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Does living longer mean living healthier? A comprehensive analysis of 204 countries and regions from 1990 to 2019

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Abstract

Background The data from the WHO showed that life expectancy (LE) and health-adjusted life expectancy (HALE) at global level both increased from 2000 to 2019, while they did not increase at the same rate. Therefore, our study aims to explore the relationship and changing trends between LE and HALE, and further comprehensively analyze the factors influencing the difference between the two.

Methods This paper uses data from the Global Burden of Disease (GBD) database in LE and HALE across 204 countries and regions from 1990 to 2019. It analyses the trends of the relationship between LE and HALE at birth and at 65 and over across 204 countries and regions from 1990 to 2019 and classifies all the countries into three types: optimization countries, low deterioration countries and high deterioration countries. Then this paper uses the random effects model to analyze the factors that influence the three types of countries and regions in terms of environmental/occupational risk, behavioral risk, and metabolic risk.

Results First, for males, for indicator of age at birth, 8 optimization countries were with "drug use" having the greatest impact, 98 low deterioration countries were with "low physical activity" being the most significant; 98 high deterioration countries were with "childhood sexual abuse and bullying" being the most significant; for indicator of age at 65 and over, 18 optimization countries were with "low physical activity" having the greatest impact, 98 low deterioration countries were with "drug use" being the most significant; 88 high deterioration countries were with "occupational risk" being the most significant. Second, for females, for indicator of age at birth, 6 optimization countries were with "drug use" having the greatest impact, 107 low deterioration countries were with "child and maternal malnutrition" being the most significant; 91 high deterioration countries were with "drug use" being the most significant; for indicator of age at 65 and over, 14 optimization countries were with "occupational risks" having the greatest impact, 109 low deterioration countries were with "occupational risk" being the most significant; 81 high deterioration countries were with "drug use" being the most significant.

Conclusions Based on the results, it suggested that the policy need to focus on the facts of drug use, occupational risk and low physical activity to narrow the gap between LE and HALE.

Keywords Life expectancy, Health-adjusted life expectancy, Risk factors

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Introduction

Global average LE has increased significantly due to economic development, improvements in people's living standards, advancements in medical technology, and improvements in sanitary conditions [1]. The data released by the World Health Organization showed that LE and HALE both increased from 2000 to 2019, while they did not increase at the same rate. The difference between them at birth increased from 7.45 in 2000 to 8.46 in 2019 for males, and from 9.99 to 11.26 for females. Moreover, the difference between the two for the age 65 and over increased from 3.53 in 2000 to 4.1 in 2019 for males, and from 4.59 to 5.28 for females. These findings suggest that: at the global average level, first, the LE increased at a faster rate than HALE for both males and females; second, the females had a greater increase in both LE and HALE and also a larger rise in the difference values between them than males, which also indicated the "health paradox" for females during this period. Thus, it is essential to understand why this gap exists and to identify the characteristics and trends of the relationship across countries. Furthermore, it is important to explore the factors that may be influencing these trends for males and females separately. Addressing these questions has important theoretical and practical significance. First, it can provide a more comprehensive understanding of the characteristics of the relationship between these two measures across different countries. Second, it can provide valuable policy insight for achieving healthy longevity by analyzing the contributing factors.

Based on compression of morbidity theory [2], many chronic diseases are difficult to cure even with advances in medical technology, but the onset of disease can be delayed. If the onset can be delayed enough, the impact of these chronic disease symptoms on a person's entire life will be short enough that it results in a higher likelihood of the symptoms appearing later in life [3]. However, some researchers have argued that an increase in LE does not necessarily bring about morbidity compression; rather it could result in an expansion or dynamic equilibrium between the two. The expansion of morbidity theory [4, 5] argued that a decline in mortality may result in a deterioration in overall health. As medical technology advances, fatal diseases may gradually shift to become non-fatal diseases, meaning that current survivors are more debilitated and at a higher risk of non-fatal diseases than fatal diseases. Given the challenges in treating chronic diseases, this means that older individuals may be living with non-fatal diseases for a more extended period. Conversely, the dynamic equilibrium theory [6, 7] suggested that the factors that decrease mortality also reduce the severity and progression of chronic diseases. Consequently, an increase in overall LE is accompanied by an increase in both the rates of chronic diseases and the time spent with chronic diseases. The way in which these factors influence LE and disability rates depends on how they affect the incidence and severity of chronic diseases and how these diseases affect disability.

In consider of the conflicting views on the relationship between LE and HALE, a great number of studies using the data to analyze the dynamic trends for them. Crimmins and colleagues analyzed the United States trends form form1970 to 2010, it found that the compression of morbidity occurred in the United States among people 65 years and over [8]. In contrast, the United Kingdom has seen the opposite trend, with an increase in prevalence, healthy life expectancy at age 25 and over increased at a slower rate than LE from 1993 to 2013 [9]. In addition, there is mixed evidence in the same population [10]. With the available data increased, more and more studies were focus on the cross-national differences in healthy living, Mathers and his colleagues (2000) estimated the health LE for 191 countries in 2000, it found that the health LE at birth ranging from 29.5 years to 73.8 years [11]. Comparative work using longitudinal data and multistate analysis is usually limited to developed countries, such as European Union countries [12, 13]. Some studies suggested that neither compression nor expansion of late-life disability is an inevitable consequence of declining mortality. Instead, patterns have varied over time across different demographic and socioeconomic groups. For example, the increase in LE from 1970 to 1980 was largely due to disability prevalence [14]. While, the percentage of disability free LE increased during the 1980s and 1990s [15]. Several long-term studies of disability free LE have noted that not all groups obtain the equal benefit. Crimmins and colleagues (2016) found that between 1970 and 2010, for the whole life course, the increase prevalence of limitations in ADL and IADL was greater than the increase without such limitations, but at age 65 and over, the change was consistent with compression for both men and women [8]. Freedman and his colleagues also found that, for the limitations in ADL and IADL from 1982 to 2011, the dynamic trends were consistent with compression for men, but not women [16, 17] (see Table 1). In this context, both theoretical and empirical studies have been controversial about the relationship between LE and HALE, and the association between the two needs to be analyzed in depth.

