# Beyond Differences in Means: Rising Mortality Stratification among Income Groups in Finland, 1996-2014

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Abstract

The study of the mortality differences in social groups has traditionally focused on factors such as life expectancy and mortality rates. These indices can give us insights into how social characteristics is linked with mortality. But more insights can be gained by examining differences in age-at-death distributions between social groups. Here we measure the degree of overlap in the age-at-death distributions – mortality stratification – to capture important between-group differences that conventional life expectancy comparisons miss. This stratification can reveal the extent to which the two groups experience unique mortality regimes and experience of social lives. However, mortality stratification, and its relationship with life expectancies, is not well studied. We focus on five income groups in Finland, conditional on surviving to 30 and based on the Finnish registry data. We find that both stratification and difference in life expectancies in these groups increased substantially from 1996 to 2005. In more recent years, the difference in life expectancies declined, whereas stratification stagnated. This could be explained by the increase in lifespan standard deviation among the lowest income group. Our decomposition analyses suggest that the most effective way to reduce mortality stratification is to reduce the low income group's deaths in ages between 50 and 74. Because mortality stratification reflects differences in both life expectancy and age-at-death variability, it provides a useful summary measure of mortality differences between social groups.

*Keywords:* mortality stratification, income, between-group difference, Finland

**Beyond Differences in Means: Rising Mortality Stratification among Income Groups in Finland, 1996-2014**

A socioeconomic gradient in mortality has been well established: People with higher socioeconomic status (SES) outlive those with lower SES on average. There has been mounting evidence of mortality differentials among people with different income levels (e.g., Chetty et al., 2016; Kaplan et al., 1996), occupation (e.g., Hayward et al., 1989; van Raalte, Martikainen, & Myrskylä, 2014), and educational attainment (Montez et al., 2011; Sasson, 2016; Sasson & Hayward, 2019). Research to date on has focused on comparison in age-standardized mortality rates (e.g., Mackenbach et al., 2003, 2018), or group means, i.e., life expectancies (e.g., Brønnum-Hansen & Baadsgaard, 2012; Chetty et al., 2016). Based on period life tables, life expectancy is the average age a hypothetical cohort of newborns are expected to live given the current conditions. Larger difference in life expectancy indicates larger difference in length-of-life between SES groups *on average*. Such comparison based on mean values, however, may fail to capture other important dimensions of between-group differences (van Raalte, Sasson, & Martikainen, 2018).

One extreme example that may help elucidate this is when two age-at-death distributions have the same mean but have different levels of dispersion or variation. This means that age at death is more dispersed or variable for one group than for another. A simple comparison between means would lead to a flawed or partial conclusion that there is no difference in mortality between the two groups-. Thus, a more comprehensive investigation into between-group differences in mortality is needed.

Besides difference in means, we propose to measure another dimension of between-social group differences, the degree of non-overlap in the area of two distributions, which is referred to as stratification (Zhou, 2012; Zhou & Wodtke, 2019). Essentially, mortality stratification captures the extent to which the two groups experience divergent mortality regimes. We can quantify to what extent social groups are stratified based on their age-at-death distributions. The more overlap two age-at-death distributions have, the less they are stratified. There is a large literature on lifespan inequality, which measures to what extent individuals' ages at death are dispersed within a group. Existing lifespan inequality measures such as standard deviation, Gini coefficient, and Theil index have been widely used in mortality inequality research (Edwards & Tuljapurkar, 2005; van Raalte & Caswell, 2013). Furthermore, lifespan inequality is usually negatively correlated with life expectancy (Colchero et al., 2016; Smits & Monden, 2009; Vaupel, Zhang, & van Raalte, 2011). Mortality stratification between two social groups is conceptually different from the difference in life expectancy or lifespan inequality between the same two groups, but it relies on the levels of the latter two.

< Fig. 1>

To further demonstrate the conceptual differences and possible links between stratification and inequality, we adapt Zhou & Wodtke's (2019) hypothetical scenarios to mortality. Fig. 1 shows age-at-death distributions for different scenarios. In both cases A and B, the life expectancies of the two social groups are 70 (left) and 75 (right), thus the difference in life expectancy between the two groups is 5 years. The two groups in A have low lifespan inequalities and the two groups in B have high lifespan inequality, so the two cases have different stratification levels. Case A represents moderate mortality stratification, whereas case B has low stratification. Likewise, although the two social groups in C and D have the same difference in life expectancy, 10 years, C represents a higher level of mortality stratification due to low lifespan inequality. Examining vertically, from A to C or from B to D, lifespan inequalities of the two groups are the same, but as the difference in life expectancy increases also mortality stratification increases. Therefore, mortality stratification is affected by both differences in life expectancy and lifespan inequality.

Our stylized examples suggest uncertain relationships between mortality stratification and the other two types of between-group mortality differences. Changes in these measures are also sensitive to mortality changes at different locations (i.e. ages) of the distribution, and over time they may produce different or even conflicting insight on mortality trends (Zhou & Wodtke, 2019). For instance, if the richest people were to live longer, or the poorest people were to live shorter, differences in life expectancy and lifespan inequality would increase, while the level of mortality stratification would remain stable.

The conceptual and operational distinctions between mortality stratification and other between-group measures entail a comprehensive investigation of past trends of mortality stratification. In this article, we take advantage of the newly-released, large-scale, and high-quality Finnish registry data. We will show the observed trends of mortality stratification and differences in life expectancy and lifespan inequality of for the lowest and highest 20% income groups over the period of 1996 to 2014. To better understand the relationship between mortality stratification and differences in life expectancy, we will present results of counterfactual analysis where differences in life expectancy are fixed at the 1996 levels. We will then turn on our analysis to age decomposition and identify the ages that are mainly responsible for the observed levels and changes in mortality stratification.

## Methods

### Data

Subsequent analyses are based on the Finnish registry data, in which death registry is linked to income data from Finnish Tax Administration and the National Social Insurance Institution at individual level. Thanks to the high quality and rarity of such data format, the Finnish administrative data have been extensively used for studies in inequalities in mortality (e.g., Hoffmann et al., 2019; van Raalte et al., 2014, 2018). It allows us to situate our findings of mortality stratification in the broader context of previous work.

We use household disposable income per unit to classify individuals into five income quintiles within each year, sex, and age group. Death counts and exposure are calculated afterwards. The original datasets cover the years from 1996 to 2014[1] and age is formatted as five-year age group (30-34 to 95 + ). We use two-dimensional penalized composite link model to ungroup and smooth the rates. This includes two steps. First, for each year, five-year age group is ungrouped into single-year ages using penalized composite link model. Second, death counts and exposures are smoothed across age and period with P-splines. See Rizzi, Gampe, & Eilers (2015) and Currie, Durban, & Eilers (2004) for more details about the methods. We choose to present the results using smoothed data for the purpose of reducing the effects of unstable counts or rates. The overall trends of all indices using unsmoothed data are generally the same.

We use income, instead of occupation or educational attainment, to classify people because economic condition may be more related to people's health than education or occupation. Recent research shows that the net effect of income is much larger than that of education or occupation on mortality in Finland (Hoffmann et al., 2019). Another advantage is that income is a continuous variable, so the proportion of each category is invariant across time (Tarkiainen et al., 2012). Occupation or education may have gone through substantial compositional change over time, and thus makes it difficult to analyze the time trend. For instance, high school degree thirty years ago may actually be equivalent to college degree today. Period data may thus be subject to selection problem.

Over the period between 1996 and 2014, life expectancy of each income quintile has been increasing steadily. For lifespan inequality, in contrast to the decreasing trend among the upper four quintiles, there has been an increasing trend in the lowest income group.

[1] Results in this manuscript is based on data from 1996 to 2014. We are harmonizing and updating our data to 2017, which will be presented at PAA 2020.

Similar results have been reported in prior research (van Raalte et al., 2018). See Fig. A1 in appendix for the details.

