long time. More recently, with the completion of the “epidemiological transition” in high and low-middle income countries (Omran, 2005), mortality has ceased to be as tied to health as it was before, and life expectancy does no longer fully capture the health status of a population. From the 1960s, with the study of Sanders (1964) and Sullivan (1971), the assessment and monitoring of population health changes have shifted towards indicators that combine both mortality and morbidity (or disability). Evaluations of trends over time of these new population health measures have crystallized around three distinct theories, namely: compression (Fries, 1980), expansion (Gruenberg, 1977; Kramer, 1980) and dynamic equilibrium of morbidity and mortality (Manton, 1982). The hypothesis of compression of morbidity maintains that the causes that have led to decreased mortality would also be linked to a lower incidence of chronic diseases and delays in onset of chronic diseases and disability. The “compression of morbidity” scenario asserts that the gained years of life will be years free of disease and disability. According to the expansion of morbidity hypothesis, increases in life expectancy are driven mainly by improvements in medical care and secondary prevention strategies that avert fatal outcome from degenerative diseases, whilst the epidemiology of these conditions remains more or less the same. As a result, people survive chronic diseases, but in turn they live a longer part of their life with the condition, i.e. morbidity expands together with longevity. The third theory of population health change combines elements of both the compression and expansion hypotheses into a scenario characterized by a slowdown in the rate of progression of disease that would lead to an increase in overall prevalence due mostly to increases in the prevalence of mild and less disabling disease states, largely stable rates of severe disease.

It has often been remarked that empirical evidence supporting any of these theories is scarce. However, there has been increasing interest in the use of health expectancy indicators for public policy and planning and for the evaluation of public health programs over the last decades. Hence, the lack of support for any of the abovementioned theories is not only due to the scarcity of studies, but also to the heterogeneity and discordance of results.

The present study is set in England. England (and more generally the UK) is one of the few countries for which time-series of life expectancy and health expectancy have been available since the 1980s (Robine & Michel, 2004), and thus it has been possible to study trends over about three decades. Nevertheless, no clear pattern has been found. Between 1981 and 1999, dynamic equilibrium of morbidity was found. In the UK, between 1980 and 1994 there seemed to be an increase in Disability-Free Life Expectancy (DFLE) for females aged 65 years (Bebbington & Darton, 1996), and handicap-free life expectancy increased between 1976 and 1991, but the trend reversed downward between 1991 and 1994 (Bebbington, Bone, Jagger, Morgan, & Nicolaas, 1995; Robine & Romieu, 1998). A more recent study (Jagger et al., 2016) investigated how various health expectancies have changed in England between 1991 and 2011, and showed that cognitive impairment compressed in absolute terms, self-perceived health compressed in relative terms, and disability evolved in dynamic equilibrium, with less severe disability increasing and more severe disability declining. The findings of studies on the evolution of life expectancy and health expectancy over the past three decades in the UK are summarized in Table 1, although the comparison is limited due to the fact that the studies referred to different age groups and disability was measured in different ways.

Other recent studies on the older population set in high-income countries (Crimmins, Zhang, & Saito, 2016; Freedman, Wolf, & Spillman, 2016; Sundberg, Agahi, Fritzell, & Fors, 2016) present mixed evidence, but also common findings. The studies that distinguished mild and severe forms of disability (Freedman et al., 2016; Sundberg et al., 2016) find a decline in severe disability and a rise in milder levels.

Health expectancies can be assessed in absolute terms or relative to trends in life expectancy (Robine, Jagger, Mathers, Crimmins, & Suzman, 2003). Attention has been focused on these two alternative measures to understand the advancement in the process of healthy aging. What has often been neglected, however, is the importance of the actual number of expected years with and without disability, because estimates of expected years with and without disability are informative of the overall burden of disability.

Our study intends to contribute to the debate on compression, expansion and dynamic equilibrium of mortality and morbidity by assessing how DFLE has evolved in England over a decade. We use data from the English Longitudinal Study of Ageing (ELSA), and therefore focus on adults aged 50 years and older, to estimate DFLE applying the Sullivan method. Doing so, our research provides new evidence by (i) updating results for the last fifteen years in England among the non-institutionalized population aged 50 years and older; (ii) interpreting disability according to the International Classification of Functioning Disability and Health (ICF) framework, which is a comprehensive approach to disability proposed by the WHO as international framework; (iii) distinguishing severity levels of disability to better understand changes in DFLE; (iv) considering both longitudinal and cross-sectional samples to provide robust estimates.

Data and Methods

Sample

We used data from the ELSA. The ELSA is a longitudinal study sampled from the Health Survey for England (HSE), a large annual cross-sectional survey on the health of the population of England, and designed to collect longitudinal multidisciplinary data on health, social outcomes, wellbeing and economic circumstances from a representative sample of the English population aged 50 years and older living in private households, defined "core members" of the ELSA sample. The data also includes interviews with "young partners," who are individuals under the age of 50 whose partners are core members and "new partners" in the correct age range who entered relationships with core members after those members were recruited to ELSA. So far, eight waves have been issued. As the study progresses, the youngest groups are depleted. Therefore, refreshment samples of participants aged 50+ have been included at wave 3, wave 4, wave 6 and wave 7 of data collection.