Based on the analysis for the changing trends, there are also some researches for explorations into reasons, four different areas have been explored to date: first, demographic and socio-economic changes, such as transfer education [18], occupational and working conditions [19], shift in health and preventive care [20], increased income and social inequality [21, 22]; second, changes in chronic diseases and related treatments, earlier diagnosis and better treatment can reduce the prevalence

Table 1 Summary of main findings of previous empirical studies

Topic	Data	Variables	Countries/areas	Results
[8] Trends in disability-free life expectancy	National Health Interview Survey	Disability free life expectancy	United States	Compression of morbidity for 65 + and no compression of morbidity across the life cycle from 1970 to 2010
[9] Health and mortality in working-age population	Health Survey	Healthy life expectancy	England	Extension of morbidity for 25 + from 1993 to 2013
[10] Trends in health expectancy	Cognitive Function and Ageing Study I and II	Health expectancy	England	Between 1991 and 2011, gains in life expectancy at age 65 years (4.5 years for men and 3.6 years for women) were accompanied by equivalent gains in years free of any cognitive impairment (4.2 years for men and 4.4 years for women).
[11] Estimates of healthy life	Representative health surveys across the world	Healthy life expectancy	191 countries	Health life expectancy at birth ranges from 29.5 years to 73.8 years in 2000
[12] Trends in disability free life expectancy	European Community Household Panel	Disability free life expectancy	EU countries	Disability free life expectancy changing values rang from − 2.2 years in Germany to 3.1 years in Italy from 1991 to 2003
[13] Assessment of the global and national life expectancy	World Mortality Dataset	Life expectancy	The whole world	The global life expectancy appears to have declined by 0.92 years between 2019 and 2020 and by another 0.72 years between 2020 and 2021, but the decline seems to have ended during the last quarter of 2021.
[14] Trends in disability-free life expectancy	National Health Interview Survey	Disability free life expectancy	United States	The life expectancy free of disability for males has been much larger than those for females from1970-1990.
[15] Trends in disability-free life expectancy	Longitudinal Studies of Aging I and II	Disability free life expectancy	United States	Extension of morbidity for 70 + from 1980 to 1990
[16] Active life expectancy between blacks and whites	National Long Term Care Survey and National Health and Aging Trends Study	Active life expectancy	United States	For whites, longevity increased, disability was postponed to older ages, and the proportion of life at older ages spent without disability increased; for blacks, longevity increases were accompanied by smaller postponements in disability, and the percentage of remaining life spent active remained stable and well below that of whites from 1982 to 2011
[17] Active life expectancy between men and women	National Long Term Care Survey and National Health and Aging Trends Study	Active life expectancy	United States	Extension of morbidity for women while compression of morbidity for men from 1982 to 2011

of diseases or delay the onset of disability [23]; third, changes in health-related behaviors, such as changes in the obesity, smoking, physical activity, alcohol consumption and social contacts [24–28]; fourth, the use of assistive devices and technology, it can maintain or improve functional capabilities [29, 30]. The analysis of factors influencing to LE and HALE often occurs in isolation, lacking systematic and comprehensive treatment, in particular, most of the studies confused direct causes with root causes.

To address these gaps, this study seeks to contribute to the literature in the following ways. First, analysis is on the long-term trends of interaction, by focusing on the relationship between LE and HALE and their respective trends, this paper seeks to better describe how HALE evolves with increasing LE. Second, analysis includes all countries and regions, given the large differences in mortality levels and health status among different countries and regions, this paper will examine the unique characteristics of the relationship for all types of countries and regions. Third, analysis is on the comprehensive direct-factors varying with time, given the direct causes tend to have greater implications for policymaking, this paper aims to focus on the comprehensive direct causes and uses random effect model to analyze the effect varying with time.

Method

Data

For the previous studies, both the number and range of the country are limit. The data used in this paper comes from the Global Burden of Disease (GBD) database, which is managed by the World Health Organization and operated and maintained by the Institute for Health Metrics and Evaluation at the University of Washington. The GBD database includes information on mortality and causes of death, diseases, populations, and risk factors for the period spanning from 1990 to 2019 for 204 countries

and regions. The GBD have several advantages for our research: first, it is a comprehensive database including all the 204 countries; second, according to our research purpose, GBD provides the every-year data of LE, HALE and risk factors for every country by age group and sex; third, the GBD re-estimated all the data for all previous years every round due to the definition adjustments to make the data consistent for all the time period and can be compared among different times, countries, sexes and age groups.

