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Original Research

Association of change in cardiovascular health based on life's essential 8 with incident cardiovascular disease

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ABSTRACT

Objective: To evaluate whether and to what extent changes in cardiovascular health (CVH) based on life's essential 8 (LE8) are associated with incident cardiovascular disease (CVD).
Methods: A total of 7,194 participants were derived from UK Biobank. CVH was evaluated using a modified version of LE8. Participants were classified into three groups according to their LE8 score: high CVH (LE8 score≥80), moderate CVH (50≤LE8 score<80), and low CVH (LE8 score<50). Changes in CVH between 2006/2010 and 2012/2013 were analyzed.
Results: During a median of 10.3 years of follow-up, CVD was observed in 597 participants. Compared to the consistent moderate group, the moderate to low group was associated with about 128 % increased risk of CVD (Hazard ratio [HR]: 2.28; 95 % confidence interval [CI]: 1.61, 3.23), and the relevant HR (95 % CI) was 2.19 (1.46, 3.29) for the consistent low group; no statistically significant results were observed in the other groups. Moreover, no statistically significant exposure-response association between absolute change in LE8 score and incident CVD was documented ($P_{overall}$=0.15).
Conclusion: Change in CVH based on LE8 was associated with the risk of CVD; however, the relationship varied widely in different CVH change patterns.

1. Introduction

Cardiovascular disease (CVD) remains the leading cause of death globally for approximately 30 years[1,2]. To address this great challenge, the American Heart Association (AHA) provided Life's Simple 7 (LS7) metrics, including four behavioral metrics and three biological metrics, in 2010 to monitor cardiovascular health (CVH)[3]. Furthermore, AHA published Life's Essential 8 (LE8) metrics, an updated algorithm of LS7, in 2022[4]. Compared with LS7, LE8 included sleep duration, and more subgroups and corresponding weight coefficients were constructed in each metric to address the relatively low sensitivity to interindividual differences and intraindividual change[4]. LE8 offers more precise information for the monitoring and promotion of CVH.

Similar to LS7, some studies have shown that high CVH assessed using LE8 was associated with a low risk of CVD[4–8]. However, these studies evaluated CVH based on a single assessment; whether and to what extent the change in CVH assessed using the LE8 is related to incident CVD is unknown. Notably, even for LS7, studies on the change in CVH and subsequent cardiovascular events are limited, and their findings are inconsistent[9–11]. Nevertheless, changes in CVH are very common in the real world[12–14]. For example, individuals with poor CVH at baseline are often recommended to improve CVH in the future. It is crucial that clinicians and policymakers should understand the potential clinical benefits or harm of changing CVH.

Consequently, this study aimed to evaluate the association of change in CVH based on LE8 with incident CVD utilizing the data collected at the initial assessment visit (2006–2010) and first repeat assessment visit (2012–2013) of the UK Biobank (UKB).

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2. Methods

2.1. Study population

All data used in this study were derived from the UKB. Detailed information about the UKB are provided in previous studies[15]. Approximately 500,000 participants aged 40–70 years old were recruited between 2006 and 2016, and health information was collected at the baseline. Between 2012 and 2013, approximately 20,000 participants were selected to participate in the first repeat assessment visit, and health assessment data were re-collected. Written informed consent was obtained from each participant, and the study was approved by the North West Multi-center Research Ethics Committee.

Overall, 20,343 participants finished the first two health examinations. Participants with doctor-diagnosed CVD or hospital inpatient records about CVD before the first repeat assessment visit were excluded (n = 1,715). We also excluded participants with missing data on LE8 metrics (n = 4,601 for baseline and n = 6,713 for the first repeat assessment visit). Participants with missing covariate information were also excluded (n = 120). Ultimately, 7,194 participants were included in the main analysis. Detailed information about population selection is provided in **Supplementary Figure 1**. Because of the high proportion of missing data from LE8 score, we compared the characteristics of participants with and without LE8 score at baseline and first repeat assessment visit, respectively. Detailed information is provided in **Supplementary Tables 1–2.**

