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Lessons from a Laggard? Study of CVD incidence and survival inequalities in Finland, 2000-2020, based on novel bivariate health-death distributions

Chiara Micheletti[1,2,3], Alyson van Raalte[1,5], Pekka Martikainen[4,5], Shubhankar Sharma[4,5]

[1]Max Planck Institute for Demographic Research
[2]Universitat Autònoma de Barcelona
[3]Centre d'Estudis Demogràfics (CED-CERCA)
[4]Helsinki Institute for Demography and Population Health
[5]Max Planck–University of Helsinki Centre for Social Inequalities in Population Health

1 Introduction

Life expectancy improvement has slowed or stalled in many high-income countries since around 2010 (Dowd et al., 2025). Although the causes are multifaceted, slowing decline in cardiovascular disease (CVD) mortality is playing an outsized role (Mehta et al., 2020; Lopez and Adair, 2019). This is perhaps not surprising, as CVDs remain the leading cause of death in most of these countries (Bergeron-Boucher et al., 2020). What is surprising, however, is that this deceleration in CVD mortality decline does not appear to be a "floor effect". In fact, cardiovascular mortality has plateaued in several countries with high CVD burdens, while continuing to decrease in others where levels were already much lower (Dowd et al., 2025; Acosta et al., 2022).

Why this is the case remains poorly understood. The large diversity of experience across countries invites detailed case studies of CVD health and mortality dynamics from laggards and leaders. Key questions remain. Are diverging CVD trends owing to differences in cardiovascular disease incidence or to survival following cardiovascular disease events? Are changing patterns in CVD incidence and survival homogeneous across socioeconomic groups, despite their different smoking histories and behavioural risk factors? Are particular age groups or cohorts more strongly implicated in these dynamics?

Finland is a particularly interesting setting to examine these issues. Like many other high-income countries that rank poorly in life expectancy, it has an extremely high burden of cardiovascular mortality (Bergeron-Boucher et al., 2020). These challenges are longstanding. For example, from at least the 1960s through to 2015, Finland experienced more age-standardized CVD deaths than the United States (Dattani et al., 2023). Yet, unlike the United States and several other poor-performing countries, Finland's progress in reducing mortality has slowed, though it remains far from stagnation. In 2010-19 mortality declined at a pace of 1.7% annually, compared to 2.2% annually in 2000-09, putting Finland among the top

10 out of 31 selected high-income countries in its pace of mortality decline (Dowd et al., 2025). This makes the the Finnish population a shining example among long-term life expectancy laggards. Progress remains possible.

Survival with cardiovascular conditions might be an especially important aspect to investigate, and one that has received comparatively little attention. This is especially true in Finland given its long history with high CVD levels. A recent study estimated that 72% of Finns will experience a hospitalisation from CVD (defined as ischaemic heart disease, heart failure, cerebrovascular disease, atrial fibrillation, or/and peripheral arterial disease) over their lifetime, based on current rates (Sharma et al., 2025). Yet, most studies of cardiovascular diseases, including those from sophisticated multistate models, aggregate CVD dynamics over age. This neglects a potentially important component of the story, as it is unclear whether CVD decline is widespread across the age spectrum, or limited to different ages or cohorts with distinct life histories.

In this paper, we take advantage of the exceptionally detailed Finnish register data to look at changing CVD incidence and survival dynamics across age, sex, and years of education since 2000. We do so using a novel methodology: age-health curves derived from bivariate distributions of health and survival (Micheletti et al., 2025). These curves allow us, at a glance, to determine the average years of life lived free from any CVD prior to death, at each age at death.

2 Methods

We use sociodemographic information from individual-level population registers, which are linked to hospital discharge and Death Registers, on the entire Finnish population aged 40–100 years. Hospitalizations were captured from 1970 to 2000, and we examined the death dynamics over 1996–2020 in five-year periods. A serious cardiac event is defined as having a diagnosis of ischemic heart disease (IHD), heart failure, cerebrovascular disease, atrial fibrillation, or/and peripheral arterial disease as the main diagnosis of a hospital episode. Health is defined as never having experienced a serious cardiovascular disease event.

Using the multistate life table techniques described in Riffe et al. (2024), we generate bivariate age-at-death distributions $f(h, u)$ estimating the number of individuals who die having accumulated a certain number of years in “good” health (h) (in this case, never having experienced a serious cardiovascular disease event) and in “less-than-good” health (u) by the time of death ($x = h + u$). Then, following Micheletti et al. (2025), we compute the *healthy years curves*, a tool measuring the number of years individuals have accumulated in good health at all possible ages at death x and defined as

$$\Psi_H(x) := \int_0^x h \left[\frac{f(h, x-h)}{\int_0^x f(a, x-a) da} \right] dh \tag{1}$$

Equation 1 is simply an average of the values of h for all individuals who died at

