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Global health inequality: analyses of life disparity and healthy life disparity

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Background: Alongside average health measures, namely, life expectancy (LE) and healthy life expectancy (HLE), we sought to investigate the inequality in lifespan and healthy lifespan at the worldwide level with an alternative indicator. **Methods:** Using data from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019, we evaluated the global distribution of life disparity (LD) and healthy life disparity (HLD) for 204 countries and territories in 2019 by sex and socio-demographic index (SDI), and also explored the relationships between average and variation health indicators. **Results:** Substantial gaps in all observed health indicators were found across SDI quintiles. For instance, in 2019, for low SDI, female LE and HLE were 67.3 years (95% confidence interval 66.8, 67.6) and 57.4 years (56.6, 57.9), and their LD and HLD were 16.7 years (16.5, 17.0) and 14.4 years (14.1, 14.7). For high SDI, female LE and HLE were greater [83.7 years (83.6, 83.7) and 70.2 years (69.3, 70.7)], but their LD and HLD were smaller [10.4 years (10.3, 10.4) and 7.9 years (7.7, 8.0)]. Besides, all estimates varied across populations within each SDI quintile. There were also gaps in LD and HLD between males and females, as those found in LE and HLE. **Conclusion:** In addition to the disadvantaged LE and HLE, greater LD and HLD were also found in low SDI countries and territories. This reveals the serious challenge in achieving global health equality. Targeted policies are thus necessary for improving health performance among these populations.

Introduction

Life expectancy (LE) and healthy life expectancy (HLE) are crucial summary measures of overall population health.[1] Period LE is the average number of additional years a person at a given age would expect to live if current death rates remain constant (the length of life),[2] while HLE takes into account years lived in unhealthy states and measures the average number of years expected to be lived in good health (the quality of life).[3] However, as average indicators, both miss to capture the heterogeneity in individuals' lifespan and healthy lifespan.[4,5] For instance, two populations having the same level of LE may experience substantial differences in individuals' lifespan.[6] Therefore, increasing attention has been directed towards quantifying lifespan inequality. Such studies provide evidence for the provision of medical care, as well as the designation of policies related to retirement and pension schemes in the long term.[7,8]

Lifespan inequality can be measured by absolute [e.g. life disparity (LD) and the standard deviation] and relative indicators (e.g. Gini coefficient and lifetable entropy).[8] These indicators have been used to compare health conditions across populations.[7,9] A particularly relevant indicator to quantify population health is LD (denoted as $e^{\dagger}$), defined as the average years of life lost attributable to death.[7,9,10] Greater LD indicates that more life years are lost as a result of the uneven distribution of deaths, with some people dying before their expected age at death.[9] Since these indicators may produce discrepant estimates, even when being applied to the same population,[11,12] sensitivity analyses which include more than one of these indicators would provide more robust results.

Currently, at the global level, lifespan inequality and healthy lifespan inequality have been evaluated based on selected indicators, for instance, the standard deviation.[4,5] LD, a life table-based index, has not been used to quantify such inequality. Despite previous studies have proven that LD is highly correlated with other measures including the standard deviation,[7,10] they are not necessarily exchangeable due to their distinctive properties and the underlying concept they measure.[11,12] Therefore, it would also be necessary to evaluate LD-based healthy lifespan inequality, particularly considering its mathematical features and straightforward public health interpretation.[9,10,13]

In this study, we quantified the global lifespan and healthy lifespan inequality, by estimating LD and healthy life disparity (HLD) at the worldwide level. We also explored their associations with LE and HLE. Additionally, partitioning all observed populations by socio-demographic index (SDI) and calculating their HLD values could further deepen our knowledge of global health inequality.

