The Lifetime Trajectories and Drivers of the Socioeconomic Health Gap in Biomarkers and Allostatic Load

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1. Introduction

There is a significant health gap between socioeconomic groups. Narrowing the gap is a shared goal for many countries and international institutions. For instance, consider the EU4Heaalth Programme for the period of 2010-2027 and the Dutch Global Health Strategy 2023-2030. To design effective preventive interventions, we need to know when and how many of these correlations between socioeconomic status (SES) and health arise before reaching the endpoint of life. Much of the literature studies the health disparities across socioeconomic groups has used measures of morbidity, mortality, or self-rated health as outcomes [1, 2, 3]. While self-assessed health is inherently subjective and non-specific, morbidity measures are an endpoint of a health trajectory, so they are realized comparatively late in life after most of the wear and tear on individuals' health has already taken place.

Therefore, this paper examines the health evolution over the life cycle by using longitudinal biomarkers from blood, urine, electrocardiogram (ECG), anthropometry, and blood pressure of a large-scale, prospective cohort and biobank. In contrast to clinical health assessments, biomarkers from prospective cohort studies offer an opportunity to investigate health gradients through biological pathways and analyze how they accumulate and develop with aging before the onset of health deterioration [4]. Several biomarkers are highly predictive of morbidity and mortality and are already observable well before the health outcomes have been realized. Hence, biomarkers complement the previous literature on the health gap by providing objective measures that can already be health outcomes have been realized.

This paper contributes to a growing literature that establishes the strong relationship between SES and health outcomes over the life cycle and unravels the factors that contribute to changes in the health gap [2, 5, 6]. Gaps in both observing and investigating the evolution of socioeconomic health disparity before reaching the diagnostic endpoints. We investigate the trajectories of the socioeconomic health gap using a set of biomarkers and examine the drivers of this gap through regression-based decomposition.

2. Data and Methodology

The Lifelines cohort study and biobank is a large-scale longitudinal survey conducted in the northern Netherlands, with around 10% of the total population in that area. Participants were invited to the Lifelines research site to take physical examinations, including measurements of blood pressure, and ECG, as well as blood and urine collection. By linking Lifelines survey data, we combine these biomarkers with individuals' demographic and socioeconomic status, health behaviors, morbidity, and mortality information. The baseline was completed between 2007 and 2013, with 151, 080 samples, with two follow-ups of biomarkers available until the end of 2023.

To conceptualize the condition of multiple physiological systems, we use the concept of allostatic load, which indicates the statuses of multiple physiological regulatory systems in response to stress exposure. Following previous research, we calculate the allostatic load index based on three biomarkers from the cardiovascular system, five from the metabolic system, and one from kidney function [1] [7, 8]. The construction of the allostatic load index involves applying clinically established threshold cut points for each biomarker:

$$ALindex_i = \sum_{k=1}^{9} I_{i,k} \tag{1}$$

Where k denotes the biomarkers and $I_{i,k}$ is a binary variable indicating whether the level of biomarker k in individual i is above or below the threshold. The $I_{i,k}$ is equal to 1 if individuals are identified as "at-risk" based on a certain biomarker's cut-point. The value of allostatic load index indicates the number of health risks. Figure 1 shows the average number of biological risks by age and educational attainment.

We employ a linear regression for different 10-year age bins to estimate the association between the allostatic load index and potential drivers. Then, we decompose the total R-squared of these regressions based on Owen values to see the average contribution of each regressor to the total R-squared among all possible sequences regression [9].

$$ALindex_{i,a} = \sum_{j=1}^{J} X_{i,a}^{j} \gamma_{j,a} + \epsilon_{i,a} \tag{2}$$

Where $ALindex_{i,a}$ is the level of the current allostatic load index. $X_{i,a}^{j}$ is a vector of factors, including health behaviors (smoking, drinking, physical activities), education attainment, household income, and neighborhood SES.

[1] Specifically, systolic blood pressure (SBP), diastolic blood pressure (DBP), ECG related to the cardiovascular system. Body mass index (BMI), total cholesterol, high-density lipoprotein (HDL), glycosylated hemoglobin (HbA1c), and triglycerides related to the cardiovascular system. Glycosylated hemoglobin, and triglycerides related to the metabolic system. Finally, creatinine is related to kidney function.