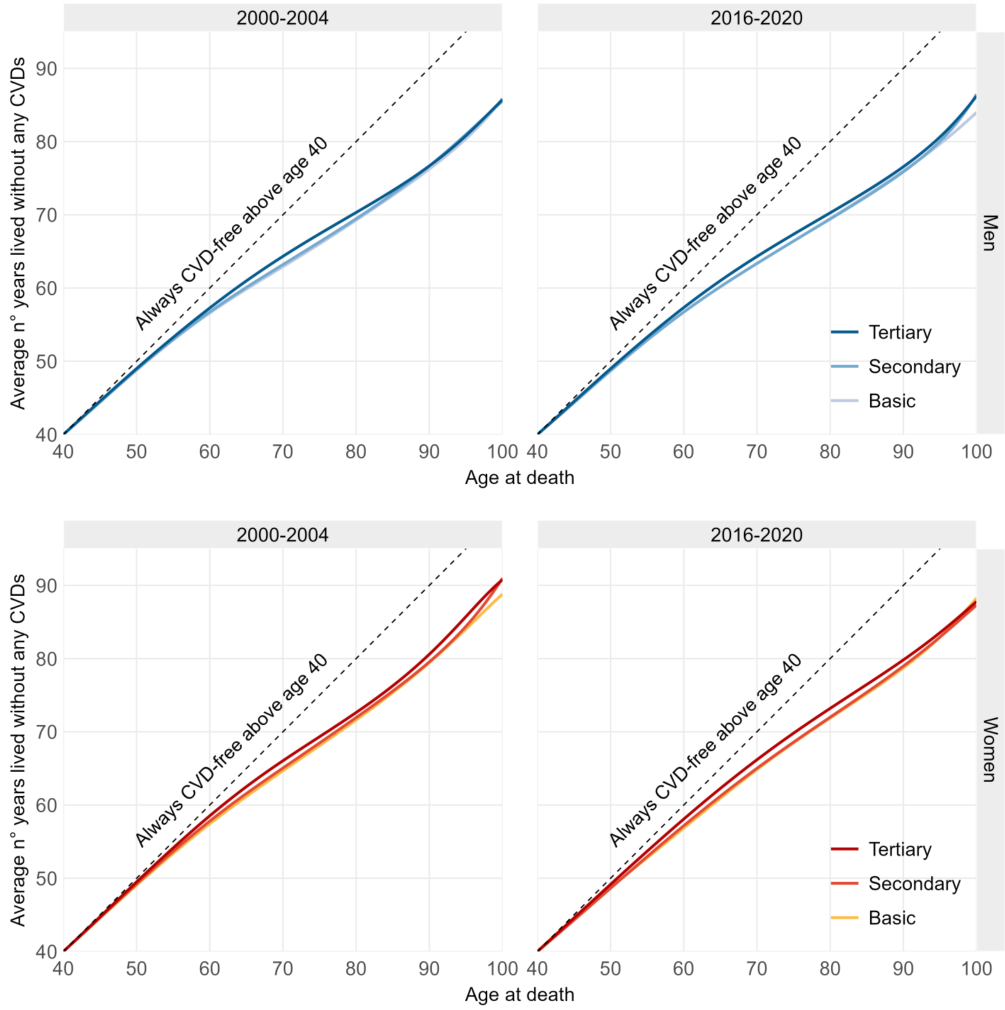

Figure 1. CVD-free curves $\Psi_H(x)$ for Finnish males and females in 2000-2004 and 2016-2020 by educational level.

age x. Since we are interested in the study of cardiovascular diseases, in our paper h corresponds to the amount of years spent CVD-free. Therefore, in the following, we will refer to $\Psi_H(x)$ as "CVD-free curve".

3 Preliminary results

In this section we present the CVD-free curves $\Psi_H(x)$ calculated for different subpopulations and compared across different domains. We consider individuals aged 40+.

Comparison across educational levels

Figure 1 shows the curves by educational level, for each sex-period combination. In our data, educational attainment is the highest level of education obtained: basic education (International Standard Classification of Education, ISCED 0-2),