Dependent variables

The focus of this paper is to explore the relationship between LE and HALE. The selection and construction of indicators followed the methodology described below.

Life expectancy

Two indicators were selected to measure LE: LE at birth and remaining LE at age 65 and over（based on 65-69 age group）, both of which are directly available in the GBD database. There are measurements for 204 countries and regions spanning from 1990 to 2019. Since there are significant gender differences in LE, males and females are analyzed separately.

Health-adjusted life expectancy

To explore the relationship between LE and HALE, HALE was assessed using two indicators, both of which correspond to LE: HALE at birth and remaining HALE at age 65 and over（based on 65-69 age group）. This data is directly available in the database. The WHO defines the HALE as follows: "average number of years that a person can expect to live in 'full health' by taking into account years lived in less than full health due to disease and/or injury. Sullivan's method uses the equivalent lost healthy year fraction (adjusted for comorbidity) at each age in the current population (for a given year) to divide the hypothetical years of life lived by a period life table cohort at different ages into years of equivalent full health and equivalent lost healthy years".[1]

Relationship between LE and HALE

In this paper, we used the difference value to represent the relationship between LE and HALE, it is calculated by subtracting the HALE at birth and remaining HALE at age 65 from the LE at birth and remaining LE at age 65, respectively, for each country for each year. The difference values reflect the absolute value of non-healthy states throughout the lifespan and the senior years.

Independent variables

In addition to describing the relationship between LE and HALE and its evolution, this paper also seeks to analyze the factors that influence them. The mechanism for mortality and morbidity decrease is through modifying environmental, occupational, behavioral, and metabolic risk factors. GBD provides a framework to estimate both the trends in risk exposure and in burden attributable to risks. In GBD, the risk factors were defined as "an attribute, behavior, exposure, or other factor which is causally associated with an increased (or decreased) probability of a disease or injury. If the probability decreased, the risk is a protective factor". The measure of the risk factors is "a population's exposure to a risk factor that takes into account the extent of exposure by risk level and the severity of that risk's contribution to disease burden, it takes the value zero when no excess risk for a population exists and the value one when the total population is at the highest level of risk; we report it on a scale from 0–100% to emphasize that it is risk-weighted prevalence".[1]The GBD database compiles direct exposure risk factor data by country and year from 1990 to 2019, categorized into four levels. The first level has three overarching categories: environmental/occupational, behavioral, and metabolic risks. These broad categories are further subdivided and measured in more detail at the second, third, and fourth levels, yielding 19, 22, and 40 indicators, respectively. Selecting the appropriate category for analysis involves striking a balance between detail and complexity. While higher levels offer more detail, they can introduce multiple covariates that may affect the analysis. Conversely, lower levels may lack the granularity required for in-depth exploration. After comprehensive consideration, this paper selected the 19 indicators at level 2, as the influence factors for analysis. The GBD database has standardized the scores of all risk factors, it facilitates comparisons across different risk factors, countries/regions, and years. A detailed description of the calculation method and the indicators at each level can be found in the GBD 2019 Risk Factors Panel Report (2020) [31]. In addition, risk factor values are calculated and estimated separately for different age groups and sexes. Values for the entire age group are directly available and those for the senior age group were calculated through age-weighted summary calculations.

Research framework and methodology

The research framework and methodology are described below. First, we calculate the annual differences between LE and HALE for males and females using two indicators across 204 countries/regions. We then describe the changes and trends in these values from 1990 to 2019. The 204 countries/regions are then divided into three categories by subtracting the 1990 difference value from the 2019 difference value (named "trend value") for each country: countries with trend values less than 0 are

[1] GBD 2019 Online Tools Overview.

placed in the first category, named as "optimization countries" (indicating that the longer they live, the healthier they are); countries with trend values greater than 0 and less than the mean trend value (the mean trend value calculated only taking into account the countries with trend value greater than 0, not all the 204 countries) are placed in the second category, named as "low deterioration countries"; countries with trend values greater than the mean trend value are placed in the third category, named as "high deterioration countries" (the country list and corresponding trend values, see Table S1, S2, S3, S4 in supplementary materials). Second, we used the analysis of variance to compare the risk factor scores among three categories of countries. Last, we used the random effects model to analyze the risk factor effect varying with time among 204 countries/regions from 1990 to 2019. The GBD collected most of the data based on the official vital registration data and survey data from WHO member countries and regions, although it is not a strict panel data, the data collection is based on the random principle with enough samples every round, it can be treated as an approximate panel data, so we employ a random effects model to analyze the factors influencing the difference values for the three types of countries and regions.

Results

Sample description

Differences in LE and HALE across 204 countries and regions

The characteristics of the 204 countries and regions in terms of the difference between LE at birth and HALE at birth from 1990 to 2019 are outlined below (see Table 2). First, for males, the average difference between these measures is 7.97 years. No country has a difference of less than 5 years, while 199 countries have a difference between 5 and 10 years, and 5 countries have a difference of more than 10 years. Second, for females, the average difference is 10.42 years. In this case, no country has a difference of less than 5 years, while 94 countries have a difference between 5 and 10 years, and 110 countries have a difference of more than 10 years. These results show that the difference between LE at birth and HALE at birth is greater for females than for males. This suggests that the duration of unhealthy years throughout the lifespan is longer for females in comparison to males.