DFLE estimates for 2002 are based on core-member respondents at wave 1 (N=11,391), of which 54.1% (6,205) are women. To estimate DFLE a decade after, we used data from wave 6 (2011/2012) and we intend to extend the analysis to the latest observation time point, i.e. 2016/2017, as soon as mortality data from ONS will be made available for England only.

At wave 6, we considered two alternative sample definitions. The first, which we refer to as the cross-sectional sample, consisted of core-member respondents of wave 6 with complete records on disability variables measured at this wave. This included also the refreshment samples from previous waves (i.e. waves 3, 4) who participated in the last wave and corresponded to 7,507 observations, of which 56% women. The second definition consisted of respondents selected at wave 1 and interviewed again at wave 6, whether they did or did not take part in the surveys in between. We refer to this as the longitudinal sample. It corresponded to 4,602 observations, of which 55.7 women.

Measures

Disability. Since the 1960s, disability has been increasingly interpreted through a disablement process, along which functional limitations expose to activity restrictions, with a hierarchy in the occurrence of restrictions (Nagi, 1965). As a result, disability has often been measured by activity limitations, most commonly using Activity of Daily Living (ADL) (Jagger, Arthur, Spiers, & Clarke, 2001; Lazaridis, Rudberg, Furner, & Cassel, 1994) or combining in hierarchical scales ADL and Instrumental Activity of Daily Living (IADL) (Spector & Fleishman, 1998) and mobility functions (Barberger-Gateau, Rainville, Letenneur, & Dartigues, 2000). In this work, we adopt a more recent and comprehensive approach to conceptualize disability, elaborated in 2001 by the WHO, the ICF (World Health Organization, 2011), which is currently the predominant theoretical model of disability (Jette, 2009). The novelty in the approach is that disability is interpreted not only as a medical condition, but also in terms of its social implications. The ICF views disability along a continuum, consisting of three main domains: “body-function and structure”, “activity limitations” and “participation restrictions”. The validity and applicability of the ICF to capture disability among the older population was tested in previous works, on which we rely for the selection and classification of the variables capturing each of the domains (Pongiglione, De Stavola, Kuper, & Ploubidis, 2016) (Pongiglione, Ploubidis, & De Stavola, 2017). In this setting, we add an extra criterion for the inclusion of items. Only items collected at each wave, from the first to the sixth, were included to measure disability. This corresponded to a battery of 42 items, sub-classified across the three domains, as follow. Body function and structure were measured by 12 variables including hypertension, arthritis, Parkinson, psychosocial problems, dementia, self-rated eyesight (3 items) and hearing, being troubled with pain, incontinence and depression. Some of these items are most commonly considered health conditions rather than disability. A previous study measured disability including and not including hypertension, arthritis, Parkinson, psychosocial problems and dementia among the impairment domain and found no difference (Pongiglione et al., 2016). We also performed sensitivity analysis excluding these items from the measurement of disability. Activity was measured by 19 variables consisting in 10 mobility functions such sitting for two hours, climbing stairs; 6 ADLs, i.e. dressing, walking across room, bathing, eating, getting in/out bed, toileting; being able to follow a conversation, walking for quarter of mile and quality of sleep. For participation, 11 variables were selected: 6 IADLs, i.e. preparing hot meal, using map, grocery shopping, making calls, doing housework, managing money; being member of any organization and doing any social activity; and limitations due to health in using transports and working (retirement and early retirement due to ill health). Disability classes were estimated for both cross-sectional and longitudinal samples at each wave to assess the validity of stationarity assumption of the Sullivan method (see next paragraph).

Mortality. Mortality rates were estimated using estimates of the English population and reported deaths in 2002 and in 2012, by sex and single year of age, obtained from the Office for National Statistics (ONS). Mortality rates were produced by 5-year age groups. A challenge related to the use of this source is that ONS mortality rates pertain to the total population, while disability prevalence refers to ELSA's sample, which does not include institutionalized individuals. An analysis of representativeness of mortality in ELSA was performed by computing the Standardised Mortality Ratio (SMR) between the ELSA mortality rates and the reference population mortality rates (i.e. English population aged 50 plus). We found that ELSA mortality converges to that of the general population over time (results available upon request).

The problem of combining national data on the general population (on mortality) with survey-based information on noninstitutionalized populations (on disability) is not new to this study, and it is particularly crucial for older populations (Cambois, Jagger, Nusselder, Van Oyen, & Robine, 2016; Pongiglione, De Stavola, & Ploubidis, 2015). A commonly applied option was proposed by Sullivan (Sullivan, 1971) and assumes that the entire population of health-related institutions have disability. In this study, no assumptions were made, thus implicitly assuming same prevalence among institutionalized and non-institutionalized populations. A study by Cambois and colleagues tested these different hypotheses (i.e. Sullivan hypothesis, hypothesis of same prevalence between household and institutionalized populations) and found that for advanced age groups the overestimation resulting from the Sullivan's hypothesis can be greater than the underestimation descending from the assumption of same prevalence in institutionalized and household populations (Cambois et al., 2016). We acknowledge this finding, although there is no guarantee that in our context the same result holds, and neither hypothesis can avoid bias completely.