Methods

Computing life table parameters

Mortality data for each age, sex and location were collected from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2019 (http://ghdx.healthdata.org/gbd-results-tool).[14] These data were used to construct life tables for all 204 GBD countries and territories and for both sexes in the year of 2019. This dataset provides updated and comprehensive demographic evaluations of important indicators for 204 countries and territories and selected subnational locations, based on the estimation process using various data sources and strategies.[15] LD, underlined by Vaupel and Canudas-Romo[16] and defined as the average years of life lost attributable to death,[7,9,10] was applied to measure lifespan inequality. The formula is as follows:

$$e^{\dagger} = \frac{1}{l_0}\int_0^{\omega} d(x)e(x)dx,$$

The discrete formula is as below:

$$e^{\dagger} = \left(\sum_{x=0}^{94}\left[d(x)\left(e(x)+a(x)\left[e(x+n)-e(x)\right]\right)\right]+d(95+)e(95+)\right)/l(0)$$

where $d(x)$ and $e(x)$ are the life table distribution of deaths and the remaining life expectancy at age x, $a(x)$ is the average number of years lived between age x and $x+n$ by those that die in the age interval. ω is the open-aged group (95 years and over in this study). $l(0)$ is the initial radix of the population or starting proportion of the cohort, i.e. 100%. In our study, $l(0)$ is set to be 1.

Computing healthy life table parameters

In this study, we followed the methods used in previous GBD publications to estimate HLE for all observed populations.[3,15] Life table parameters, combined with the years lived with disability (YLDs) per capita by age group, sex, and location which were also obtained from GBD 2019, were used to calculate healthy life table parameters, using Sullivan's method.[17] In GBD studies, YLDs were computed as the products of prevalence estimates and disability weights for mutually exclusive sequelae of diseases and injuries.[18] Average health values at age x, defined as $\pi_H(x)$, were computed as 1 − YLDs per capita in that age interval. Healthy person-years at age x, i.e. $L_H(x)$ could be calculated by multiplying L_x (person-years lived at age x) by $\pi_H(x)$ (the average health value at the corresponding age group). Adjusted L_x values, that is, $L_H(x)$ were then used to calculate the total healthy person-years lived from age x, denoted as $T_H(x)$. HLE, denoted as e_H, was computed as the ratio $e_H(x) = T_H(x)/l(x)$.

Healthy lifespan inequality was measured by HLD (denoted as $e_H^{\dagger}$) and defined as the average healthy life years lost due to death. We computed HLD by further applying Sullivan's method[17] to extra life table parameters. For example, the product of $\pi_H(x)$ and life table distribution of deaths, denoted as $d(x)$, returns healthy death distribution $d_H(x) = d(x)\pi_H(x)$. HLD can be mathematically defined as follows:

$$e_H^{\dagger} = \frac{1}{l_H(0)}\int_0^{\omega} d_H(x)e_H(x)dx,$$

The discrete formula is:

$$e_H^{\dagger} = \Big(\sum_{x=0}^{94}\left[d_H(x)(e_H(x)+a(x)\left[e_H(x+n)-e_H(x)\right])\right] + d_H(95+)e_H(95+)\Big)/l_H(0)$$

where $l_H(0)$ is the number of healthy survivors at age 0. In our case, we forced this value to be the sum of all those who died while in the healthy state, that is, $l_H(0) = \sum_{x=0}^{95+} d_H(x)$. Confidence intervals at 95% for all observed health measures were estimated using 1000 times bootstrap, with mortality inputs chosen from a triangular probability distribution based on confidence intervals from GBD release.

Socio-demographic index

The SDI indicator was introduced in GBD 2015 and it is based on the Human Development Index methodology.[3] The index ranges from 0 to 1 and originally it had three main inputs: total fertility rate (TFR) in ages 15–49 years, mean education for those aged 15 years and older, and lag-distributed income per capita.[18] Since then, further refinements to this indicator have been implemented with each GBD cycle. Beginning in GBD 2017, TFR component was replaced by total fertility rate under the age of 25.[15] GBD 2019 SDI is calculated as it was in 2017, but multiplied by 100 at the end for reporting, in order to facilitate interpretation and engagement.[18]

SDI is constructed to capture the background social and economic conditions which shape health outcomes in each location.[15,18] Based on SDI reference quintile values, SDI was categorized into five levels (low, low-middle, middle, high-middle and high).[19] This index has been widely used in GBD publications to investigate the health and disease burden inequalities.[3,15,18] In this study, by including SDI quintiles, we examined whether SDI-related differences also existed in lifespan inequality measures.