**Measurements**

We propose to measure mortality stratification between two social groups by the proportion of non-overlapping area over total area of two age-at-death distributions. This measure is known as Wave Hedges distance in the literature of statistics and relevant fields such as information theory (Cha, 2007). The mortality stratification index (*S*) between two groups is expressed as follows.

$$S_{ij} = 1 - \frac{\int_{\alpha}^{\omega} \min\{d_i(x), d_j(x)\}dx}{\int_{\alpha}^{\omega} \max\{d_i(x), d_j(x)\}dx} \quad (1)$$

where $\alpha$ is the starting age, in our case, 30. We chose 30 as our starting age because some people are still in college and not in the labor market yet. $\omega$ is the maximum lifespan of the population. In our case, the last interval, 110+, is open-ended. $d_i(x)$ and $d_j(x)$ are age-at-death distributions for group *i* and group *j*, separately. *S* reaches the maximum value of 1 when the two density functions have no overlap (maximum stratification). *S* reaches the minimum value of 0 when the two density functions are the same and overlap perfectly (no stratification). From 0 to 1, larger *S* means higher stratification. When we have $k$ groups where $k$ is larger than 2, the overall stratification level can be calculated as the weighted average of $S_{i,j}$:

$$S_{total} = \sum_{i=1}^{k}\sum_{j=1}^{k} w_{ij}S_{ij} \quad (2)$$

The weights $w_{ij}$ are determined by group sizes. It is expressed as follows:

$$w_{ij} = \frac{n_i n_j}{\sum_{i=1}^{k}\sum_{j=1}^{k} n_i n_j} \quad (3)$$

where $n_i$ is the group size of group *i* and $n_j$ is the group size of group *j*.

In fact, there are many other indicators that measure the distance or similarity between distributions. Some have been used in mortality studies. For instance, Kullback–Leibler divergence (KLD) has been used to compared the distance between age-at-death distributions of certain population subgroups (Sasson, 2016) or countries (Edwards & Tuljapurkar, 2005). Different measures capture different dimensions of statistical distance, and have different properties. The stratification measure (or Wave Hedges distance) is distinct and in some cases preferable to the KLD in three ways. First, it is a symmetric measure, whereas some other indices such as KLD are asymmetric. The KLD from group A to group B is different from the KLD from group B to group A. Second, it is easier to interpret than other indices. Larger proportion of non-overlapping means greater likelihood that a random individual of the group with lower life expectancy will die earlier than another random individual from the group with higher life expectancy. Third, as a non-parametric index, the value of stratification is not dependent on actual values of age at death but on the relative positions of the two distributions. A monotonic transformation of age at death of all individuals will not change the value of stratification. Hence, stratification is comparable across different mortality contexts. For instance, sex stratification in lifespan a hundred years ago is comparable to sex stratification today.

We compare mortality stratification between income groups with (1) difference in life expectancy and (2) difference in lifespan inequality. We calculate absolute difference[2] in life expectancy at age 30 between high and low income groups. Lifespan inequality is measured by standard deviation, and likewise, absolute difference in lifespan inequality is calculated afterwards. For multiple-group cases, we take the weighted average of difference in life expectancy and difference in lifespan inequality.

**Counterfactual analysis**

[2] Alternatively, we also used relative difference, life expectancy ratio. The trends and other results are very similar to those yielded by absolute difference. Thus, we only show the results of absolute difference here.

For a deeper understanding of the distinction between differences in life expectancy and mortality stratification, counterfactual analysis is conducted to examine one question: what would the trend of mortality stratification be if absolute or relative differences in means had been kept constant since 1996? We take the lowest and highest 20% income groups as an example. To answer this question, we keep the age-specific mortality rates of the highest 20% income group as the observed values, whereas replace the mortality rates of the lowest 20% income group in different ways. Two "naïve" scenarios are tested. First, consider the case in which mortality is reduced at all ages equally, i.e. same rate of mortality improvement over age. We multiply the observed mortality rates of the low income group by the same rate of mortality improvement so that the new difference in life expectancy between the low and high income groups is the same as that of 1996. Second, consider the scenario in which mortality improvements prioritize the youngest ages, i.e. saving lives of the youngest first. We start replacing the mortality rates of the lowest 20% income group by the corresponding rates of the highest income 20% from the youngest age group to older age groups until absolute or relative difference of that year is the same as that of 1996 year's. After this process, we recalculate trends of mortality stratification in accordance to the two counterfactual scenarios. Of course, there are infinite ways to reduce mortality of the low income group. Insights can still be gained from our scenarios.

**Age decomposition of stratification and changes in stratification**

We can rewrite equation (1) into the following equation so that it becomes a sum of decomposable age components.

$$S_{ij} = \frac{\int_{\alpha}^{\omega}\left(\max\{d_i(x), d_j(x)\} - \min\{d_i(x), d_j(x)\}\right)dx}{\int_{\alpha}^{\omega}\max\{d_i(x), d_j(x)\}dx} \qquad (7)$$

Likewise, change in $S_{ij}$ ($\Delta S_{ij}$) between two time points can also be decomposed into age components by subtracting $S_{ij}^{t_2}$ by $S_{ij}^{t_1}$. In this way, we are able to disentangle the ages that contributed most to (1) lifespan stratification in a certain year and (2) changes in lifespan stratification between two years.

## Results

### Observed trends of mortality stratification and its relationships with other dimensions of between-group differences in mortality

<Fig. 2>

Fig. 2 reports trends of average mortality stratification and average differences in life expectancy and lifespan inequality (measured by standard deviation) among the five income groups between 1996 and 2014. Overall, between-group differences in age at death increased sharply among income quintile groups for both men and women (panel A). Among women, mortality stratification increased by 73%, from 0.11 in 1996 to 0.18 in 2014. Likewise, male mortality stratification increased by 29%, from 0.20 to 0.26. Similarly, differences in life expectancy also increased substantially for both men and women over the years we studied. It increased by 57% for women, from 1.67 to 2.61, and 31% for men, from 3.51 to 4.60 in the period 1996-2014. Average difference in lifespan inequality increased by 84% for women, from 0.88 to 1.62, and 33% for men, from 1.35 to 1.80.

There are differences between sexes and between measures in the overall trends. Men experienced most of the changes in earlier years, and stratification has declined in recent years, while women experienced continuous changes throughout the period. In the meanwhile, we find very similar sex patterns for differences in life expectancy. As for lifespan inequality, apart from similar increasing trends like stratification in the first decade, both sexes experienced stagnation and even clear decline in recent years.

Besides sex differences in the trends of mortality stratification and other measures, differences in the three measures are noteworthy. One insight is that life expectancy and lifespan inequality give us more optimistic results. Particularly for women, with difference in life expectancy being nearly constant and difference in lifespan inequality falling, mortality stratification, however, increased. This suggests that the narrowing gap in life expectancy or lifespan inequality is not necessarily translated into decreasing mortality stratification.

<Fig. 3 >

Different patterns in different measures can be reflected in the two panels in Fig. 3. In general, the association plots suggest a clear positive association between stratification and the other two types of between-group differences. Higher mortality stratification is perceived when difference in life expectancy is also higher. This association is stronger among men than among women (Pearson correlation coefficient are 0.981 and 0.941 for men and women, respectively). For women, when difference in life expectancy is between 2.3 and 2.5 in the second half of the period, stratification varies between 0.14 and 0.18, a relatively larger range. This again suggests again that mortality stratification captures between-group differences in mortality that are not captured by mean-based difference measures. Larger difference in lifespan inequality is associated with higher stratification, but the association nearly disappeared for females once the difference in lifespan inequality is above 1.7. In the most recent four years, stratification increased whereas difference in lifespan inequality decreased for females.

<Fig. 4>

Besides the association between observed values of the indices, the relationship between mortality stratification and other dimensions of between-group difference can be better understood by a graph reporting association between change in stratification and change in other measures in two consecutive years, i.e. first differences. Positive association means the two measures increase or decrease at the same time. In Fig. 4, we show the corresponding pairwise (for every two of the five income groups) associations between yearly change in stratification and yearly change in the other two indices. In most years, as we expected, stratification and difference in life expectancy both increased or decreased. But exceptions do exist. The percentage of points in the second quadrant (upper left) is 11.94%. This indicates stratification increased when difference in life expectancy decreased in some recent years, especially for women. In most cases, stratification and difference in life expectancy both increase (59.44%) or both decrease (26.39%). Only 2.22% of the points are in the bottom right quadrant. Change in stratification is more consistent with change in difference in life expectancy for men than for women.

Panel B suggests that change in stratification is much less associated with change in difference in lifespan inequality. Pearson correlation coefficients for Panel A and B are 0.553 and 0.769, respectively. Although in most years stratification changed in lockstep with difference in lifespan inequality (53.1% and 11.4% for upper right and bottom left quadrant, respectively), in 18.3% of cases we find stratification increased but the gap in lifespan inequality narrowed and in 17.2% of the cases stratification decreased while difference in lifespan inequality increased. It is found that in both panels, especially Panel A, there are more points in the upper left part than in the bottom right part, suggesting that in the Finnish case, stratification inclines to increase when difference in life expectancy or lifespan inequality decreases than the other way around.