Analysis

To measure disability according to the ICF theoretical framework and in order to categorize disability in classes of severity we used Latent Class Analysis (LCA). A previous study (Pongiglione et al., 2017), which estimated disability classes using our same sample (ELSA), identified four severity classes as the best classification of disability after comparing the performance of two to six-class disability measures. Hence, we estimated a categorical latent variable of disability with four classes at each of the eight ELSA waves. For binary items u_j (with $j = 1, 2..., 42$) and a categorical latent variable C with four classes (k = 1,...4), the marginal probability of observing the item u_j being equal to one is

$$\Pr(u_j = 1) = \sum_{k=1}^{4} \Pr(C = k) \Pr(u_j = 1|C = k) \quad (1)$$

Where the second part of Eq. 1, denotes the conditional probability of the item being equal to one given that the class is equal to k and Pr(C=k) is the marginal probability of the class being k. The model was fitted at each wave, for both the cross-sectional and longitudinal samples, separately for men and women.

To estimate disability classes, item non response was dealt with using Full Information Maximum Likelihood (FIML) in MPlus (version 8.1). FIML provide unbiased estimates in the presence of missing data under the MAR.

Disability-free life expectancy. DFLE was estimated using the Sullivan method (Sullivan, 1971). Sullivan's method relies on the assumption that a specific cohort observed at a certain age in a given year will be experiencing the same disability prevalence rates observed among the other age groups in the same year. Problems of under- or overestimation may occur when disability prevalence changes over time, although several studies demonstrated that Sullivan's method can be extended to estimate health expectancy without stationarity assumptions (Imai & Soneji, 2007; Mathers & Robine, 1997). To assess the plausibility of the stationarity assumption on disability, we estimated disability at each wave in order to assess whether the age-specific disability prevalence were stable across waves. However, this implicitly requires strong and untestable assumptions about health or disability transitions between assessment times, when collection intervals are long (Wolf & Gill, 2009). DFLE was estimated for each disability class, i.e. mild DFLE, moderate DFLE and severe DFLE. The prevalence of mild, moderate and severe disability was estimated in order to be mutually exclusive rather than cumulative, consequently disability-free years and years with disability sum up to TLE separately for each level of disability. For each class of disability, we also report the ratio of DFLE over TLE and express them as proportions. Finally, given that the Sullivan health expectancy is subject to random variation, 95% confidence intervals were calculated from the standard errors of the probability of each disability class (Jagger, Van Oyen, & Robine, 2014).

Results

Disability distribution across waves

Table 2 and Table 3 illustrate, respectively for men and women, the distribution of disability classes at wave 1 and wave 6 for cross-sectional and longitudinal samples, without standardizing for age. At wave 1, around 37% of women and 46% of men were classified as non-disabled and the most severe form of disability affected 12% of women and 9.5% of men. At wave 6, in the cross-sectional sample the percentages of respondents belonging to non-disabled group were larger than at wave 1 for women and smaller for men. When compared to proportions obtained from the longitudinal sample, cross-sectional percentages of non-disabled at wave 6 were larger both for males and females. This was most likely because of confounding by age, with members of the longitudinal sample older than members of the cross-sectional sample.

Disability-free life expectancy

In this section, we compare DFLE in 2002 and 2012, and estimates based on cross-sectional and longitudinal samples. Since the longitudinal sample consisted on a subsample of survivors interviewed at wave 1 and followed up to the sixth wave, we expected longitudinal estimates of DFLE to be higher (i.e. more years without disability) compared to cross-sectional ones. For each class of disability, we report the number of expected years with disability (Disability Life Expectancy (DLE)), which represents the absolute gap between DFLE and TLE, and proportional results for DFLE over TLE. This is shown in Table 4 and Table 5 respectively for men and women for the cross-sectional sample. Years lived with each level of disability are reported in 2002 and 2012, and the difference between the two periods (ΔDLE) corresponds to absolute compression if negative (i.e. fewer expected years with disability in 2012 compared to 2002), and absolute expansion if positive. Changes in the proportions of DFLE on TLE in 2002 and 2012 are also reported. Opposite to the differences in absolute values, the differences in proportional DFLE correspond to proportional compression in case of positive values (i.e. proportion of life without disability larger in 2012 compared to 2002) and to expansion for negative values. Among men, years of life with severe disability have slightly increased, and symmetrically proportions of severe DFLE have declined only marginally, especially at younger ages. Life expectancy with moderate disability has increased in absolute terms and declined as proportion of TLE; life expectancy with mild disability has increased in absolute terms (i.e. positive difference in DLE between

2012 and 2002), but its proportion on TLE has declined (i.e. positive difference in DFLE over TLE between 2012 and 2002). In general, however, absolute and proportional differences between 2002 and 2012 were small and confidence intervals overlapped. Among women the number of expected years with severe disability has slightly declined in 2012, but only by about 0.3 years, and the proportion of severe DFLE has increased. The opposite was observed for mild DLE, which has increased in absolute terms and as proportion of TLE (i.e. smaller proportion of life expectancy without mild disability). For moderate disability, changes varied across ages, with reduced years in disability and larger proportion of life free of disability at younger ages, and the opposite observed at older ages. As for men, overall, variations were quite small and in most cases, the confidence intervals overlapped. All combined, these results pointed at identifying a dynamic equilibrium for women, while men experienced a worse pattern than females, because their years with any level of disability increased, although only slightly, and proportions of life without disability increased only for mild disability.