3. Results

We start by presenting some graphic analysis relating to education and allostatic load, followed by a discussion of the drivers of allostatic load. Figure 2 illustrates the average allostatic load index by age, gender, and education. It reveals a significant gradient in allostatic load across education groups, with the disparity becoming apparent in early adulthood for both females and males. Specifically, for females, the health gap opens up sharply after age 20, narrows in middle age, and slightly increases again later. For males, the gap opens a bit later, around age 25, and increases until middle age, then stabilizes in later years. From this, we can infer that at the onset of early adulthood, the biological health gap between low and high-education groups is relatively small, indicating that the gap only becomes pronounced during adulthood. Early life conditions, childhood experience, and selection may explain the health gap at the young ages.

There may be a few concerns regarding the graphic analysis. The first concern is the impact of the cohort effect. We conduct the analysis by cohort and find that the differences between cohorts are relatively small. However, there is a slight downward trend in the allostatic load index from older to younger generations, likely due to improvements in healthcare, for example. The second concern is mortality bias, which could skew our analysis by increasing the observed health gap in old age. Additionally, we performed a graphic analysis by average household income, and the results were consistent with our findings here.

Figure 3 presents the relative importance of various drivers contributing to the increase of allostatic load, based on the decomposition by age group regressions. The columns display the total R-squared of each regression. Health behaviors exhibit a significant contribution to the increase in allostatic load across gender and age groups. For females, drinking poses a relatively large contribution to the cumulative biological risks, particularly before age 55. The importance of smoking declines rapidly, becoming a minor factor after age 35. Education and income play a relatively significant role after age 25. In contrast, for males, physical activity contributes substantially to allostatic load across all age groups, with its influence increasing even more after age 55. Drinking and smoking also remain important factors, though the impact of smoking declines sharply after age 45.

Health behaviors show a relatively high contribution to the increase of allostatic load across gender and age bins. For females, drinking shows a relatively large contribution to the risks of allostatic load, especially before age 55. The importance of smoking decreases quickly to a small proportion after age 35. Education and income play a relatively important role after age 25. Unlike females, physical activity shows a much higher contribution to allostatic load for males across age bins, even higher after age 55. The contribution of drinking and smoking are relatively important, though the share of smoking sharply decreases after age 45.

4. Conclusion

Using representative data from Dutch Lifelines, we investigate the life cycle profile of biological health and its underlying determinants using objective biomarkers obtained from biomaterial collection and measurements. We develop the allostatic load index to reflect physiological deregulation in response to stress exposure. Consistent with previous research, we highlight the significant role of allostatic load as a mediator in SES-related health disparities in mortality. In our life cycle analysis, we observe that the biological health gap emerges early in adulthood. Socioeconomic factors emerge as a significant determinant throughout the life cycle. Furthermore, our research highlights the importance of the role played by health behaviors in decreasing biological health risks, with different behaviors demonstrating distinct relative importance across age groups and genders.