**Changing mortality stratification between the rich and the poor**

<Fig. 5 >

For a detailed understanding of temporal changes in mortality, in Fig. 5 we present age-at-death distributions of the lowest and the highest 20% income groups at the beginning and the end of the period. Vertical dashed lines represent the life expectancy for the two distributions. For men, mortality stratification was already high in years between 1996 and 2000, as the non-overlapping area is large (37.7%). During the same time, female mortality stratification is much lower. Also, differences in life expectancy and lifespan inequality are larger among men than among women.

For years between 2010 and 2014, we see a larger divergence in the distributions. For both sexes, age-at-death distributions of the rich have shifted to the right, and became more compressed. The distribution of the poor has also shifted to older ages, but at a slower pace. For women, there is almost no difference in modal age at death for 2010-2014 (both around 90). However, we find a little hump of distribution of the poor at middle ages, leading to the poor group's larger lifespan inequality and lower life expectancy. The hump is even bigger in the distribution of poor males. Unlike the case for females, the gap in modes still exists for males over the years of 2010 to 2014. Slower shifting process (reflected in lower mean or mode) and greater variation due to excessive deaths at middle ages together contribute to the rising mortality stratification between male income groups. In the last part of this section, we will report results of age decomposition analysis to better account for the hump we show here.

**Counterfactual trends of mortality stratification**

<Fig. 6 >

Fig. 6 shows the observed the trends of mortality stratification and difference in life expectancy between the lowest and the highest 20% income groups. Overall, the trends for males between the two groups are similar to the trends of average results of all the five income groups. Over the first one and a half decades, male mortality stratification and difference in life expectancy between the lowest and highest income groups increased steadily. Stratification increased by nearly 34% from 0.36 in 1996 to 0.46 in 2010. Note that 0.46 is a high value for stratification. It means the two age-at-death distributions only have 54% overlap area. Thus, mortality stratification is particularly high in this year. Over the same period, difference in life expectancy also rose steadily, but it started decreasing noticeably since 2010. At the same time, mortality stratification also declined slightly. For women, both indices increased over the whole period. Mortality stratification increased by 68%, from 0.17 in 1996 to 0.28 in 2014. In more recent years, it increased slightly faster than difference in life expectancy.

Conceptually, change in difference in life expectancy may not necessarily bring about the same change in mortality stratification. To further demonstrate the distinction between difference in life expectancy and mortality stratification, we move on to answer a counterfactual question: if the low income group had started to converge toward the high income group in mortality, such that the difference in life expectancy had been constant since 1996, would mortality stratification have been increasing, decreasing, or constant?

<Fig. 7>

Fig. 7 presents the counterfactual trends with different colors referring to different mortality reducing strategies. Here, difference in life expectancy is fixed at 1996 level[3]. Our results show that saving the youngest first yields lower stratification levels compared to the observed values, but for both sexes the size of stratification is still increasing over time. This implies that with constant difference in life expectancy, stratification may still increase. Constant change over age leads to lower stratification than saving the youngest first. For females, the corresponding values of stratification in earlier years of the period are even lower than the initial value at 1996. Therefore, stratification can also decrease when difference in life expectancy is constant. However, it starts to increase from 2003. In more recent years, female mortality stratification is higher than the 1996 level again. Differences in the results from the two counterfactual scenarios suggest that the observed increase in

[3] We also did analysis for relative difference fixed at 1996 level, and the results are very similar, except that the counterfactual trends are at slightly higher levels. This is because when relative difference had been constant since 1996, absolute difference would still have increased slightly overtime.

stratification over the years are not caused by younger adult ages. Reducing mortality at older ages of the low income group can better reduce stratification.

**Age components of changes in stratification**

<Fig. 8 >

For both men and women, mortality stratification is mainly caused by discrepancy between the two groups at middle adult ages (50~69), although the exact age profile differs slightly (see Fig. A2 in appendix for detailed results of age decomposition for stratification in 1996-2000 and 2010-2014). The direct way to analyze relative importance of ages in stratifying mortality between the rich and poor is to decompose age contributions in changes in mortality stratification between two periods. In Fig. 8 we report the contributions of age groups to change in stratification between 1996-2000 and 2010-2014. For both men and women, ages between 50 and 74 contribute the most to the increase in mortality stratification. There is not much change due to ages below 50 for women. Males at ages between 35 and 49 of the poor group are catching up with their rich counterparts. These ages contribute negatively, but the negative contribution is not enough to offset the impact of larger mortality at ages between 50 and 74 among the low income people. Consequently, we see positive contributions at older ages (for women 85-94, for men 85-99) to the increase of stratification. In other words, the difference in the proportion of long-lived people between the rich and the poor is becoming larger.

## Discussion

**Summary of findings**

In this study, we introduce a novel concept in population health research, mortality stratification, which is an index of the degree of overlap between two age-at-death distributions. Monitoring stratification unmasks between-group differences that go un-noticed in conventional ways of comparing life expectancy, and helps to link two lines of research:

between-group comparisons of life expectancy and of lifespan inequality. The most striking finding to emerge is that income has become more and more important in stratifying lifetimes in Finland. Stratification increased even during periods where life expectancy differences remained stable or decreased, particularly among females.

**Rising importance of SES in mortality**

Rising importance of income in determining lifetime has been corroborated by studies in many other countries looking at various measures of SES and at differences in life expectancy. Conceptual differences between mortality stratification and other indices should not be ignored, but we expect the overall trends to be related. Numerous studies have shown widening inequalities in life expectancy in the United States across income (Chetty et al., 2016b) and education (E. R. Meara, Richards, & Cutler, 2008; Sasson, 2016; Sasson & Hayward, 2019) in the last few decades. An increasing trend of socioeconomic differential in life expectancy has also been confirmed in Western countries such as Spain (Permanyer et al., 2018), Finland (Tarkiainen et al., 2012), and Denmark (Brønnum-Hansen & Baadsgaard, 2012). A recent study found that relative inequality in age-standardized mortality across educational groups increased in 17 European countries including Finland from 1980 to 2014, but absolute difference showed a decreasing trend except for some Central and East European countries such as Hungary and Czech Republic (Mackenbach et al., 2018). Absolute difference in age-standardized death rates tend to decrease, while relative difference tend to increase (Mackenbach et al., 2003, 2018), which implies that caution needs to be taken when selecting and interpreting the results from different measurements.

Several attempts have been made to go beyond differences in means and expand our knowledge about SES differences in length of life. This line of research focuses on SES differences in lifespan inequality. Earlier research on lifespan inequality mainly focused on the entire population. In the long run of history, rising life expectancy and falling lifespan inequality are generally in lockstep with each other (Alvarez, Aburto, & Canudas-Romo, 2019; Colchero et al., 2016; Smits & Monden, 2009; Vaupel et al., 2011; Wilmoth & Horiuchi, 1999). Decreasing individual-level inequalities in length of life may not be surprising considering massive improvement in reducing premature deaths (Vaupel et al., 2011; Zhang & Vaupel, 2009). As proved by some recent studies, however, the decreasing trends of lifespan inequality may have flattened or even reversed for many countries including the US (van Raalte et al., 2018), Europe (Aburto & van Raalte, 2018; Aburto et al., 2018; Seaman, Leyland, & Popham, 2016), and Latin American countries (Aburto & Beltrán-Sánchez, 2019; García & Aburto, 2019).

As for population subgroups, research to date suggests a diverging pattern of lifespan inequality between SES groups in multiple countries. Cross-sectional data in the 1990s of 10 European countries, including Finland, shows that low-educated groups tend to have larger variation in age at death (van Raalte et al., 2011). Comparing over time, lifespan variation also follows divergent trajectories among SES groups. In the US, lifespan inequality increased among poorly educated people but decreased among people with college education from 1990 to 2010 (Sasson, 2016). Similar patterns in lifespan inequality were also found in Spain, where lifespan inequality decreased among high education people but stagnated among low-education people (Permanyer et al., 2018). A registry-based study in Denmark shows that the level of dispersion in the age-at-death distribution was unchanged for the lowest income quartile from 1986 to 2014, whereas it fell for all the other income quartiles over the same period (Brønnum-Hansen, 2017). For Finland, recent evidence shows that lifespan inequality of lowest SES groups (measured by occupation, education, or income) are increasing for both sexes, whereas lifespan inequalities of other SES groups are decreasing (van Raalte et al., 2011, 2014, 2018). These findings point to the so-called "double burden" of the low SES people (van Raalte et al., 2018). That is, compared with high SES people, they not only live shorter on average, but also face greater uncertainty in the time of death.