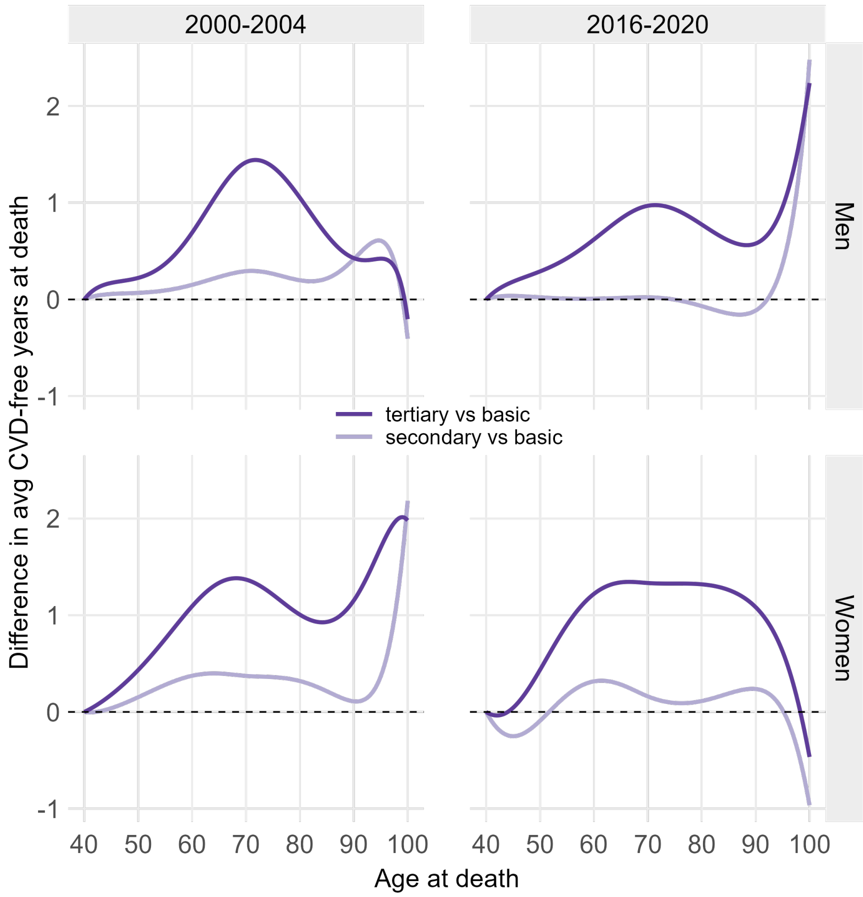

Figure 2. Differences in CVD-free curves for Finnish males and females in 2000-2004 and 2016-2020. In dark purple $\Psi_H^{ter}(x) - \Psi_H^{bas}(x)$, in light purple $\Psi_H^{sec}(x) - \Psi_H^{bas}(x)$.

secondary education (ISCED 3-4), and tertiary education (ISCED 5-8).

The curves are remarkably similar. Still, tertiary educated individuals cumulate on average more CVD-free years across all ages at death. Men's curves depart earlier from the diagonal, in line with the finding that they experience a higher CVD burden than women (Sharma et al., 2025).

Since the plot alone makes it difficult to grasp the magnitude of the differences between educational levels, Figure 2 presents the actual values for each age at death. The reference group is those with basic education. Positive values indicate an advantage for the more educated (secondary in light purple, tertiary in dark purple) over the basic educated in terms of average CVD-free years at death.

Tertiary-educated individuals consistently demonstrate substantial advantages over those with basic education in terms of CVD-free years at death. The gap between tertiary and basic education appears more dramatic than the one between secondary and basic education, suggesting that higher education provides increasingly greater health benefits. The differences exhibit very irregular patterns at the oldest ages, possibly reflecting smaller sample sizes.

Figure 3. Differences in CVD-free curves for Finnish males and females by educational level $\Psi_H^{t_2}(x) - \Psi_H^{t_1}(x)$, with t_1 = 2000-2004, t_2 = 2016-2020.

Comparison across periods

Figure 3 quantifies how the average number of CVD-free years at death has changed between the two periods for each educational level. Negative values (below the dotted line) indicate that individuals cumulated, on average, less CVD-free years at death in 2016–2020 than in 2000–2004.

In general, we observe smaller differences over time than across groups, with tertiary educated men experiencing the most negligible changes. The curves do not change dramatically between the two periods and the longevity gains reflected in increased life expectancy (see Table 1) are not accompanied by significant changes in the duration of life spent with CVDs. These findings may point to a stagnation in cardiovascular morbidity in Finland.

Sex	Education level	LE_{40} 2000–2004	LE_{40} 2016–2020
Men	Basic	34.61	37.47
	Secondary	36.80	40.05
	Tertiary	40.00	43.42
	Total	36.36	40.28
Women	Basic	40.92	42.41
	Secondary	43.10	45.06
	Tertiary	44.15	46.95
	Total	42.24	45.05

Table 1. Life expectancy (LE_{40}) at age 40 for the overall population (total) and by gender and educational attainment in Finland.

4 Future Outlook

For any given age at death, with this methodology we are able to see how many years have been spent, on average, following a major cardiovascular event. Thus it allows us to tease apart the important questions relating to disease avoidance or postponement, and survival with disease, over different age ranges. This is particularly important in countries like Finland that have a long history of CVD, and thus a high proportion of the population living with a CVD history.

These insights are preliminary, giving a flavour of some of the kinds of analyses we can conduct. Between now and EPC, we intend to refine the study and investigate the sex and educational differences in greater depth.

We are exploring the feasibility of comparing these CVD results to survival dynamics with cancers. Currently around a quarter of the population die of cancer, and the temporal dynamics have been very different to CVD.

We also plan to incorporate uncertainty into the estimation of the CVD-free curves.

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