Discussion

Our study adopted a comprehensive interpretation of disability, derived from the WHO's ICF framework, and used a multi-categorical classification of disability to study trends in DFLE by severity level over a decade. We also proposed possible explanations for the observed changes in DFLE by moving from the aggregate-level measure of health expectancy to an equivalent individual-level outcome, considering BMI and year of birth as explanatory factors for changes in YLD from 2004 to 2012.

Results were different for men and for women. While men experienced larger increases in life expectancy than women -and the phenomenon of men catching up with female life expectancy has been previously reported and recently confirmed in England and Wales (Bennett et al., 2015)- the increase in DFLE was very similar across genders. For men, severe DLE roughly stayed constant, while moderate DLE increased both in absolute and proportional terms. Women experienced proportional and absolute decline of severe DLE, while their mild DLE increased. When we compared results of cross-sectional and longitudinal samples at wave 6, we found the same direction of changes and similar estimates. The longitudinal sample performed slightly better, suggesting that the subset of survivors, consisting in the longitudinal sample, were healthier than the cross-sectional sample and therefore they both survived over the entire observation period and suffered less from disability.

Our work contribute to support the evidence that women are experiencing a compression of severe disability and expansion in milder levels, which corresponds to a general dynamic equilibrium. This is in line with what observed over the past two decades in the US (Freedman et al., 2016), and in England (Jagger et al., 2016). Our results complement the study by Jagger et al. (2016), and advance the understanding of current dynamics of healthy aging in England. In fact, Jagger and colleagues provided evidence on trajectories in health expectancy considering separately various health indicators, including disability (measured by ADLs and IADLs), and showed different paths depending on the dimension of health considered. This is extremely useful to address specific policies and intervene on the spheres of health that appear particularly at risk of deterioration. Given the complexity of the concept of disability, however, it is often difficult to measure it independently from other dimensions of health. Hence, assessing and combining results based on different measures of disability can bring further understanding on the process of healthy aging. Additionally, our study distinguished a more refined scale of severity, including also moderate levels. Results suggest that the main burden of disability in future years is likely to come from mild disability in women, and moderate disability in men. The identification of an intermediate grade of disability appears informative, especially in the comparison between men and women. With regard to gender differences, a critical aspect in our study is that estimates of DFLE are based on a disability measure that also includes some health conditions. Therefore, differences in diagnosis of specific health conditions between 2002 and 2012 might result in gender differences in disability measure. For this reason, we undertook a sensitivity analysis removing health condition from disability measure and found similar results to those produced including these items (results available upon request). This reassures that the influence of these variables was only modest and the gender gap that we observed was not (only) due to gender differences in prevalence and incidence of these conditions.

A possible interpretation of the worse trends in DFLE experienced by men compared to women is that one of the consequences of living longer is that they are exposed to the risk of deteriorating health for a longer time. It may be that men’s life expectancy is currently increasing because they are in the process of stop dying due to disability, and consequently living longer with disability. At the same time, women, who were already more resilient to disability, may be experiencing a shift from severe to milder forms of disability, possibly because of the success of preventive and curative medicine. In a previous study (Pongiglione et al., 2016), disability at baseline was found to be positively predictive of mortality observed over a decade with the association being stronger for men, especially in the very short terms (i.e. within two years) while the effect of disability on mortality experienced by men was found to converge to women's levels in the long term. This could mean that men become more resilient to disability the longer they survive, and therefore their life expectancy with disability is increasing relatively more than among women. Finally, we also explored whether changes in YLD between waves 2 and 6 were associated with year of birth and BMI at wave 2, and whether the two factors interacted with each other. While acknowledging that these findings are quite exploratory, they suggest an interactive role of year of birth and BMI in changes in YLD, such that high BMI is particularly detrimental for younger generations.

Some limitations affect this work and must be borne in mind when interpreting the results. First of all, the cross-sectional data for 2002 does not include those in institutions whereas the 2012 data to an extent does. To overcome this limitation, we performed a sensitivity analysis excluding institutionalized respondents at wave 6. Results based on this sample (upon request) were the same as when participants in institutions were included. Therefore, the ELSA samples selected for our analysis both at wave one and six are representative of non-institutionalized population. The second limitation, concerns BMI that was measured only at wave 2 and no information on onset or duration of overweight and obesity was considered. Younger cohorts have been found to become overweight much earlier in adulthood (Johnson et al., 2015; Li, Hardy, Kuh, Lo Conte, & Power, 2008) and this might explain why being overweight or obese was associated with increase in YLD for younger individuals. Another limitation comes from the fact that we dealt with non-extinct cohorts, and therefore incurred problems of censoring, which was assumed non-informative, and YLD was estimated based on very strong assumptions. Our work has also some unique strengths. The identification of four levels of disability allowed to capture finer differences in the diverging paths of DFLE between men and women. By identifying intermediate levels of disability we were able to describe the expansion of milder grades a step further, showing that men have experienced increasing level of moderate disability while women of milder forms. Another strength is that this study replicated the cross-sectional analyses on the longitudinal sample, allowing the comparison of results across two types of respondents, the former representative of the general English population aged 50+, the latter of survivors and as such presenting different probabilities of incurring disability. Therefore, it was not unexpected that the 2012 results on the longitudinal sample were slightly better than those from the cross-sectional data.