Hence, life expectancy seems to be diverging across SES groups in the US, and possibly Europe, but not enough studies prove that. This may cause increased stratification, as we showed in the stylized figures in introduction. Also, lifespan variation is diverging between SES groups in low mortality countries that have been examined (Finland, USA, Denmark, Spain). Although we know that declining lifespan variation for both groups would lead to increased stratification, and increasing lifespan variations for both groups would lead to decreased stratification, the effects of diverging pattern of some groups increasing and others declining on stratification is unclear. It is interesting that in Finland, as elsewhere, relative differences between lifespan variation have increased more than relative differences in life expectancy, yet stratification still increased.

**Possible explanations**

An important yet unresolved question is, why is income, or SES, becoming more important in stratifying length-of-life? Let us first review possible channels that link higher income with longer life. The answers are multifold. First, income can directly benefit one's health in several ways. For instance, it provides individuals with health-promoting resources such as desirable housing conditions, safe neighborhood environments, and recreational activities (Elo, 2009; Phelan, Link, & Tehranifar, 2010). In this way, income postpones the onset of chronic conditions (Smith, 2007). Furthermore, income lowers individuals' morality risk by providing them with more access to medical resources. Inequality of medical care utilization by income is still large even in developed countries like Finland (Doorslaer, Masseria, & Koolman, 2006). Besides, it is also possible that other factors associated with income are operating. People with higher income, for example, are usually those who have higher educational attainment, which has been proved to be associated with better health habits (Li & Powdthavee, 2015), more knowledge and better thinking and decision-making strategies about health (Cutler & Lleras-Muney, 2006).

The changing role of income indicates that our society has been experiencing certain fundamental changes that has enhanced one of the aforementioned mechanisms by which income, perhaps as a proxy for social status, affects mortality. During the past decades, medical resource and technology have gone through substantial changes. With fast and vast development in technology, the relationship between SES and mortality may have also changed ( Hayward, Hummer, & Sasson, 2015). On the whole, people with high SES are more likely to directly take advantage of new development in science and technology to promote their health and increase their survival chances(Glied & Lleras-Muney, 2008; Link & Phelan, 1995). For instance, research has found that high income and high education are associated with high likelihood of using new drugs (Glied & Lleras-Muney, 2008; Lleras-Muney & Lichtenberg, 2005). The penalty of low income may be income per se, as new drugs are usually more costly so that low income people tend not to choose them, although this mechanism might be less important in countries (like Finland). Another important cause of the differences in adopting new medical technology may be that higher SES people are better informed (Glied & Lleras-Muney, 2008; Lleras-Muney & Lichtenberg, 2005). Indeed, the gap in health knowledge between SES groups persists and has become even wider in the new media age (Brodie et al., 2000). Individuals with more health information are more likely to use new health technology when they are ill, and have larger chance of practicing a healthier lifestyle when they are not ill. Besides, there may also be differences in taking the risk and weighing the costs and benefits of adopting new technology (Lleras-Muney & Lichtenberg, 2005) and thus they have differential response to health knowledge (Meara, 2001). In sum, the accelerated progress in technology benefits people differentially by income, making income more important in stratifying individuals' length-of-life now than it was in the past.

The new information age might be seen as a continuation of the technophysio evolution processes that began in the past centuries. The technophysio evolution theory holds that the massive improvement in human population health (including body size, height, longevity, etc.) from the 18th to the 20th century can be largely attributed to greater human control over their environment with the help of technology (Fogel & Costa, 1997). This concurrent process of technological and biological change is referred to as "technophysio evolution", in distinction to the evolution theory based on genetic mutation and natural selection (Fogel & Costa, 1997). Since this theory is socio-environmental, it can be argued the technophysio evolution does not happen homogenously among individuals. Again, the same rationale holds here. High-income people are usually those who reap the most benefits from new technology (Glied & Lleras-Muney, 2008; Link & Phelan, 1995). Thus, the ongoing massive technological changes may have brought about faster technophysio evaluation at the higher end of social ladder, leading to the increase of mortality stratification.

Besides technological changes that may have prolonged high SES people's lives more than low SES people's, the persistent or even higher mortality stratification among income groups over time, as suggested by Phelan and colleagues (2010), may have resulted from the "replacement of intervening mechanisms". The key message of this hypothesis is that although the major mechanisms at play in the past, such as poor hygienic condition and less protection from infectious diseases, have died down, some unprecedented or once-weak mechanisms have emerged (Phelan et al., 2010), which may have been continuously driving age-at-death distributions across income groups away from one another. Cigarette or alcohol consumption, dietary behaviors, and circulatory diseases, to name a few, are closely linked with income (and other socioeconomic characteristics) and are simultaneously becoming more and more important in determining length-of-life. To reduce mortality stratification, therefore, we are facing different challenges in regard to these new mechanisms stratifying mortality by SES.

Another reasonable speculation would be that rising mortality stratification by income stems from rising income inequality. In other words, it is not that absolute value of income has become more important in determining the length-of-life, but rising income inequality has led to the rising mortality stratification by income. Our measure of income is income quintile of household disposable income per person, not absolute value. Therefore, when income distributions become more heterogeneous, it is natural to expect ages at death between income quintiles to become more heterogeneous accordingly. The Gini coefficient for household disposable income in Finland increased steadily in the first decade since 1996 and stagnated in recent years after 2007 (Pareliussen et al., 2018), which is consistent with that of mortality stratification, especially for men. The similarity between the two trends suggests that rising income inequality may be an underlying mechanism, but testing this in a robust causal framework would require a larger dataset with more varying trends. If true, the policy implication here would be that to reduce mortality stratification by income, a great amount of effort should be paid to reduce income inequality.

**Middle ages, not young adult ages are the cause of rising stratification**

Previous work has shown that the ages and causes of death driving differences in life expectancy and lifespan variation are not the same (Seligman, Greenberg, & Tuljapurkar, 2016), with young adult ages being particularly important in driving trends in lifespan variation (van Raalte et al., 2011), and ages closer to the life expectancy at birth being the main drivers in divergence in life expectancy (Khang et al. , 2010). Findings from our decomposition analysis reveal that ages between 50 and 74, i.e. ages in between the main drivers of lifespan variation and life expectancy differences, are the main driver of increasing mortality stratification for both sexes. The most prominent causes of death for these ages are diseases of circulatory system and neoplasms. Alcohol-related causes may also play an important role especially for preretirement ages. One policy implication is to cut middle and old age deaths among people with low income, such as alcohol and smoking related deaths. By doing so, we will not only expect life expectancy and lifespan equality of low SES group to increase, but also see a declining trend of mortality stratification. Surprisingly, earlier adult (ages from 30 to 49) mortality did not contribute to the rise of stratification. Their contribution to stratification is relatively stable over time.

**Mortality stratification versus other between-group difference measures**

In general, therefore, it seems that socioeconomic inequalities in mortality are increasing across low mortality countries. But there has been no consensus on the measurement of between-group comparisons. A major contribution of this study is that we provide a new angle that relates different groups of people. Prior to this study, conventionally, researchers have mainly relied on life expectancy or age-specific mortality rates to examine between-group differences. However, comparisons of life expectancies are insufficient. Two same life expectancies may come from two different age-at-death distributions. Epidemiologists often compare age-standardized mortality rates across between groups, but absolute and relative differences often yield opposite trends (Mackenbach et al., 2003, 2018).

The current study helps to better understand socioeconomic differences in mortality from the perspective of stratification. Our findings indicate that, for between-group comparison, mortality stratification uncovers some important dimensions that are missing when focusing only on differences in life expectancies, despite the fact that the former is positively associated with the latter in the Finnish case. For example, in certain years, female difference in life expectancies decreased but female mortality stratification increased. This paradoxical result suggests that more attention should be given to stratification in between-group comparisons of mortality. A set of counterfactual analysis reinforces this conclusion. Even if difference in life expectancy is constant or decreasing, stratification can still increase. These results are rather discouraging. They imply that previous studies comparing life expectancy may have underestimated socioeconomic differences in mortality. For a comprehensive understanding of mortality differences between SES groups, further work is needed to examine past trends of mortality stratification in other countries and compare the results with trends of differences in life expectancy. Note that our stratification index can be applied to study other between-group differences in mortality, such as sex and racial/ethnic differences

Besides differences in life expectancy and lifespan inequality across groups, what else can we know? Our stratification index provides a new angle. It captures to what extent SES stratifies length of life between groups. For two-group cases, constructing the index involves age-at-death distributions of the two groups. As mentioned in the introduction, mortality stratification depends on both life expectancy and lifespan inequality of the two groups. Hence, stratification helps to link the above mentioned two lines of research together, i.e., comparison in life expectancy and lifespan inequality across groups.