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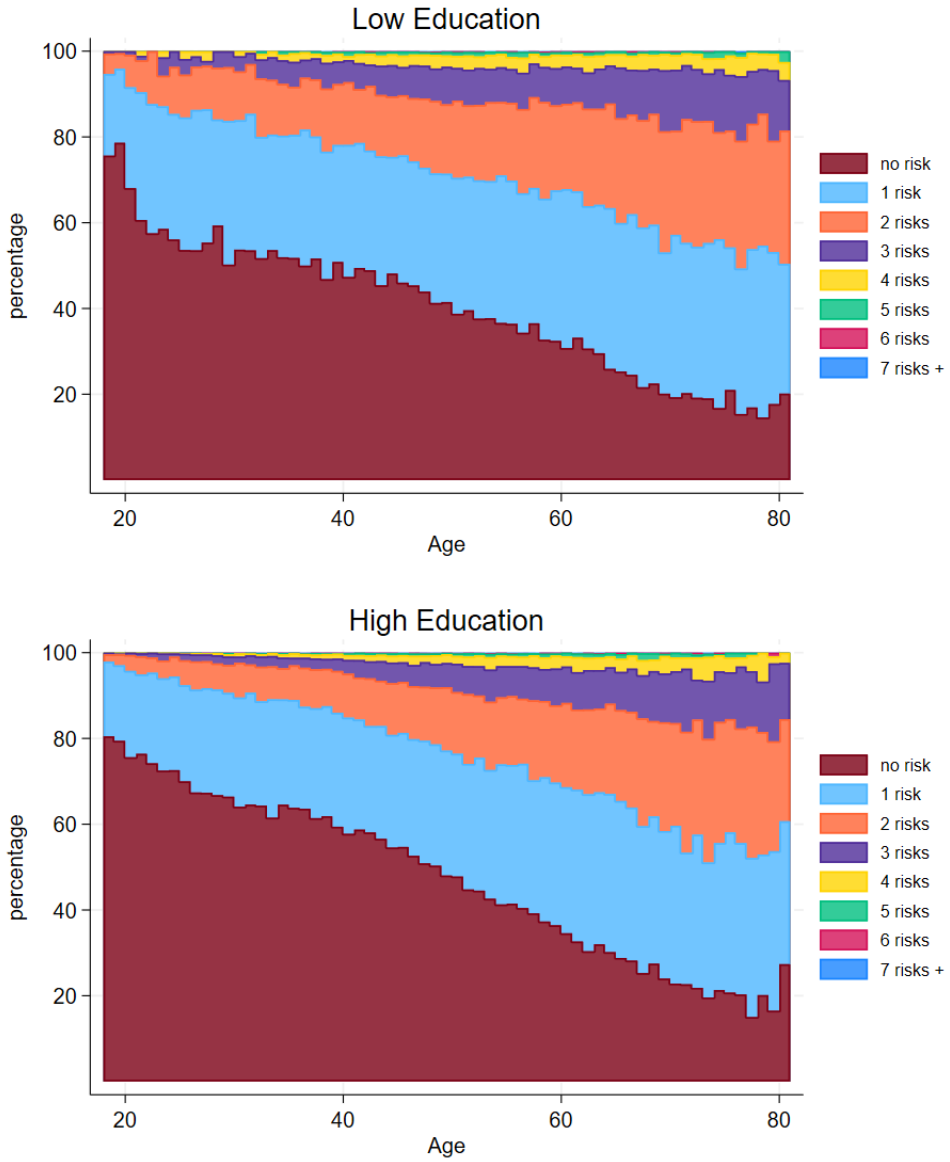


Figure 1: The evolution of the allostatic load index over the life cycle

Note: The figure illustrates the percentage change in the number of risks based on the allostatic load index. We averaged the allostatic load index by age to demonstrate the progression of biological health risks with aging.

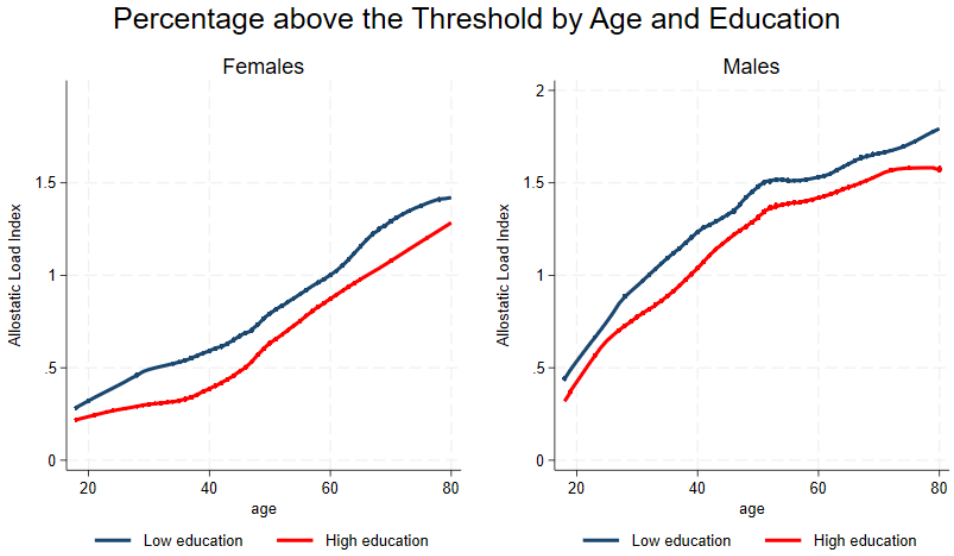


Figure 2: The R-squared contribution of factors to allostatic load index based on the Shapley and Owen decompositions