Results

Globally, all observed indicators varied significantly across SDI quintiles (table 1). For both sexes, LE and HLE increased with rising SDI; however, LD and HLD declined as SDI increased. For females in low SDI quintile locations, LE and HLE were 67.3 years (95% confidence interval 66.8, 67.6) and 57.4 years (56.6, 57.9), 16.4 and 12.8 years shorter than those in high SDI quintile locations. Conversely, their LD and HLD were 16.7 years (16.5, 17.0) and 14.4 years (14.1, 14.7), 6.3 and 6.5 years greater than females in high SDI quintile, respectively. The similar pattern could also be seen among males, additionally they had lower LE and HLE but greater LD and HLD at all SDI levels, compared with their female counterpart. Detailed estimates for healthy lifespan inequality were also provided in the Supplementary data.

For females and males, proportions of HLE in relation to LE presented small differentials between high and low SDI (83.9% in high SDI and 85.3% in low SDI for females, 86.9% in high SDI and 87.9% in low SDI for males). However, gaps in the proportion of HLD in relation to LD across SDI quintiles were much larger. For low SDI, percentages were 86.2% for females and 88.5% for males, while for high SDI level, corresponding values were only 76% for females and 79.7% for males. Within the same SDI level, the observed estimates also differed, as shown for each location in figure 1.

Figure 2 illustrates sex-specific intersections of LE and LD and the corresponding healthy metrics, i.e. HLE and HLD across SDI quintiles in 2019. In general, negative relationships were observed for

Table 1 Summary health metrics by sex and SDI quintile, 2019

Sex	SDI	LE	LD	HLE	HLD	HLE/LE	HLD/LD
Females	Low	67.3 (66.8, 67.6)	16.7 (16.5, 17.0)	57.4 (56.6, 57.9)	14.4 (14.1, 14.7)	85.3	86.2
	Low-middle	71.6 (71.3, 72.0)	14.7 (14.6, 14.9)	60.9 (60.2, 61.4)	12.4 (12.1, 12.6)	85.1	84.4
	Middle	77.3 (77.1, 77.6)	12.0 (11.9, 12.2)	66.4 (65.6, 66.8)	9.8 (9.6, 9.9)	85.9	81.7
	High-middle	80.6 (80.3, 80.7)	10.6 (10.6, 10.7)	69.2 (68.4, 69.6)	8.4 (8.3, 8.6)	85.9	79.2
	High	83.7 (83.6, 83.7)	10.4 (10.3, 10.4)	70.2 (69.3, 70.7)	7.9 (7.7, 8.0)	83.9	76.0
Males	Low	63.9 (63.3, 64.3)	17.4 (17.2, 17.8)	56.2 (55.4, 56.6)	15.4 (15.0, 15.8)	87.9	88.5
	Low-middle	67.8 (67.4, 68.1)	15.5 (15.3, 15.7)	59.7 (59.0, 60.1)	13.4 (13.1, 13.6)	88.1	86.5
	Middle	72.1 (71.9, 72.4)	13.3 (13.2, 13.5)	64.0 (63.4, 64.3)	11.4 (11.2, 11.5)	88.8	85.7
	High-middle	74.4 (74.2, 74.6)	12.4 (12.3, 12.5)	66.0 (65.5, 66.4)	10.4 (10.2, 10.5)	88.7	83.9
	High	78.5 (78.5, 78.6)	11.8 (11.7, 11.8)	68.2 (67.5, 68.6)	9.4 (9.3, 9.5)	86.9	79.7

Notes: Values in parentheses are 95% uncertainty intervals. LE, life expectancy; LD, life disparity; HLE, healthy life expectancy; HLD, healthy life disparity.