Researchers have also studied the group effect by decomposing total variance into between- and within-group variance, such that the contribution of group can be estimated (van Raalte et al., 2012). One distinction in this approach is that group size affects the proportion of variance explained by group, but not the level of stratification between two groups. Another advantage is that stratification is more intuitive to grasp and underscores the role of group. Variance of age-at-death is mostly within group, and the contribution of differences in life expectancies between socioeconomic groups to the total variance is usually very small (van Raalte et al., 2012). For the same population, 0.4 of stratification may happen when only 5% of total variance is explained by group. However, this does not mean that group is not important. As we showed before, male mortality stratification between the lowest and highest 20% income group is 0.454 in years between 2010 and 2014. The proportion of non-overlapping area is almost half, meaning there still remains great potential to equalize survival ages.

**Differential mortality change by income and its impact on stratification**

Another insight may be gained from mortality stratification is related to how the shape of death density for different social groups changes temporally, which comprises two fundamental processes, compression and shifting. Compression refers to the process of individual lengths of life becoming more homogeneous (Fries, 1980; Wilmoth & Horiuchi, 1999). By contrast, shifting mortality happens when the age-at-death distribution moves to older ages while maintaining its shape (Bergeron-Boucher, Ebeling, & Canudas-Romo, 2015; Bongaarts, 2005; Canudas-Romo, 2008; Vaupel, 1986; Vaupel & Gowan, 1986). The exact level of compression is often measured by lifespan inequality indices, and shifting process can be measured by a location measure of the death density, such as the life expectancy at birth or modal age at death.

At population level, mortality change has transitioned from dominantly compression to shifting in the US and many European countries in mid-20$^{th}$ century (Bergeron-Boucher et al., 2015; Janssen & de Beer, 2019). The timing of transition and pace of mortality change, however, may differ among SES groups. Theoretically, temporal change in mortality stratification is subject to the dynamics of compression and shifting of the two population subgroups. For instance, holding compression constant for both social groups, a lag of shifting mortality in the less advantaged group will lead to increasing mortality stratification. Therefore, additional insights may be gained by quantifying the contributions of the two processes to differences in mortality stratification across time. Our findings suggest that male morality stratification is caused by low income group is falling behind in both processes, while it is mainly the compression that accounts for female mortality stratification. Further research might develop new decomposition methods to quantitatively explore how compression and shift influence stratification.

## Conclusion

Life expectancy trends demonstrate that, on average, long lives are increasingly becoming the domain of the rich and privileged. To the extent that individuals surround themselves with others of a similar income level, the poorer will have fewer connections to healthy and long-lived adults, while the wealthy will have less experience of premature death within their community. However, increasing mortality stratification is perhaps an even clearer indication of growing mortality inequalities than traditional indicators such as diverging life expectancies or differences in age-at-death variability. This is because under diverging life expectancies, a substantial proportion of the disadvantaged groups could nevertheless be experiencing tremendous progress in longevity on par with those in the most advantaged groups. Growing mortality stratification, however, takes the divergence in the full age-at-death distribution into account, and is a clearer signal that social groups are effectively experiencing different survival ages. Increased stratification more clearly and explicitly informs of the challenges in the public provisioning of health care services that are age dependent. For these reasons, we argue that policymakers should be monitoring stratification alongside life expectancy and lifespan variation.

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**Figures**

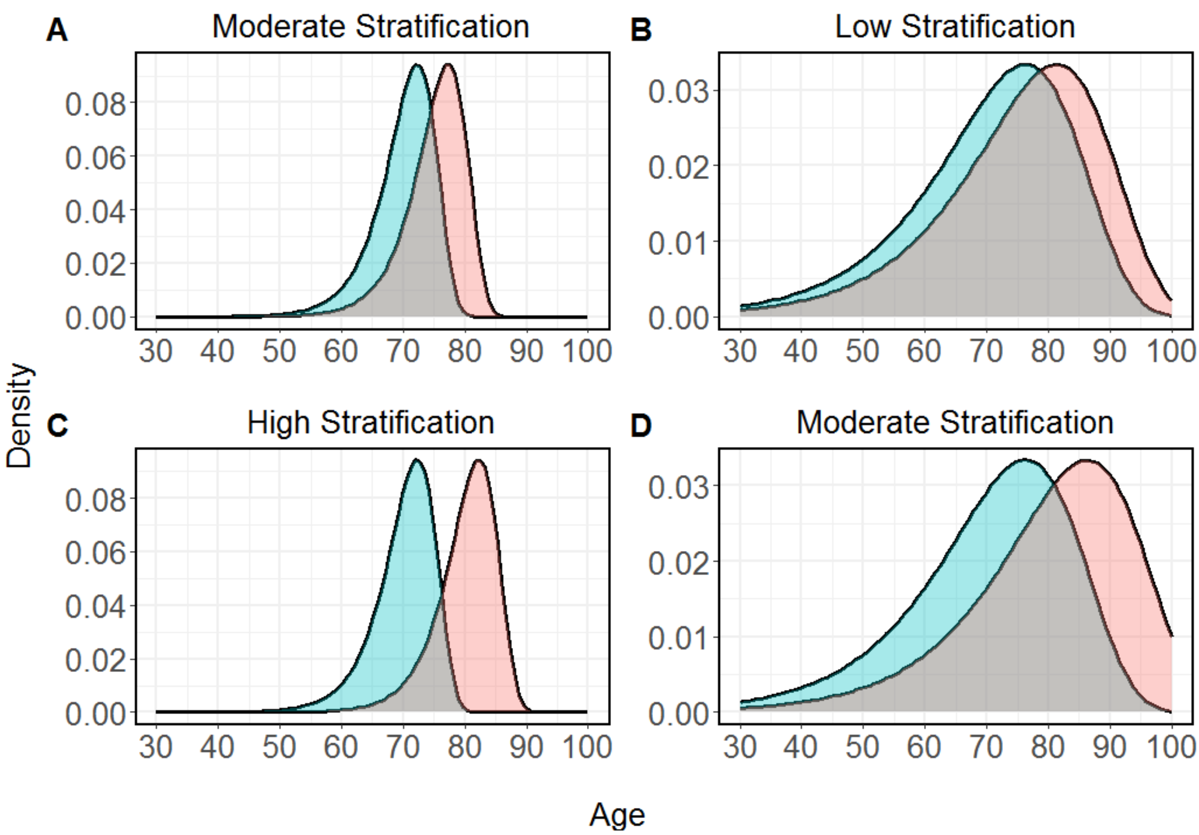


*Fig. 1* Hypothetical scenarios of age-at-death distributions of two social groups

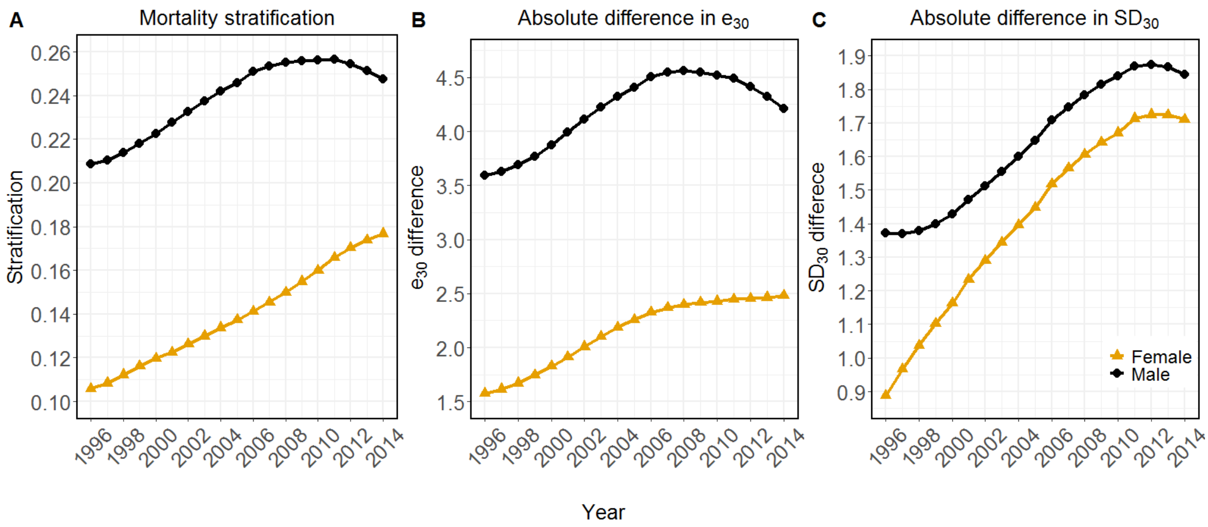


*Fig. 2* Trends of mortality stratification and absolute differences in life expectancy and lifespan inequality in Finland, by sex, total population, 1996-2014