The characteristics of the 204 countries and regions in terms of the difference between the remaining LE at age 65 and the remaining HALE at age 65 from 1990 to 2019 are outlined below (see Table 2). First, for males, the average difference between the two is 3.53 years. Specifically, 52 countries have a difference of less than 3 years, 150 countries have a difference between 3 and 5 years, and 2 countries have a difference of more than 5 years. Second, for females, the average difference is 4.39 years. Here, 4 countries have a difference of less than 3 years, 153 countries have a difference between 3 and 5 years, and 47 countries have a difference of more than 5 years. These findings indicate that the difference between the remaining LE at age 65 and remaining HALE at age 65 is greater for females than for males. This again suggests that females experience a longer period of unhealthy years in old age compared to their male counterparts.

Risk factor profiles for 204 countries and regions

Following the analysis of the difference between LE and HALE for the 204 countries and regions, this section shifts its focus to delineating the trends in the difference between the two metrics. The objective is to provide an overall view of how LE and HALE have evolved over time among different countries. To this end, all 204 countries/regions are categorized into three groups: optimization countries, low deterioration countries, and high deterioration countries.

Table S5 (see supplementary materials) presents the results of the analysis of variance among the three categories of countries and risk factors for males. There are two main findings. First, in terms of the trend in the difference between LE and HALE at birth, there are 8 countries in the first category, 98 countries in the second category, and 98 countries in the third category. This indicates that, over the entire lifespan, only 8 countries experienced the "compression of morbidity" from 1990 to 2019. There are significant disparities between the three categories of countries on four risk factors: "unsafe water," "other environmental risks," "high LDL cholesterol," and "high body-mass index." Second, in terms of the trend in the

Table 2 The overview of difference value between LE and HALE for 204 countries and regions from 1990 to 2019

	LE at birth - HALE at birth	Classification	Number of countries	RLE at 65 - RHALE at 65	Classification	Number of countries
Male	Mean = 7.97 SD = 5.19	0–5 years	0	Mean = 3.53 SD = 1.24	0–3 years	52
		5–10 years	199		3–5 years	150
		Over 10 years	5		Over 5 years	2
Female	Mean = 10.42 SD = 5.68	0–5 years	0	Mean = 4.39 SD = 1.51	0–3 years	4
		5–10 years	94		3–5 years	153
		Over 10 years	110		Over 5 years	47

Note: LE: life expectancy; HALE: Health-adjusted life expectancy; RLE: Remaining life expectancy; RHALE: Remaining health-adjusted life expectancy; SD: Standard deviation

difference between remaining LE and remaining HALE at age 65, 18 countries are in the first category, 98 countries are in the second category, and 88 countries are in the third category. This indicates that for the elderly, the number of countries experiencing "compression of morbidity" was only 18 from 1990 to 2019. There are significant differences between the three categories of countries on five risk factors: "unsafe water," "air pollution," "other environmental risks," "high fasting plasma glucose," and "high LDL cholesterol".

Table S6 (see supplementary materials) presents the results of the analysis of variance among the three categories of countries and risk factors for females. There are two main findings. First, in terms of the trend in the difference between LE and HALE at birth, 6 countries are in the first category, 107 countries are in the second category, and 91 countries are in the third category. This suggests that, across the entire lifespan, only 6 countries experienced "compression of morbidity" from 1990 to 2019. There are significant differences between the three categories of countries on five risk factors: "unsafe water," "air pollution," "other environmental risks," "tobacco," and "high LDL cholesterol." Second, in terms of the trend in the difference between remaining LE and remaining HALE at age 65, 14 countries are in the first category, 109 countries are in the second category, and 81 countries are in the third category. This indicates that, for the elderly age group, only 14 countries experienced "compression of morbidity" from 1990 to 2019. There were significant differences among the three categories of countries on six risk factors: "unsafe water," "air pollution," "other environmental risks," "tobacco," "high LDL cholesterol," and "kidney dysfunction."

Analysis of influencing factors

This study aimed to examine how risk factors influenced the difference between LE and HALE among 204 countries and regions from 1990 to 2019. Given that 30-year follow-up data was available for each country, panel models were used for the analysis. Panel models typically consist of three types: mixed effects models, fixed effects models, and random effects models. To determine the most appropriate model for each panel data analysis, we conducted two-by-two comparisons among the three models using F-tests, BP-tests, and Hausman tests. Based on the results of these tests, the random effects model was found to be the most suitable for the panel data in this paper. The results of the data analysis presented in the subsequent sections are all based on this method.

The results of the random effects model of the influence of risk factors on the difference between LE and HALE for males at birth for the three categories of countries (see Table 3) showed the following. First, for the optimization countries, the risk factor with the largest

Table 3 Random effects model of risk factors influencing the difference value between LE and HALE at birth