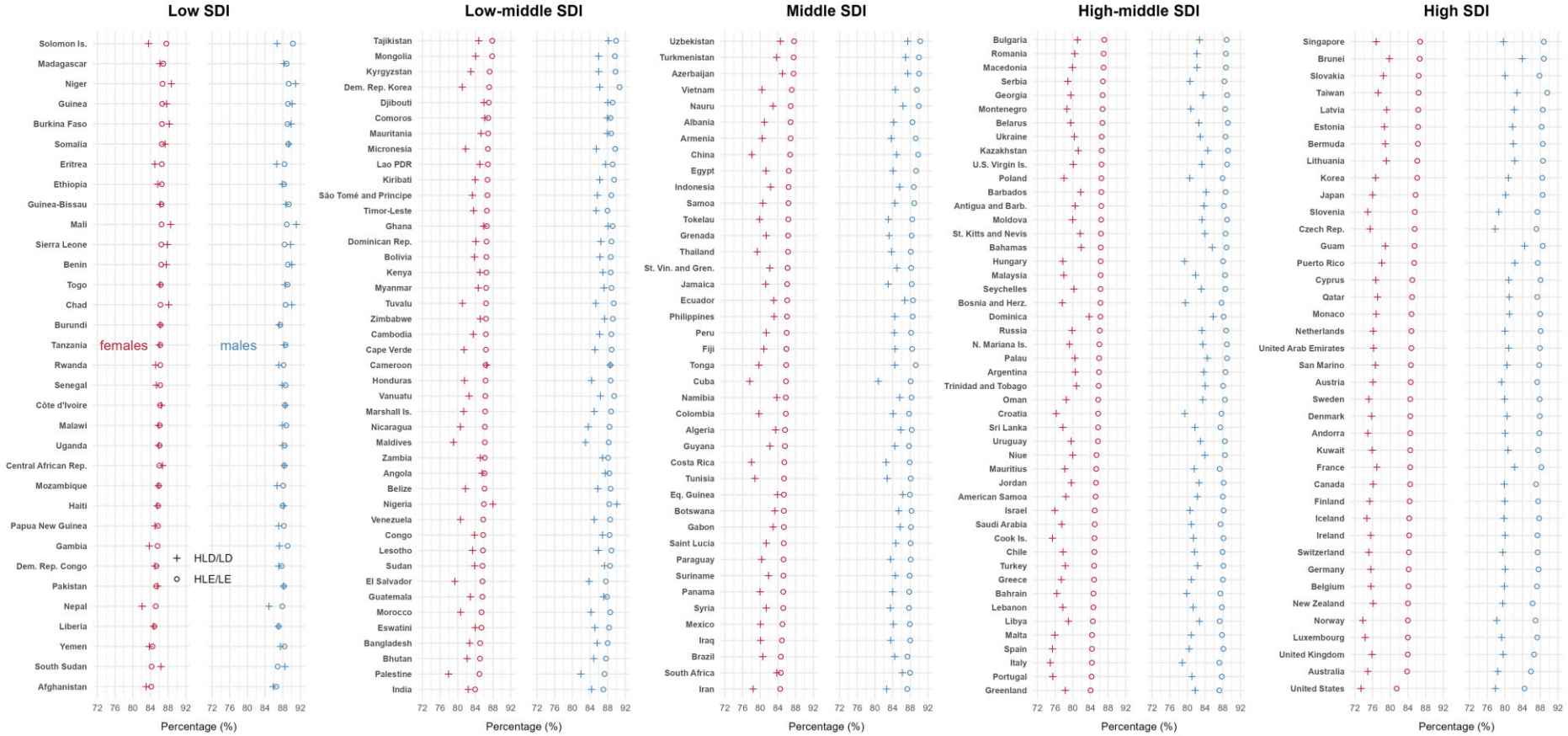

Figure 1 Relative distributions of healthy estimates across sexes and SDI quintiles, 2019. For females and males, HLD/LD (depicted as plus symbol) = healthy life disparity/life disparity, HLE/LE (depicted as circle symbol) = healthy life expectancy/life expectancy. Countries and regions by SDI quintile are sorted ascendingly in HLE/LE for females. SDI, socio-demographic index. Source: Authors' calculations based on data from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019.