This study offers robust evidence on the features and directions of aging in contemporary England. All levels of disability life years have expanded, with the exception of severe disability for women, which stayed the same. This means that people with disability will need assistance for longer time and therefore the overall burden of disability on health system and families will increase. This is a very important finding, which would be ignored if focusing only on relative changes in DFLE. To conclude, at least two central messages must be taken from this work, which have important policy and research implications. (i) It is helpful to distinguish between milder and more severe levels of disability because their trends seem to be divergent. (ii) Although, this work did not show a causal effect, the evidence of a modifying effect of BMI and year of birth can be taken as a warning for closely monitoring BMI in younger generations and paying particular attention to avoiding an early onset of overweight and obesity.

References

Al Snih, S., Ottenbacher, K. J., Markides, K. S., Kuo, Y.-F., Eschbach, K., & Goodwin, J. S. (2007). The effect of obesity on disability vs mortality in older Americans. *Archives of internal medicine, 167*(8), 774-780. doi:10.1001/archinte.167.8.774

Barberger-Gateau, P., Rainville, C., Letenneur, L., & Dartigues, J.-F. (2000). A hierarchical model of domains of disablement in the elderly: a longitudinal approach. *Disability and rehabilitation, 22*(7), 308-317. doi:10.1080/ 096382800296665

Bebbington, A., Bone, M. R., Jagger, C., Morgan, K., & Nicolaas, G. (1995). Health Expectancy and Its Uses. In: HMSO.

Bebbington, A., & Darton, R. (1996). Healthy life expectancy in England and Wales: recent evidence.

Bennett, J. E., Li, G., Foreman, K., Best, N., Kontis, V., Pearson, C., . . . Ezzati, M. (2015). The future of life expectancy and life expectancy inequalities in England and Wales: Bayesian spatiotemporal forecasting. *The Lancet, 386*(9989), 163-170. doi:10.1016/S0140-6736(15)60296-3

Cambois, E., Jagger, C., Nusselder, W., Van Oyen, H., & Robine, J.-M. (2016). International Comparisons of Disability Prevalence Estimates: Impact of Accounting or Not Accounting for the Institutionalized Population. In *International Measurement of Disability* (pp. 207-229): Springer.

Crimmins, E. M., Zhang, Y., & Saito, Y. (2016). Trends over 4 decades in disability-free life expectancy in the United States. *American journal of public health, 106*(7), 1287-1293. doi:10.2105/AJPH.2016.303120

Donev, D., Zaletel-Kragelj, L., Bjegovic, V., & Burazeri, G. (2016). Measuring the Burden of Disease: Disability Adjusted Life Year (DALY). University of Ljubljana, Ljubljana, Slovenia, 2014. In.

Freedman, V. A., Wolf, D. A., & Spillman, B. C. (2016). Disability-free life expectancy over 30 years: a growing female disadvantage in the US population. *American journal of public health, 106*(6), 1079-1085. doi:10.2105/AJPH.2016.303089

Fries, J. F. (1980). Aging, natural death, and the compression of morbidity. *N Engl J Med, 303*(3), 130-135. doi:10.1056/nejm198007173030304

Gruenberg, E. M. (1977). The failures of success. *Milbank Mem Fund Q Health Soc, 55*(1), 3-24.

Imai, K., & Soneji, S. (2007). On the estimation of disability-free life expectancy: Sullivan's method and its extension. *Journal of the American Statistical Association, 102*(480), 1199-1211. doi:10.1198/016214507000000040

Jagger, C., Arthur, A. J., Spiers, N. A., & Clarke, M. (2001). Patterns of onset of disability in activities of daily living with age. *Journal of the American Geriatrics Society, 49*(4), 404-409. doi:10.1046/j.1532-5415.2001.49083.x

Jagger, C., Matthews, F. E., Wohland, P., Fouweather, T., Stephan, B. C., Robinson, L., . . . Collaboration, A. (2016). A comparison of health expectancies over two decades in England: results of the Cognitive Function and Ageing Study I and II. *The Lancet, 387*(10020), 779-786. doi:10.1016/S0140-6736(15)00947-2

Jagger, C., Van Oyen, H., & Robine, J.-M. (2014). Health expectancy calculation by the Sullivan method: a practical guide. *Institute for Ageing, Newcastle University, Newcastle upon Tyne, United Kingdom*.