	Male			Female		
	I	II	III	I	II	III
Intercept	-4.147	7.918**	10.766**	38.449**	13.846**	12.960**
A1. Unsafe water	0.021**	-0.005	0.022**	0.094**	-0.015	-0.018
A2. Air pollution	0.045	0.002	0.024**	0.082**	0.002	-0.010
A3. Non-optimal temperature	0.035**	-0.001	0.029**	0.032**	-0.003	-0.024
A4. Other environmental risks	-0.010	0.016**	0.026**	0.130**	0.016**	-0.008
A5. Occupational risks	-0.172	-0.080	-0.261	0.531**	-0.086	-0.175
B1. Child and maternal malnutrition	0.521**	-0.080	-0.083	0.557**	0.152**	0.101**
B2. Tobacco	0.077**	-0.019	-0.019	0.408**	0.030**	-0.013
B3. Alcohol use	0.086	0.016	0.031	0.784**	0.051**	0.023
B4. Drug use	0.855**	-0.543	-0.267	0.827**	-0.583	0.695**
B5. Dietary risks	0.084	0.003	0.044**	0.104**	0.004	-0.032
B6. Intimate partner violence	--	--	--	0.188**	0.006	-0.014
B7. Childhood sexual abuse and bullying	0.049**	-0.022	0.147**	0.770**	-0.048	0.201**
B8. Low physical activity	0.334**	0.131**	-0.011	0.776**	-0.010	0.050
C1. High fasting plasma glucose	0.083**	0.020**	0.073**	-0.014	0.005	0.063
C2. High LDL cholesterol	0.032	-0.002	0.016**	-0.198	-0.002	-0.029
C3. High systolic blood pressure	0.118**	0.006	-0.002	0.125**	-0.010	0.006
C4. High body-mass index	0.105**	0.022**	0.020	0.111	0.025**	0.033
C5. Low bone mineral density	0.303**	0.014	0.022	0.616**	0.036	0.089
C6. Kidney dysfunction	0.233**	-0.008	0.048	0.004	-0.003	0.021
Sample size/number of countries	240/8	2940/98	2940/98	180/6	3210/107	2730/91
R^2	0.708	0.466	0.754	0.839	0.511	0.710

Note: (I) Optimization countries, (II) Low deterioration countries, (III) High deterioration countries, the same below. **indicates $p<0.05$. "--" indicates that the indicator does not apply to this category, the same below

effect is "drug use" (with a standardized regression coefficient of 0.855), followed by "child and maternal malnutrition" (0.521), with "low physical activity" (0.334), and "low bone mineral density" (0.303) also having a large effect. Second, for low deterioration countries, the risk factor with the highest impact is "low physical activity" (0.131), followed by "high fasting plasma glucose" (0.020), and "high body-mass index" (0.022). Third, for high deterioration countries, the most influential risk factor is "childhood sexual abuse and bullying" (0.147), followed by "high fasting plasma glucose" (0.073). These results show that, for the first group of countries, behavioral and metabolic risk factors have a greater impact, for the second group of countries, the impact of metabolic risks is greater, while for the third group of countries, environmental/occupational risks have more influence.

The results of the random effects model of the influence of risk factors on the difference between LE and HALE for females at birth for the three categories of countries (see Table 3) showed the following. First, for the optimization countries, the risk factor with the greatest influence is "drug use" (0.827), followed by "alcohol use" (0.784), "low physical activity" (0.776), and "childhood sexual abuse and bullying" (0.770). Second, for low deterioration countries, the highest impact risk is "child and maternal malnutrition" (0.152), followed by "alcohol use" (0.051). Third, for high deterioration countries, the most influential risk factor is "drug use" (0.695), followed by "childhood sexual abuse and bullying" (0.201). These results show that environmental/occupational and behavioral risks are more influential for the first group of countries, while behavioral risks are more influential for the second group of countries. Behavioral risks are also more influential for the third group of countries.

The results of the random effects model of the influence of risk factors on the difference between remaining LE and remaining HALE for males at age 65 for the three categories of countries (see Table 4) showed the following. First, for the optimization countries, the risk factor with the greatest influence is "low physical activity" (0.105), followed by "non-optimal temperature" (0.071), and "alcohol use" (0.055). Second, for the low deterioration countries, the most influential risk factor is "drug use" (0.802), followed by "occupational risk" (0.228). Third, for the high deterioration countries, the most influential risk factor is "occupational risk" (0.254), followed by "high fasting plasma glucose" (0.024), "high body-mass index" (0.023), and "air pollution" (0.022). These results show that environmental/occupational and behavioral risks are more influential for the first group of countries. Metabolic risks are more influential for the second group, and environmental/occupational and metabolic risks are more influential for the third group.

The results of the random effects model of the influence of risk factors on the difference between remaining LE and remaining HALE for females at age 65 for the

Table 4 Random effects model of risk factors influencing the difference value between remaining LE and remaining HALE at age 65