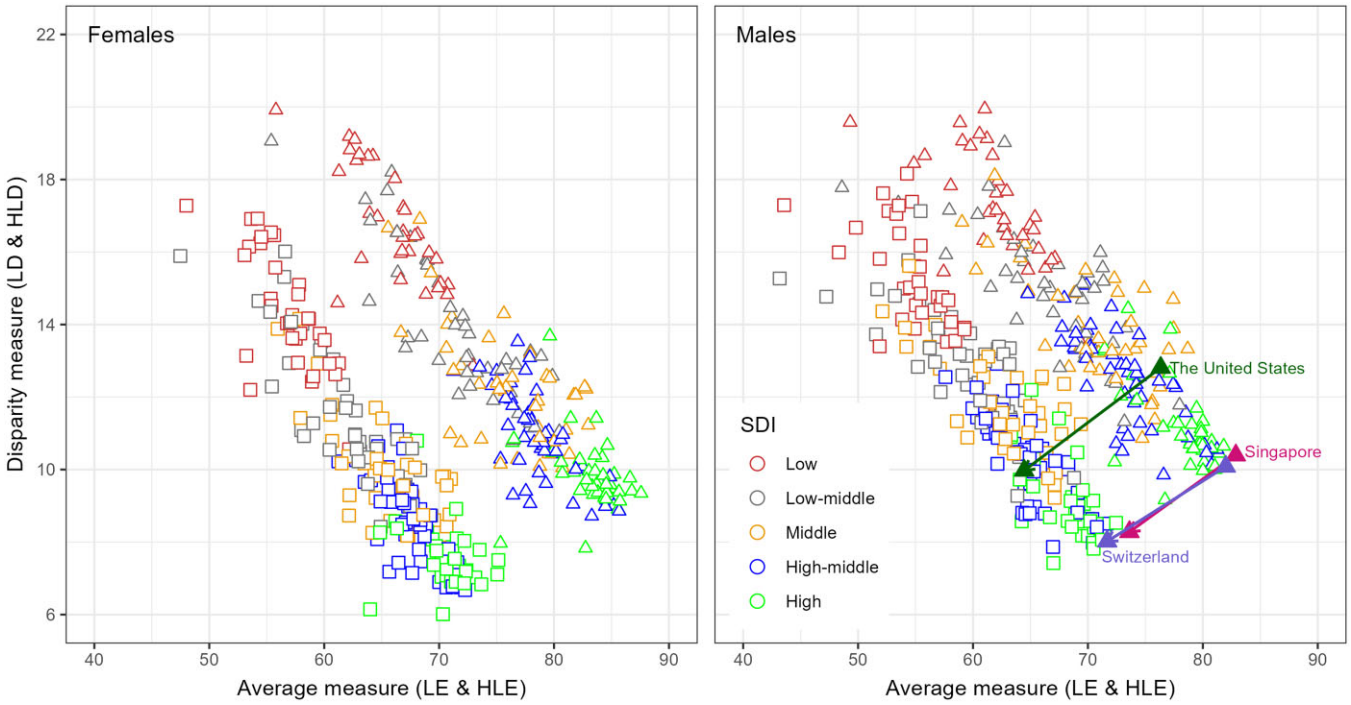

Figure 2 The relationship between life table parameters (triangle symbol for life expectancy and life disparity) and healthy life table parameters (square symbol for healthy life expectancy and healthy life disparity) across SDI quintiles, 2019. Circle symbol in the legend represents colors for different SDI quintiles. LE, life expectancy; LD, life disparity; HLE, healthy life expectancy; HLD, healthy life disparity; SDI, socio-demographic index. Source: Authors' calculations based on data from the Global Burden of Diseases, Injuries, and Risk Factors Study 2019.

both sets of data among females and males. This shows that for all SDI levels, populations with lower LE have greater LD, and those with smaller HLE are also more likely to experience larger HLD. For instance, within high SDI, male LE and HLE were 76.3 years (76.3, 76.4) and 64.5 years (63.8, 64.9) in the United States, much smaller than those in Singapore, which had the largest male LE and HLE in 2019 [82.9 years (82.8, 82.9) and 73.6 years (72.9, 74.0), respectively]. Nevertheless, LD and HLD among males were much greater in the United States than those in Singapore.

However, for some countries, higher LE was not necessarily accompanied with smaller LD, and higher HLE was not necessarily associated with smaller HLD. For instance, despite greater male LE and HLE, compared with Switzerland [82.0 years (81.9, 82.1) and 71.7 years (71.0, 72.1)], Singapore did not have smaller male LD and HLD (10.4 years vs. 10.1 years for LD and 8.3 years vs. 8.0 years for HLD). This highlights the relevance of LD and HLD as complementary measures to LE and HLE.