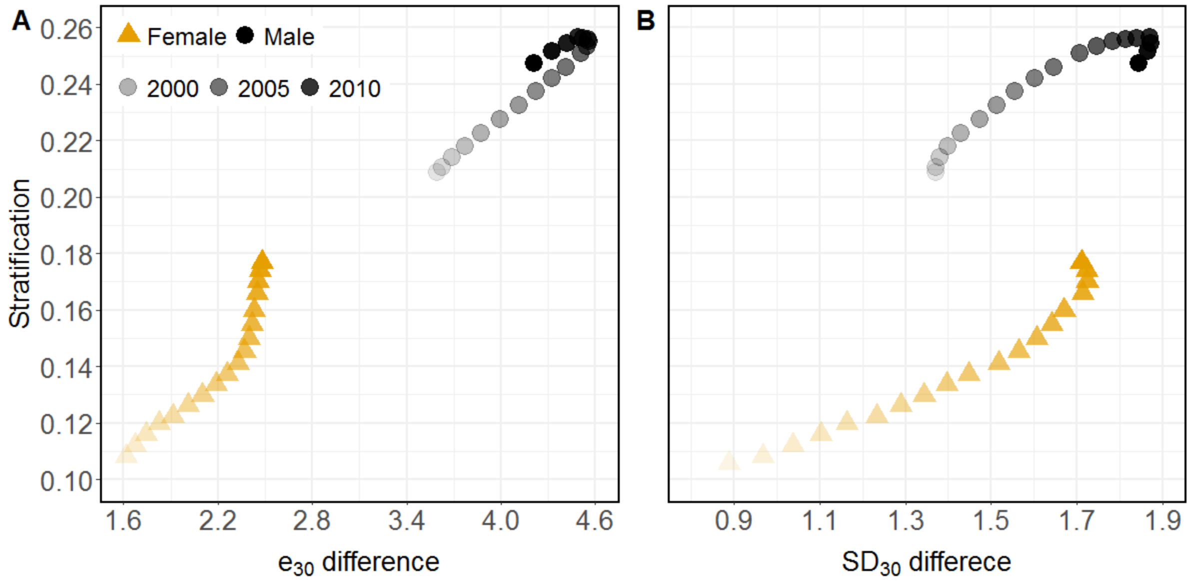


*Fig. 3* Associations between mortality stratification and difference in (A) life expectancy and (B) lifespan inequality by sex, total population

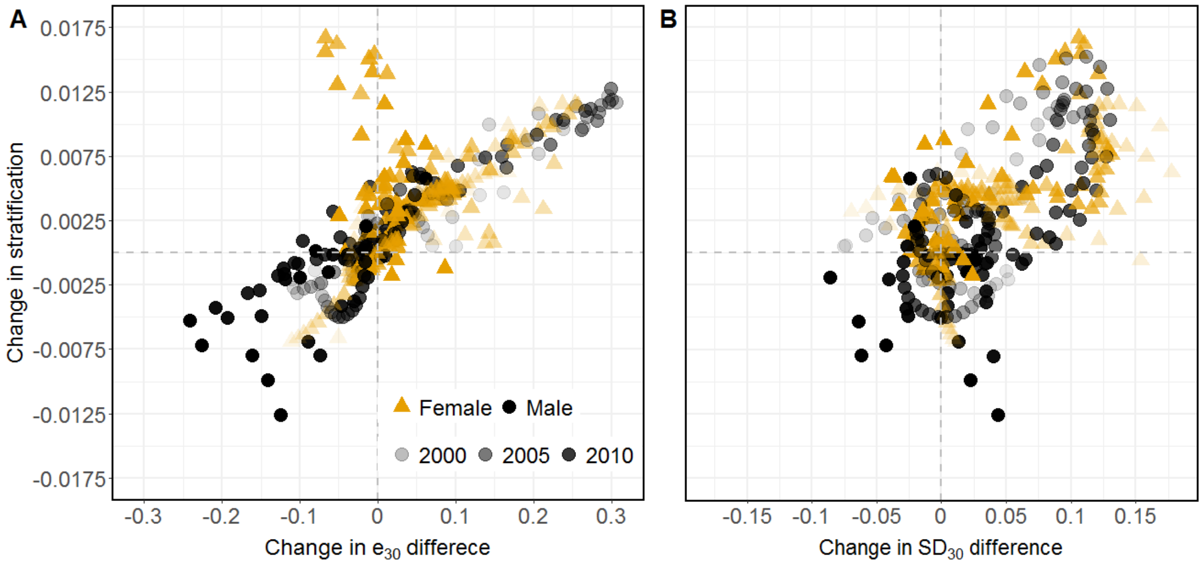


*Fig. 4* Pairwise association between yearly change in stratification and yearly change in (A) $e_{30}$ difference and (B) $e_{30}$ ratio