	Male			Female		
	I	II	III	I	II	III
Intercept	1.008**	2.553**	5.387**	9.186**	5.207**	7.559**
A1. Unsafe water	-0.010	-0.000	0.014**	0.059	-0.005	0.032**
A2. Air pollution	0.034**	-0.002	0.022**	0.019	0.009**	-0.011
A3. Non-optimal temperature	0.071**	-0.003	0.013**	0.021**	-0.006	0.015**
A4. Other environmental risks	0.011	0.003	-0.007	0.023**	-0.001	0.009**
A5. Occupational risks	-0.096	0.228**	0.254**	0.624**	0.251**	0.336**
B1. Child and maternal malnutrition	--	--	--	--	--	--
B2. Tobacco	0.002	-0.006	0.019**	-0.078	0.027**	0.033**
B3. Alcohol use	0.055**	-0.003	-0.005	-0.126	0.020	-0.016
B4. Drug use	-0.610	0.802**	0.645	0.375	0.786	0.692**
B5. Dietary risks	-0.002	-0.002	-0.021	-0.002	-0.004	0.022**
B6. Intimate partner violence	--	--	--	0.003	0.007**	-0.004
B7. Childhood sexual abuse and bullying	0.027	0.058	0.055	0.536**	0.018	-0.138
B8. Low physical activity	0.105**	0.046	0.023	-0.111	0.001	0.062**
C1. High fasting plasma glucose	0.012	0.005	0.024**	-0.007	-0.000	0.011
C2. High LDL cholesterol	0.023**	0.002	-0.011	0.073**	0.011**	-0.007
C3. High systolic blood pressure	0.003	0.001	-0.004	0.024**	0.004**	0.008
C4. High body-mass index	0.000	0.017**	0.023**	-0.006	0.009**	0.010
C5. Low bone mineral density	0.009	0.006	0.012	0.028	0.001	-0.002
C6. Kidney dysfunction	-0.002	0.010**	0.015**	0.088**	0.009**	0.017**
Sample size/number of countries	540/18	2940/98	2640/88	420/14	3270/109	2430/81
R^2	0.836	0.557	0.794	0.708	0.508	0.753

Note: **indicates $p<0.05$

three categories of countries (see Table 4) showed the following. First, for the optimization countries, the risk factor with the greatest influence is "occupational risk" (0.624), followed by "childhood sexual abuse and bullying" (0.536). Second, for the low deterioration countries, the most influential risk factor is "occupational risk" (0.251), followed by "tobacco" (0.027). Third, for the high deterioration countries, the most influential risk factor is "drug use" (0.692), followed by "occupational risk" (0.336). These results show that environmental/occupational risks and metabolic risks are more influential for the first group of countries. Metabolic risks are more influential for the second group of countries, and environmental/occupational risks and behavioral risks are more influential for the third group of countries.

Discussion

Using the Global Burden of Disease (GBD) database, this study conducted a comprehensive analysis of the evolving relationship between LE and HALE, as well as the impact of various direct risk factors on this relationship, across 204 countries and regions worldwide from 1990 to 2019. We found that with the increase in life expectancy, the difference between LE and HALE is also increasing. In 204 countries/regions, less than 10% of countries/regions are experiencing a reduction in unhealthy time. There are significant differences in the factors affecting the difference between LE and HALE between countries and genders.

Consistent with prior studies [4, 9], we found that for males, the difference between LE at birth and HALE at birth from 1990 to 2019 narrowed in only 8 countries, which were primarily influenced by behavioral risk and metabolic risk factors, with "drug use" having the greatest impact. For males, the difference between remaining LE at age 65 and remaining HALE at age 65 narrowed from 1990 to 2019 in only 18 countries and environmental/occupational and behavioral risk factors were the most influential risk factor, with "low physical activity" being the most significant. For females, the difference between LE at birth and HALE at birth narrowed in only 6 countries from 1990 to 2019. In these countries, environmental/ occupational and behavioral risks were the most impactful of the three risk categories, with "drug use" being the most influential risk factor. For females, the difference between remaining LE at age 65 and remaining HALE at age 65 narrowed in only 14 countries from 1990 to 2019. In these countries, environmental/occupational risks and metabolic risks were the most important of the three risk factor categories, with "occupational risks" having the largest impact. This study broadens existing research in terms of the number of study subjects, time scope, etc., except for a few studies [1, 32], existing researches predominantly focus on one or a limited number of countries primarily high-income nations [33, 34].

The difference between LE and HALE is influenced by multiple factors [22, 28], for males, the 98 countries where the difference between LE at birth and HALE at birth have low deteriorated, they were mainly affected by metabolic risk, with "low physical activity" being the most significant. Meanwhile, the 98 high deterioration countries were mainly affected by environmental/occupational risk factors, with "childhood sexual abuse and bullying" being the most significant. For males, the 98 countries where the difference between remaining LE at age 65 and remaining HALE at age 65 have low deteriorated, they were mainly affected by metabolic risk factors, with "drug use" being the most influential risk factor. The 88 high deterioration countries were primarily affected by environmental/occupational and metabolic risk factors, with "occupational risk" being the most influential risk factor. For females, the 107 countries where the difference between LE at birth and HALE at birth have low deteriorated, they were mainly affected by behavioral risk factors, with "child and maternal malnutrition" having the largest impact. The 91 high deterioration countries were mainly affected by behavioral risk factors, with "drug use" having the largest impact. For females, the 109 countries where the difference between remaining LE at age 65 and remaining HALE at age 65 have low deteriorated, they were mainly affected by metabolic risk factors, with "occupational risk" having the greatest impact. The 81 high deterioration countries were mainly affected by the environmental/occupational risk and behavioral risk categories, with the risk factor "drug use" having the greatest impact. This study comprehensively considers various factors affecting the difference between LE and HALE and finds significant differences in influencing factors among different risk countries and genders. Therefore, tailored strategies should be adopted for different groups to increase the proportion of HALE.