Jette, A. M. (2009). Toward a common language of disablement. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences, 64*(11), 1165-1168. doi:10.1093/gerona/glp093

Johnson, W., Li, L., Kuh, D., & Hardy, R. (2015). How has the age-related process of overweight or obesity development changed over time? Co-ordinated analyses of individual participant data from five United Kingdom birth cohorts. *PLoS medicine, 12*(5), e1001828. doi:10.1371/journal.pmed.1001828

Keyes, K. M., Utz, R. L., Robinson, W., & Li, G. (2010). What is a cohort effect? Comparison of three statistical methods for modeling cohort effects in obesity prevalence in the United States, 1971–2006. *Social science & medicine, 70*(7), 1100-1108. doi:10.1016/j.socscimed.2009.12.018

Kramer, M. (1980). The rising pandemic of mental disorders and associated chronic diseases and disabilities. *Acta Psychiatrica Scandinavica, 62*(S285), 382-397. doi:10.1111/j.1600-0447.1980.tb07714.x

Lazaridis, E. N., Rudberg, M. A., Furner, S. E., & Cassel, C. K. (1994). Do activities of daily living have a hierarchical structure? An analysis using the longitudinal study of aging. *Journal of gerontology, 49*(2), M47-M51. doi:10.1093/geronj/49.2.M47

Li, L., Hardy, R., Kuh, D., Lo Conte, R., & Power, C. (2008). Child-to-adult body mass index and height trajectories: a comparison of 2 British birth cohorts. *American Journal of Epidemiology, 168*(9), 1008-1015. doi:10.1093/aje/kwn227

Manton, K. G. (1982). Changing concepts of morbidity and mortality in the elderly population. *Milbank Mem Fund Q Health Soc, 60*(2), 183-244.

Mathers, C. D., & Robine, J.-M. (1997). How good is Sullivan's method for monitoring changes in population health expectancies? *Journal of Epidemiology & Community Health, 51*(1), 80-86. doi:10.1136/jech.51.1.80

Nagi, S. Z. (1965). Some conceptual issues in disability and rehabilitation. *Sociology and rehabilitation*.

Omran, A. R. (2005). The Epidemiologic Transition: A Theory of the Epidemiology of Population Change. *The Milbank Quarterly, 83*(4), 731-757. doi:10.1111/j.1468-0009.2005.00398.x

Pongiglione, B., De Stavola, B. L., Kuper, H., & Ploubidis, G. B. (2016). Disability and all-cause mortality in the older population: evidence from the English Longitudinal Study of Ageing. *European journal of epidemiology, 31*(8), 735-746. doi:10.1007/s10654-016-0160-8

Pongiglione, B., De Stavola, B. L., & Ploubidis, G. B. (2015). A systematic literature review of studies analyzing inequalities in health expectancy among the older population. *PloS one, 10*(6), e0130747. doi:10.1371/journal.pone.0130747

Pongiglione, B., Ploubidis, G. B., & De Stavola, B. L. (2017). Levels of disability in the older population of England: Comparing binary and ordinal classifications. *Disability and health journal, 10*(4), 509-517. doi:10.1016/j.dhjo.2017.01.005

Reynolds, S. L., Saito, Y., & Crimmins, E. M. (2005). The impact of obesity on active life expectancy in older American men and women. *The Gerontologist, 45*(4), 438-444. doi:10.1093/geront/45.4.438

Robine, Jagger, C., Mathers, C. D., Crimmins, E. M., & Suzman, R. M. (2003). *Determining health expectancies*: John Wiley & Sons.

Robine, & Michel, J.-P. (2004). Looking Forward to a General Theory on Population Aging. *The Journals of Gerontology: Series A, 59*(6), M590-M597. doi:10.1093/gerona/59.6.M590

Robine, & Romieu, I. (1998). Health expectancies in the European Union: Progress achieved. *REVES Paper No, 319*.

Rushby, J. F., & Hanson, K. (2001). Calculating and presenting disability adjusted life years (DALYs) in cost-effectiveness analysis. *Health policy and planning, 16*(3), 326-331. doi:10.1093/heapol/16.3.326

Sanders, B. S. (1964). Measuring Community Health Levels. *American Journal of Public Health and the Nations Health, 54*(7), 1063-1070. doi:10.2105/ajph.54.7.1063

Spector, W. D., & Fleishman, J. A. (1998). Combining activities of daily living with instrumental activities of daily living to measure functional disability. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 53*(1), S46-S57. doi:10.1093/geronb/53B.1.S46

Sullivan, D. F. (1971). A single index of mortality and morbidity. *HSMHA Health Rep, 86*(4), 347-354.

Sundberg, L., Agahi, N., Fritzell, J., & Fors, S. (2016). Trends in health expectancies among the oldest old in Sweden, 1992–2011. *The European Journal of Public Health, 26*(6), 1069-1074. doi:10.1093/eurpub/ckw066

Wolf, D. A., & Gill, T. M. (2009). Modeling transition rates using panel current-status data: How serious is the bias? *Demography, 46*(2), 371-386. doi:10.1353/dem.0.0057

World Health Organization. (2011). World report on disability 2011.