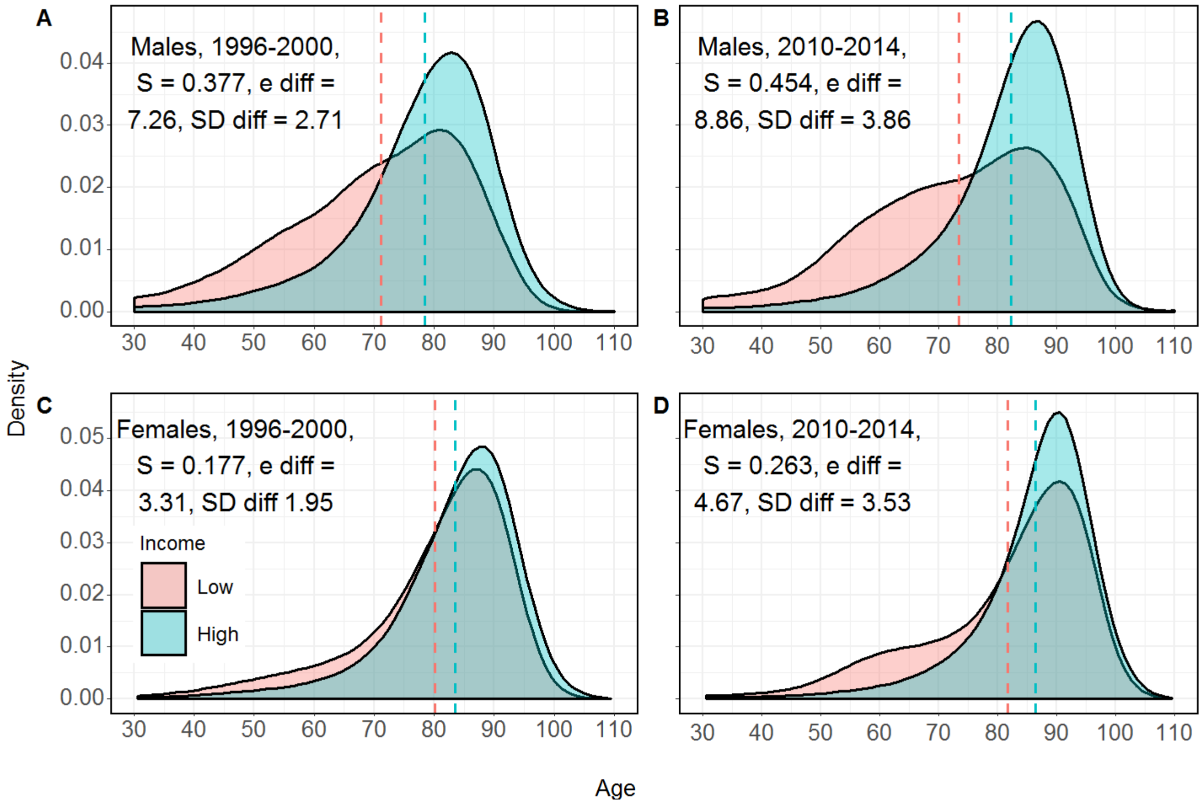


*Fig. 5* Age-at-death distributions by income and sex in selected periods

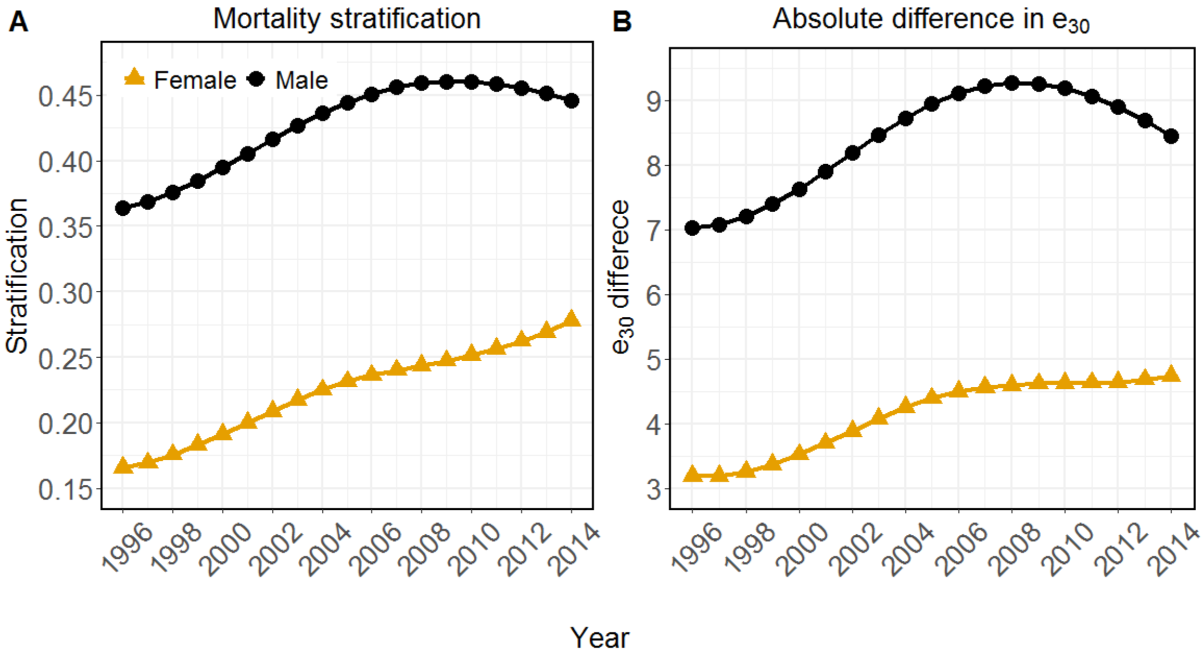


*Fig. 6* Observed trends of mortality stratification between the lowest and highest income quintiles in Finland, by sex, 1996-2014

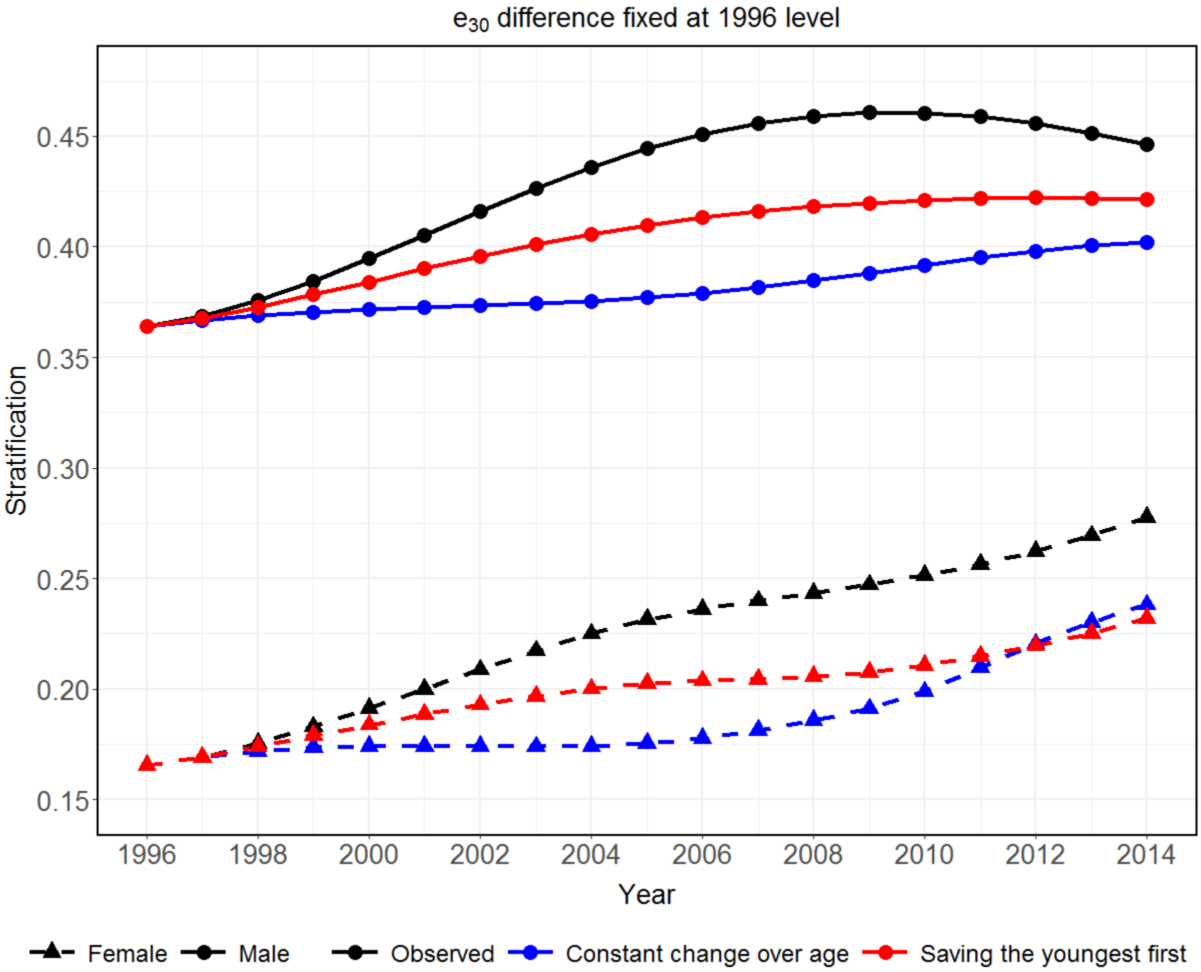


*Fig. 7* Counterfactual trends of mortality stratification between the lowest and highest income quintiles in Finland, by sex, 1996-2014

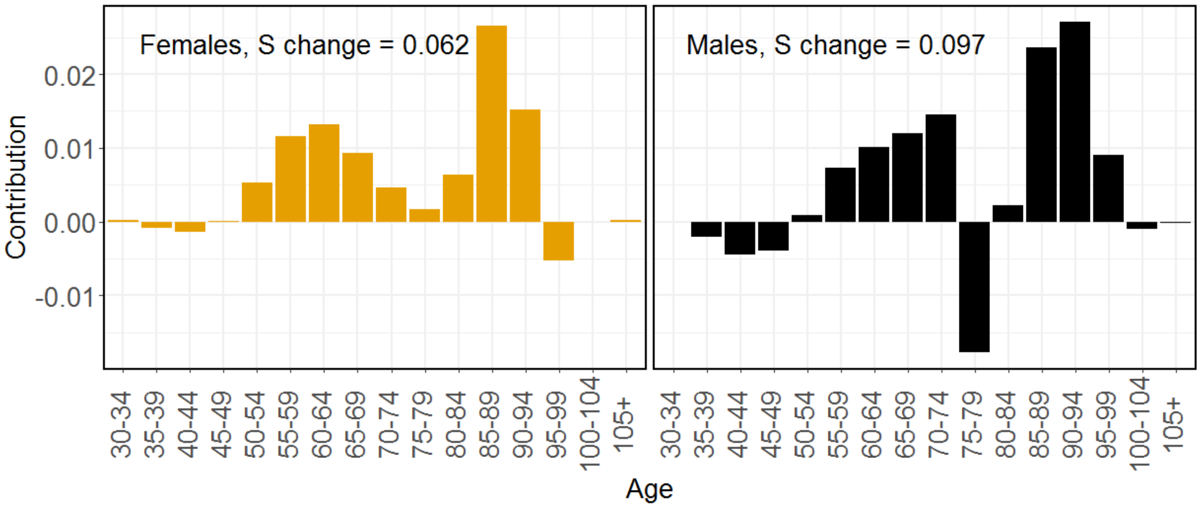


*Fig. 8* Age decomposition of change in mortality stratification between the lowest and the highest income quintiles in Finland from 1996-2000 to 2010-2014, by sex