In this paper, we analyzed the direct determinants of the relationship between LE and HALE based on the risk factors, there are several implications for our research. First, we have classified all the 204 countries into three categories based on the trend values of age-specific and sex-specific difference values between LE and HALE, according to the results of the analysis of risk factors, each category country for each age group and sex had its own different and crucial determinants, it means the optimization countries, low deterioration countries and high deterioration countries should formulate more targeted policies for different groups to face this problem. Second, the results can be considered as an essential way to indicate the effect of public health policy for each category country. According to the risk factors' changing trends and values, they can provide insights into which

country's current efforts are working or are insufficient. Third, understanding where the risk exposure and prevention is being realized, it can also generate lessons that can be applied to other risks factors in which progress are slow.

Several limitations in our study should be noted. Firstly, this study analyzed and discussed the relationship between the LE and HALE, the results for this paper are only based on the indicator "health-adjusted life expectancy" defined by WHO, while conclusions regarding health changes may vary in term of the specific health indicator and definition used, such as quality adjusted life expectancy [35], quality adjusted life year [36], disability adjusted life years [37], disability free life expectancy [38]. Secondly, in this paper, when categorizing the trends in the relationship between LE and HALE for 204 countries and regions from 1990 to 2019, we calculated the changes over the 30-year period by finding the differences between the values at two points of time, in 1990 and 2019. However, it is important to acknowledge that the trends may have fluctuated in numerous countries and regions over the 30-year period, potentially meaning that the three-type categorization may not be sufficiently precise. Thirdly, this paper divided all the 204 countries and regions into three categories based on the absolute trend values rather than uncertainty intervals, it is worth further consideration for the number and cut point of the classification. Finally, it is worth noting that this paper only analyses the direct factors, while recognizing that the changes in the relationship between LE and HALE are also influenced by some external factors. In the future, we will incorporate more external factors for research.

Conclusion

Our findings confirm that the LE increased at a faster rate than HALE. For males, for the whole life course, 8 optimization countries were with "drug use" having the greatest impact, 98 low deterioration countries were with "low physical activity" being the most significant; 98 high deterioration countries were with "childhood sexual abuse and bullying" being the most significant; for the old population, 18 optimization countries were with "low physical activity" having the greatest impact, 98 low deterioration countries were with "drug use" being the most significant; 88 high deterioration countries were with "occupational risk" being the most significant. For females, for the whole life course, 6 optimization countries were with "drug use" having the greatest impact, 107 low deterioration countries were with "child and maternal malnutrition" being the most significant; 91 high deterioration countries were with "drug use" being the most significant; for the old population, 14 optimization countries were with "occupational risks" having the greatest impact, 109 low deterioration countries were with "occupational risk" being the most significant; 81 high deterioration countries were with "drug use" being the most significant. Based on the results, it suggested that the policy need to focus on the facts of drug use, occupational risk and low physical activity to narrow the gap between LE and HALE.

Abbreviations

LE	Life expectancy
HALE	Health-adjusted life expectancy
RLE	Remaining life expectancy
RHALE	Remaining health-adjusted life expectancy
SD	Standard deviation
LDL	Low Density Lipoprotein

Supplementary Information

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Supplementary Material 1

Author contributions

BX led the study. He designed the study, led the data collection, analysis, and wrote the first draft of the manuscrip. YC contributed to the study design, and provided input into the data analysis. NC contributed to the study design, reviewed the manuscript, and helped the writing of the final draft manuscript. All authors read and approved the final manuscript.

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Data availability

The datasets supporting the conclusions of this article are available publicly, https://gbd2019.healthdata.org/gbd-results/.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Conflict of interest

The authors report no conflicts of interest in this work.

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References

1. Chen H, Ning J, Hu H, Jiang H. Distribution of the compression and expansion of morbidity in 194 countries and territories, 1990–2016: the role of income inequality. Sociol Health Illn. 2023;45(7):1523–40.
2. Fries JF. Aging, natural death, and the compression of morbidity. N Engl J Med. 1980;303(23):130–5.
3. Fries JF. The Compression of Morbidity. Health and Society. Milbank Q. 1983;61(3):397–419.