List of Tables and Figures

Table 1

Study	Period	Where	Type of HE	Age group	Conclusions
Bebbington [35](1988)	1976, 1981, 1985	England and Wales	LLI	All ages	Expansion
Bone et al.	1976-1994	UK	Handicap	Birth and 65 yrs	Dynamic equilibrium
Bebbington and Darton [37](1996)	1980-1994	England and Wales	LLI, ADL	All ages	Dynamic equilibrium
Kelly et al	1980-1996	Great Britain	SRH and LLI	Birth and 65 yrs	Expansion
Jagger et al. (2016)	1991-2011	England	ADL and IADL	65+ yrs	Dynamic equilibrium
Jagger (2015)	2000/02-2009/11	UK	SRH and LLI	Birth, 65 and 85 yrs	Expansion

yrs=years; HE=Health Expectancy; LLI=limiting long-standing illness; SRH=self-rated health Findings are general conclusions which not consider differences between age groups, genders and severity levels of health indicators.

Table 2

Disability Levels	Wave 1		Wave 6			
	Cross-sectional= Longitudinal		Cross-sectional		Longitudinal	
	n	**%**	**n**	**%**	**n**	**%**
Non-disabled	2070	46.4	1529	45.9	875	43.0
Low disabled	1138	25.5	815	24.5	500	24.6
Mildly disabled	831	18.6	670	20.1	455	22.3
Severely disabled	423	9.5	320	9.6	207	10.2
Total	4,462	100	3,334	100	2037	100

Table 3

Disability Levels	Wave 1		Wave 6			
	Cross-sectional= Longitudinal		Cross-sectional		Longitudinal	
	n	**%**	**n**	**%**	**n**	**%**
Non-disabled	1931	36.7	1653	396	924	36.0
Low disabled	1266	24.0	1030	247	639	24.9
Mildly disabled	1439	27.3	1040	249	721	28.1
Severely disabled	633	12.0	450	108	281	11.0
Total	5,269	100	4,173	100	2,565	100

Table 4

Age	TLE			Severe-disability LE				Moderate-disability LE				Mild-disability LE			
	2002	2012	Δ TLE[a]	DLE 2002	DLE 2012	Δ DLE[b]	Δ %DFLE[c]	DLE 2002	DLE 2012	Δ DLE[b]	Δ %DFLE[c]	DLE 2002	DLE 2012	Δ DLE[b]	Δ %DFLE[c]
50	28.9	31.7	2.8	3	3.3	0.3	-0.1	5.6	6.4	0.8	-0.6	7.3	7.8	0.5	0.7
				(2.7; 3.2)	(2.9; 3.6)	(-0.3;0.9)	(-2.2;2)	(5.3; 6)	(5.9; 6.8)	(0;1.6)	(-3.2;2)	(6.9; 7.6)	(7.2; 8.3)	(-0.4;1.4)	(-2.2;3.6)
55	24.5	27.2	2.7	2.8	3.1	0.3	0	5.2	6	0.8	-0.6	6	6.3	0.3	1.4
				(2.5; 3)	(2.7; 3.4)	(-0.3;0.9)	(-2.3;2.3)	(4.9; 5.6)	(5.6; 6.4)	(0;1.6)	(-3.5;2.3)	(5.7; 6.4)	(5.9; 6.7)	(-0.5;1.1)	(-1.5;4.3)
60	20.3	23	2.7	2.5	2.8	0.3	0.1	4.8	5.5	0.7	-0.6	4.9	5.3	0.4	0.9
				(2.3; 2.8)	(2.5; 3.2)	(-0.3;0.9)	(-2.6;2.8)	(4.4; 5.1)	(5.1; 5.9)	(0;1.4)	(-4;2.8)	(4.5; 5.2)	(4.9; 5.7)	(-0.3;1.1)	(-2.4;4.2)
65	16.5	19	2.5	2.1	2.7	0.6	-1.2	4.2	5	0.8	-0.6	4	4.3	0.3	1.6
				(1.9; 2.4)	(2.3; 3)	(0;1.2)	(-4.5;2.1)	(3.9; 4.6)	(4.6; 5.4)	(0.1;1.5)	(-4.7;3.5)	(3.7; 4.3)	(3.9; 4.6)	(-0.4;1)	(-2.2;5.4)
70	13	15.2	2.2	1.9	2.5	0.6	-1.9	3.6	4.3	0.7	-0.5	3.1	3.2	0.1	2.7
				(1.6; 2.1)	(2.2; 2.8)	(0;1.2)	(-6.1;2.3)	(3.3; 4)	(3.9; 4.7)	(0;1.4)	(-5.6;4.6)	(2.8; 3.3)	(2.8; 3.5)	(-0.5;0.7)	(-1.9;7.3)
75	10	11.9	1.9	1.8	2.2	0.4	-0.3	2.9	3.6	0.7	-1.9	2.2	2.5	0.3	0.6
				(1.6; 2.1)	(1.9; 2.6)	(-0.2;1)	(-6.1;5.5)	(2.5; 3.2)	(3.2; 4)	(0;1.4)	(-8.6;4.8)	(1.9; 2.5)	(2.2; 2.9)	(-0.3;0.9)	(-5.3;6.5)
80	7.7	9	1.3	1.8	2.1	0.3	0.9	2.3	3	0.7	-3.3	1.6	1.6	0	3.7
				(1.5; 2.1)	(1.7; 2.5)	(-0.4;1)	(-7.9;9.7)	(2; 2.7)	(2.6; 3.5)	(-0.1;1.5)	(-13;6.4)	(1.3; 2)	(1.2; 2)	(-0.7;0.7)	(-4.5;11.9)