Discussion

In this study, in addition to LE and HLE, we also conducted the analyses on the variation in lifespan and healthy lifespan, based on a commonly used indicator, i.e. LD. Compared with lower SDI locations, higher SDI locations generally had greater LE and HLE, but experienced smaller LD and HLD. Besides, similar to the relationship between LE and LD, an overall negative correlation could also be observed between HLE and HLD. These results are consistent with previous findings.[4,5]

However, in our study, compared with LD, HLD values were relatively smaller, which means that the variation in individual longevity among healthy people may not be as large as that among the general population. Meanwhile, apart from LD, we also observed that males had greater HLD estimates than females. These results are different from those in recently published studies.[4,5] The non-identical outcomes could be explained by different measurements of such concept, resulting in calculations built on different sources of variability. In previous research,[4,5] with the use of the standard deviation, healthy lifespan inequality was measured by assessing the variability in age-at-morbidity onset, which was derived backwardly from healthy life table estimates provided by GBD. In this study, the analysis was formulated on LD, and HLD was measured as the variability in age-at-death in the healthy population, with both original and healthy life tables calculated following the GBD methodology. This emphasizes the necessity to conduct robust check with alternative indicators, considering their distinctive properties and the underlying concept they measure.[11,12]

Unlike the straight calculation of average health measures, namely LE and HLE, evaluating variability in health can be measured by multiple indicators. Previous perturbation analysis has documented that these indicators including the standard deviation and LD, may display different results, even when being applied to the same population, and this is particularly the case in historical periods when mortality at early ages was relatively high.[11] During mortality crises, e.g. famines and epidemics, absolute and relative measurements of lifespan inequality can even produce contradictory results, with the former decreasing but the latter increasing.[12] Today, partly due to the overall improvements in infant and child mortality, lifespan inequality indicators return similar outputs,[6] but their levels and interpretation are still different.[11,12] With respect to the healthy lifespan inequality, using alternative measures, for example, LD, remains important for a fully and more robust understanding of this new emerging research area.

We also presented an uneven global distribution of LD and HLD across SDI quintiles, with low SDI quintile populations experiencing much greater LD as well as HLD than high SDI populations. This underlines the crucial role of social and economic factors when investigating different health indicators. Their substantial influence on LD across subgroups within populations has been discussed before, based on the individual level data.[20,21] At the country level

captured by different SDI quintiles,[15] such impact may also be relevant. As shown in our study, apart from the general population, SDI levels contribute substantially to the variation in lifespan among healthy people. This suggests that promoting socioeconomic equity would be important for achieving global health equity.

There are some limitations to this study. One of the concerns is the use of the Sullivan method, which assumes that both healthy and unhealthy people would experience the same probabilities of death.[22] This would cause bias when estimating HLE and HLD, as healthy individuals are more likely to have higher survival than those from the original life table. Moreover, this study shed light on global variations in lifespan and healthy lifespan in one given year, namely 2019. Longitudinal studies on this topic could further elucidate how HLD transits over time.

By introducing HLD which is based on LD, our study provides a new perspective for evaluating global health inequality. Apart from smaller LE and HLE, greater LD and HLD were also observed among males and lower SDI quintile populations. The underprivileged health condition for these populations remains a serious challenge for achieving global health equity. Despite SDI may partly explain the substantial health gaps across different locations, more studies would be encouraged to explore the underlying drivers for the uneven distribution of global lifespan and healthy lifespan.

Supplementary data

Supplementary data are available at *EURPUB* online.

Conflicts of interest: None declared.

Data availability

The data used in the study are freely available at http://ghdx.healthdata.org/gbd-results-tool.

Key points

- Global inequalities in lifespan and healthy lifespan by sex and socio-demographic index (SDI) were quantified at a population level.
- Compared with those in high SDI, absolute and relative differences in average and variation health estimates underlined the disadvantaged health performance in low SDI quintile countries and territories of the world.
- This study provides important implications for reducing global inequality in health.

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