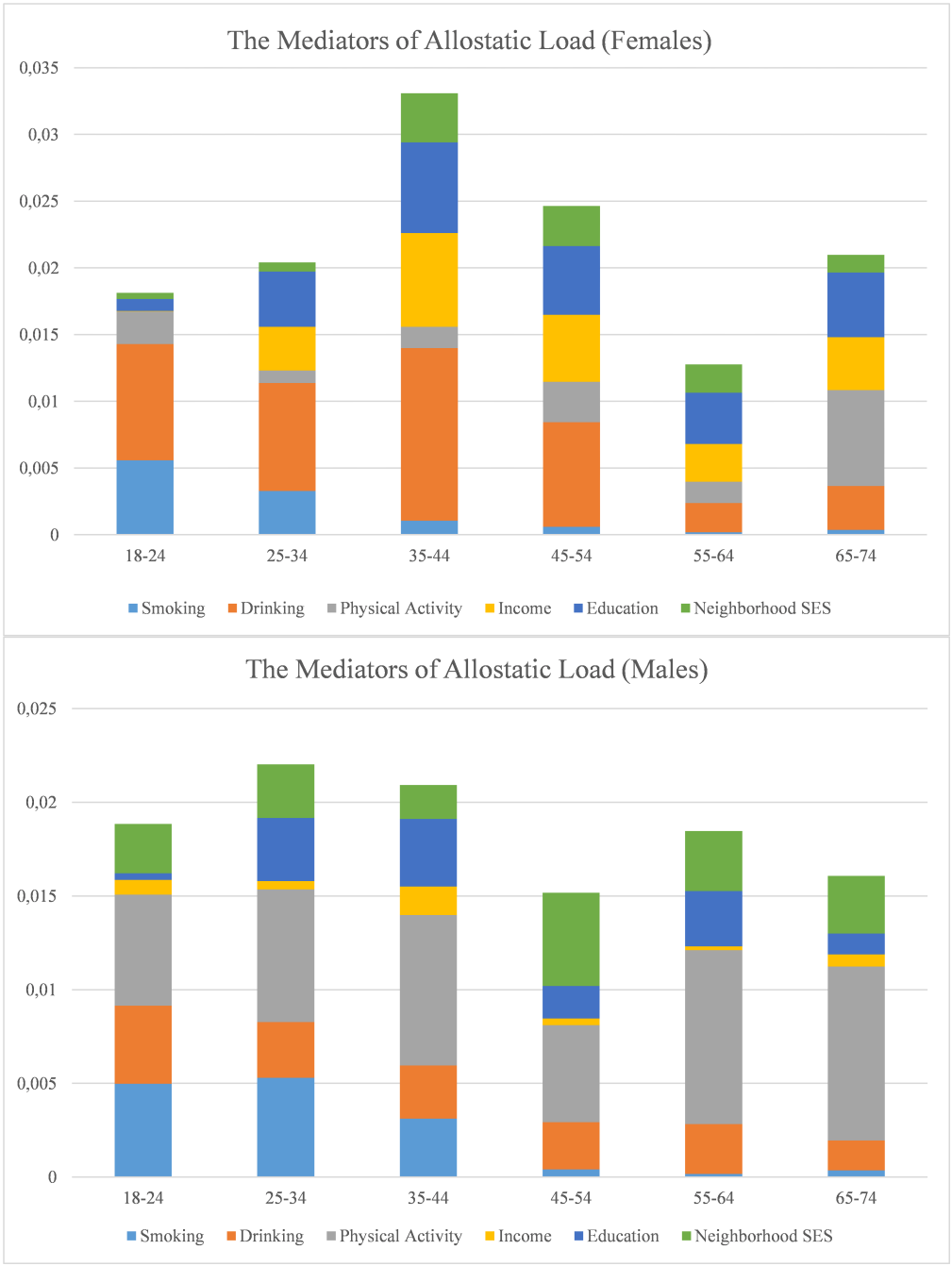


Figure 3: The R-squared contribution of factors to allostatic load index based on the Shapley and Owen decompositions

Note: The figure illustrates the results of Shapley and Owen decompositions of the allostatic load index using a set of regressors from Equation 2. These decompositions are performed separately for different age bins. The stacked column chart depicts the contribution of each regressor to the total R-squared.