## Appendix

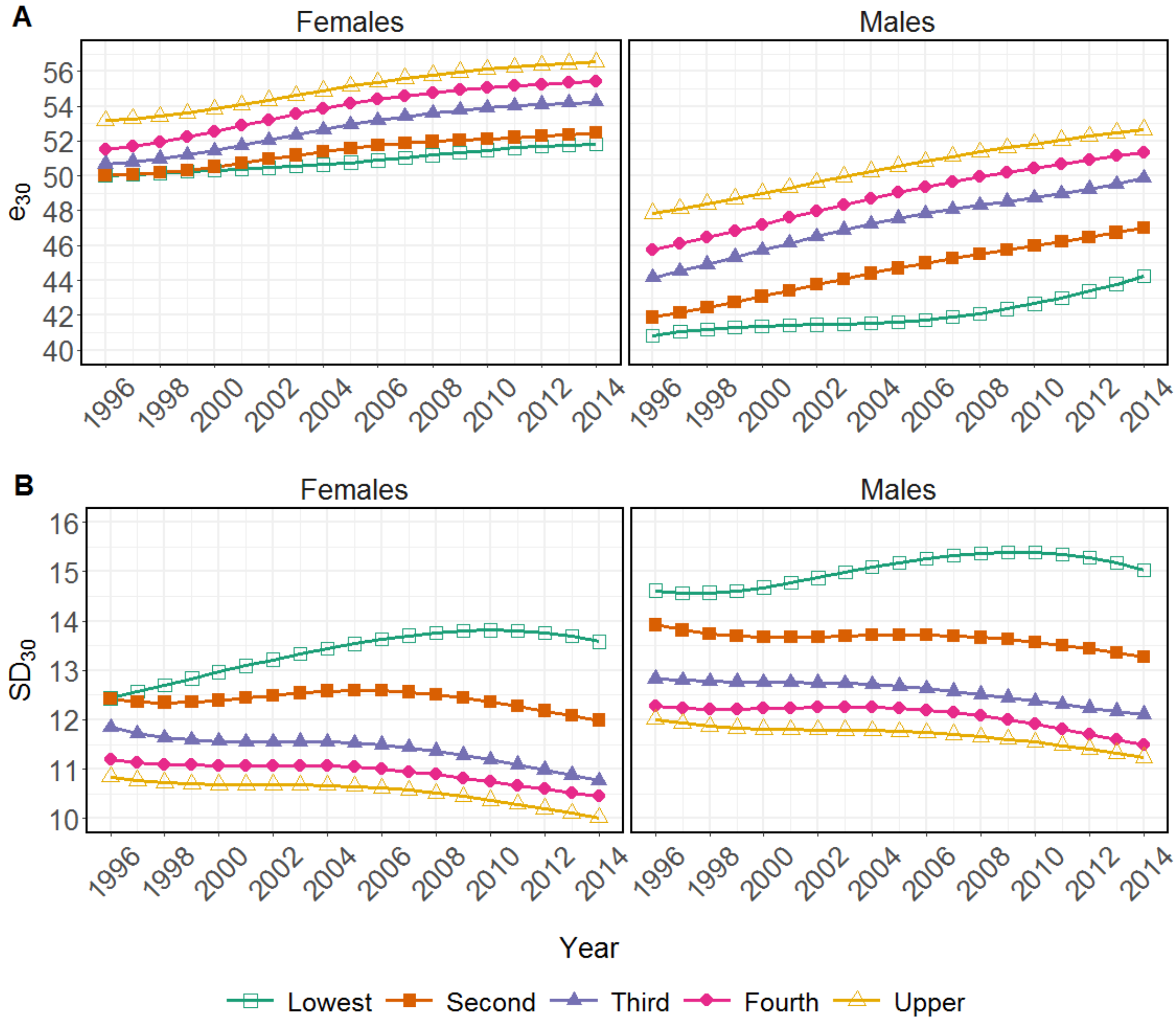


*Fig. A1* Trends of life expectancy and lifespan inequality in Finland, by sex and income quintile, 1996-2014

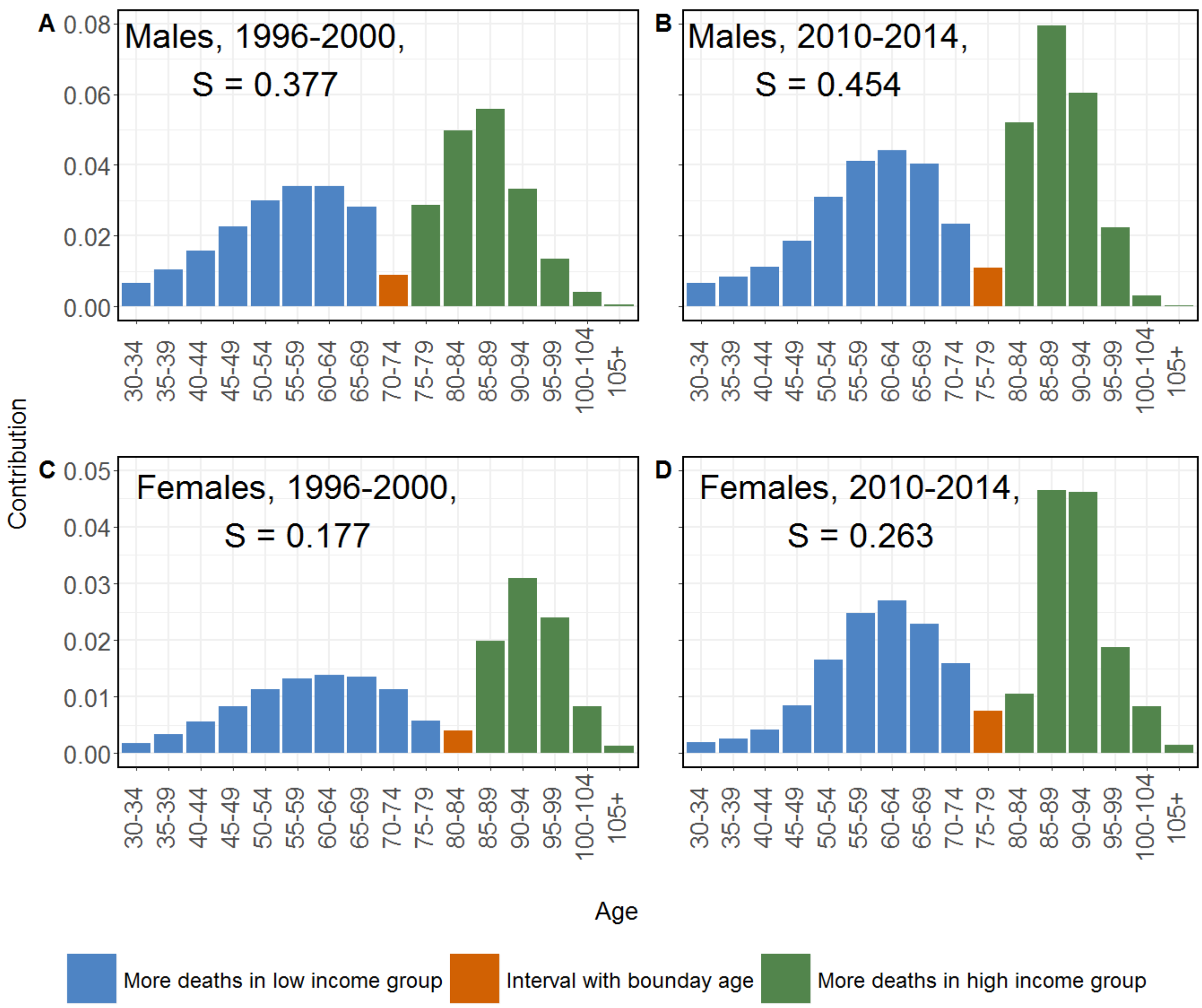


*Fig. A2* Age decomposition of mortality stratification between the lowest and the highest income quintiles in Finland, by sex, in 1996-2000 and 2000-2014