Notes: TLE=Total Life Expectancy; DLE=Disability Life Expectancy; DFLE=Disability Free Life Expectancy.
95% confidence intervals in brackets ()

[a] $\Delta TLE = TLE_{2012} - TLE_{2002}$

[b] $\Delta DLE = DLE_{2012} - DLE_{2002}$

[c] $\Delta\%DFLE = (DFLE_{2012}/TLE_{2012}) - (DFLE_{2002}/TLE_{2002})$

Table 5

Age	TLE			Severe-disability LE				Moderate-disability LE				Mild-disability LE			
	2002	2012	Δ TLE[a]	DLE 2002	DLE 2012	Δ DLE[b]	Δ %DFLE[c]	DLE 2002	DLE 2012	Δ DLE[b]	Δ %DFLE[c]	DLE 2002	DLE 2012	Δ DLE[b]	Δ %DFLE[c]
50	32.5	34.6	2.1	4.5	4.2	-0.3	1.6	9.4	9.1	-0.3	2.7	7.5	8.2	0.7	-0.6
				(4.2; 4.8)	(3.8; 4.6)	(-1;0.4)	(-0.5;3.7)	(9; 9.9)	(8.6; 9.6)	(-1.2;0.6)	(0;5.4)	(7.1; 7.9)	(7.7; 8.7)	(-0.2;1.6)	(-3.1;1.9)
55	28	30	2	4.3	4.1	-0.2	1.9	8.7	8.5	-0.2	2.8	6.1	7	0.9	-1.4
				(4; 4.7)	(3.7; 4.4)	(-0.9;0.5)	(-0.5;4.3)	(8.3; 9.1)	(8; 8.9)	(-1.1;0.7)	(-0.2;5.8)	(5.8; 6.5)	(6.6; 7.4)	(0.1;1.7)	(-4;1.2)
60	23.6	25.5	1.9	4	3.7	-0.3	2.3	7.8	7.9	0.1	2.2	4.9	5.7	0.8	-1.6
				(3.7; 4.3)	(3.4; 4.1)	(-1;0.4)	(-0.5;5.1)	(7.4; 8.2)	(7.4; 8.3)	(-0.7;0.9)	(-1.2;5.6)	(4.6; 5.2)	(5.3; 6.1)	(0.1;1.5)	(-4.5;1.3)
65	19.4	21.2	1.8	3.7	3.5	-0.2	2.8	6.9	7.1	0.2	1.8	3.8	4.6	0.8	-2.2
				(3.4; 4)	(3.1; 3.8)	(-0.9;0.5)	(-0.5;6.1)	(6.5; 7.2)	(6.7; 7.6)	(-0.6;1)	(-2.2;5.8)	(3.5; 4.1)	(4.3; 5)	(0.1;1.5)	(-5.5;1.1)
70	15.5	17.1	1.6	3.4	3.2	-0.2	3.4	5.9	6.3	0.4	1.7	2.8	3.5	0.7	-2.5
				(3.1; 3.7)	(2.8; 3.6)	(-0.9;0.5)	(-0.8;7.6)	(5.6; 6.3)	(5.8; 6.7)	(-0.4;1.2)	(-3.2;6.6)	(2.5; 3.1)	(3.2; 3.9)	(0.1;1.3)	(-6.4;1.4)
75	12	13.4	1.4	3	2.9	-0.1	3.2	4.7	5.4	0.7	-1.3	2.2	2.5	0.3	-0.4
				(2.7; 3.3)	(2.6; 3.3)	(-0.8;0.6)	(-2.3;8.7)	(4.3; 5)	(5; 5.8)	(-0.1;1.5)	(-7.6;5)	(1.9; 2.5)	(2.2; 2.8)	(-0.3;0.9)	(-5.3;4.5)
80	9	10	1	2.7	2.7	0	3.5	3.5	4.3	0.8	-4.6	1.6	1.6	0	1.9
				(2.4; 3.1)	(2.3; 3.1)	(-0.8;0.8)	(-4.4;11.4)	(3.1; 3.9)	(3.9; 4.8)	(0;1.6)	(-13.2;4)	(1.3; 1.8)	(1.2; 1.9)	(-0.6;0.6)	(-4.6;8.4)

Notes: TLE=Total Life Expectancy; DLE=Disability Life Expectancy; DFLE=Disability Free Life Expectancy.

95% confidence intervals in brackets ()

[a] $\Delta TLE = TLE_{2012} - TLE_{2002}$

[b] $\Delta DLE = DLE_{2012} - DLE_{2002}$

[c] $\Delta\%DFLE = (DFLE_{2012}/TLE_{2012}) - (DFLE_{2002}/TLE_{2002})$