4. Verbrugge LM. Longer life but worsening health? Trends in health and mortality of middle-aged and older persons and older persons. Milbank Meml Fund Quarterly/Health Soc. 1984;64(3):475–519.
5. Rudberg MA, Carnes BA, Cassel CK, Brody JA. Trading off longer life for worsening health: the expansion of morbidity hypothesis. J Aging Health. 1991;3(2):194–216.
6. Manton KG. Changing concepts of morbidity and mortality in the elderly population. Milbank Meml Fund Quarterly/Health Soc. 1982;60(2):183–244.
7. Freedman VA, Martin LG. Contribution of chronic conditions to aggregate changes in old-age functioning. Am J Public Health. 2000;90(11):1755–60.
8. Crimmins EM, Zhang Y, Saito Y. Trends over 4 decades in disability-free life expectancy in the United States. Am J Public Health. 2016;106(7):1287–93.
9. Jivraj S, Goodman A, Pongiglione B, Ploubidis GB. Living longer but not necessarily healthier: the joint progress of health and mortality in the working-age population of England. Popul Stud - J Demography. 2020;74(3):399–414.
10. Jagger C, Matthews FE, Wohland P, Fouweather T, Stephan BC, Robinson L, Arthur A, Brayne C, Collaboration A. A comparison of health expectancies over two decades in England: results of the cognitive function and ageing study I and II. Lancet. 2016;387(10020):779–86.
11. Mathers CD, Murray CJL, Lopez AD, Salomon JA, Sadana R, Tandon A, Ustün TB, Chatterji S. (2000). Estimates of healthy life expectancy for 191 countries in 2000: methods and results. Global programme on evidence for healthy policy discussion Paper No. 38. World Health Organization.
12. Robine JM, Jagger C, Clavel A, Romieu I. (2005). Disability-free life expectancy (DFLE) in EU countries from 1991 to 2003. *EHEMU Technical Report.*
13. Heuveline P. Global and national declines in life expectancy: an end-of-2021 assessment. Popul Dev Rev. 2022;48(1):31–50.
14. Crimmins EM, Saito Y, Ingegneri D. Trends in disability-free life expectancy in the United States, 1970–1990. Popul Dev Rev. 1997;23(3):555–72.
15. Crimmins EM, Hayward MD, Hagedorn A, Saito Y, Brouard N. Change in disability-free life expectancy for americans 70-years-old and older. Demography. 2009;46(3):627–46.
16. Freedman VA, Spillman BC. Active life expectancy in the older U.S. population, 1982–2011: differences between blacks and whites persisted. Health Affairs (Millwood). 2016;35(8):1351–8.
17. Freedman VA, Wolf DA, Spillman BC. Disability-free life expectancy over 30 years: a growing female disadvantage in the U.S. population. Am J Public Health. 2016;106(6):1079–85.
18. Schoeni RF, Freedman VA, Martin LG. Why is late-life disability declining? Milbank Q. 2008;86(1):47–89.
19. Borg V, Kristensen TS. Social class and self rated health: can the gradient be explained by differences in life style or work environment? Soc Sci Med. 2000;51(7):1019–130.
20. Collins JL, Marks JS, Koplan JP. Chronic disease prevention and control: coming of age at the Centers for Disease Control and Prevention. Preventing Chronic Disease: Public Health Res Pract Policy. 2009;6(3):A81.
21. Link BG, Phelan JC. Social conditions as fundamental causes of diseases. J Health Soc Behav. 1995;35(extra issue):80–94.
22. Phelan JC, Link BG, Tehranifar P. Social conditions as fundamental causes of health inequalities: theory, evidence, and policy implications. J Health Soc Behav. 2010;51(1 Suppl):S28–40.
23. Preston S, Ho J. Low life expectancy in the United States: is the health care system at fault? In National Research Council, International differences in mortality at older ages: dimensions and sources. In: Crimmins EM, Preston SH, Cohen B, editors. Panel on understanding divergent trends in Longevity in High-Income Countries. Committee on Population. Division of behavioral and Social Sciences and Education. Washington, DC: National Academies; 2010. pp. 259–98.
24. Stuck AE, Walthert JM, Nikolaus T, Büla CJ, Hohmann C, Beck JC. Risk factors for functional status decline in community-living elderly people: a systematic literature review. Soc Sci Med. 1999;48(4):445–69.
25. Hu FB. Obesity epidemiology. Oxford University Press; 2008.
26. Holt-Lundstad J, Smith TB, Layton JB. (2010). Social relationships and mortality risk: a meta-analytic review. PLoS Med, 7(7), e1000316.
27. Steptoe A, Wikman A. (2010). The contribution of physical activity to divergent trends in longevity. In National Research Council, International Differences in Mortality at Older Ages: Dimensions and Sources (pp. 193–216).
28. Martin LG, Schoeni RF. Trends in disability and related chronic conditions among the forty-and-over population: 1997–2010. Disabil Health J. 2014;7(1 Suppl):S4–14.
29. Freedman VA, Agree EM, Martin LG, Cornman JC. Trends in the use of assistive technology and personal care for late-life disability, 1992–2001. Gerontologist. 2006;46(1):124–7.
30. Freedman VA, Schoeni RF, Martin LG, Cornman JC. Chronic conditions and the decline in late-life disability. Demography. 2007;44(3):459–77.
31. GBD 2019 Risk Factors Collaborators. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the global burden of Disease Study 2019. Lancet. 2020;396(10258):1223–49.
32. Salomon JA, Wang H, Freeman MK, Vos T, Flaxman AD, Lopez AD, Murray CJL. Healthy life expectancy for 187 countries, 1990–2010: a systematic analysis for the global burden disease study 2010. Lancet. 2012;380(9859):2144–62.
33. Crimmins EM, Beltran-Sanchez H. Mortality and morbidity trends: is there compression of morbidity? Journals Gerontol Ser B: Psychol Sci Social Sci. 2011;66(1):75–86.
34. Yong V, Saito Y. Trends in healthy life expectancy in Japan: 1986–2004. Demographic Res. 2009;20(19):467–94.
35. Masseria C, Allin S, Sorenson C, Papanicolas I, Mossialos E. What are the methodological issues related to measuring health and drawing comparisons across countries? European Commission: Brussels; 2007.
36. National Institute for Heath and Care Excellence (NICE). (2013). Retrieved from http://www.nice.org.uk/website/glossary/glossary.jsp?alpha=Q
37. Murray CJ, Lopez AD. The global burden of disease: a comprehensive assessment of mortality and disability from diseases, injuries and risk factors in 1990 and projected to 2020. Global burden of disease and Injury Series (Vol.1). Harvard University Press; 1996.
38. Organization for Economic Co-operation and Development. A comparative analysis of 30 countries. OECD: Paris; 2001.

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