2.2. Cardiovascular health

We assessed CVH using a modified version of LE8 in this study because the data collected in the UKB was not the same as the data requested in the original LE8[8,16,17]. A healthy diet was defined according to nine items, including processed meat, red meat, fish, milk, spread, cereal, salt added to food, water, and fruits and vegetables, and we assigned 1 point to participants for each health category met. Physical activity was evaluated according to self-reported minutes of moderate or vigorous physical activity per week, and 1 min of vigorous physical activity was treated as 2 min of moderate physical activity[4]. Nicotine exposure was evaluated based on self-reported smoking status and secondhand smoke exposure in the household. Self-reported sleep duration per 24 h was used to assess sleep health. Body mass index (BMI) was calculated as body weight (kg) divided by height squared (m^2). The blood lipid score was measured according to non-high-density lipoprotein (non-HDL) cholesterol and the use of cholesterol-lowering medication. Non-HDL cholesterol was calculated as total cholesterol minus HDL cholesterol. The blood glucose score was evaluated based on a history of diabetes mellitus (DM) and glycated hemoglobin (HbA1c). A history of DM was confirmed by doctor-diagnosed DM and DM-related hospital inpatient records before the date of the first repeat assessment visit. Blood pressure score was evaluated according to mean systolic and diastolic blood pressure and the use of antihypertensive medication. The detailed information used to define the eight metrics is provided in **Supplementary Table 3**.

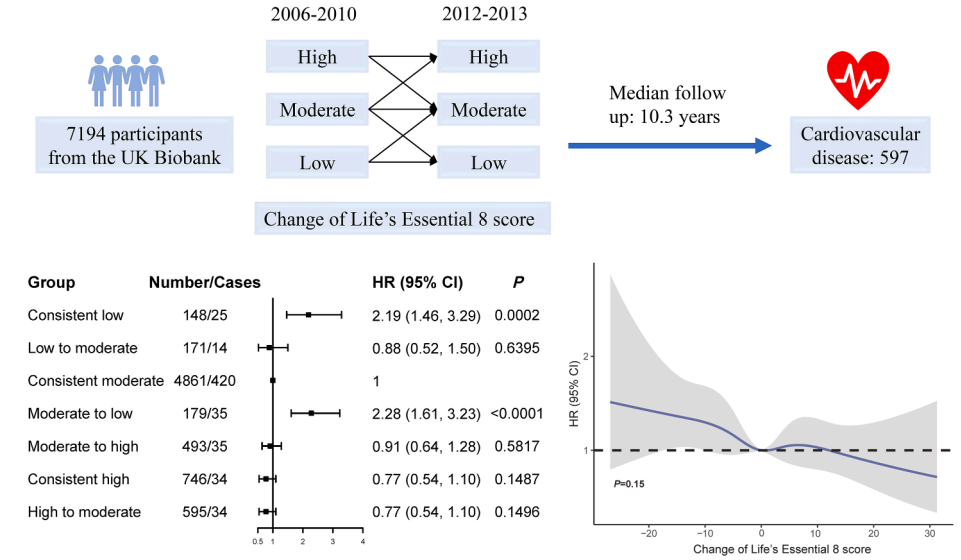
Furthermore, each metric was divided into some subgroups, and each subgroup was assigned a value between 0 and 100 points. CVH was calculated as the mean score of the eight metrics (range, 0–100). The detailed subgroups and corresponding scores of each metric are provided in **Supplementary Table 4**. Moreover, participants we re grouped into three groups according to LE8 score: high CVH (LE8 score≥80), moderate CVH (50≤LE8 score<80), and low CVH (LE8 score<50).

2.3. Covariates

Information about age, sex, race/ethnicity, Townsend deprivation index, education level, family history of CVD, alcohol consumption status, and depression status were collected in the UKB. Education level, family history of CVD, and depression status were confirmed according to information collected at baseline and the first repeat assessment visit. Age and alcohol consumption status were assessed based on information collected at the first repeat assessment visit. Additionally, sex, race/ethnicity, and Townsend deprivation index were evaluated based on information collected at baseline because this information was not re-collected. Detailed information about the covariates is provided in **Supplementary Table 3**.

2.4. Outcomes

Based on previous studies, CVD includes coronary heart disease and stroke in this study. Hospital inpatient and underlying or contributory causes of death records were used to confirm CVD based on the



Change in cardiovascular health based on Life's Essential 8 was associated with the risk of cardiovascular; however, the relationship varied widely in different cardiovascular health change patterns.

Central Illustration

International Classification of Diseases Tenth Revision codes I20–I25 for coronary heart disease and I60–I69 for stroke[18,19]. The follow-up time was from the date of the first repeat assessment visit to the date of CVD diagnosis, death, or June 1, 2023, whichever occurred first.

2.5. Statistical analysis

The baseline characteristics of the participants were described according to the CVH change patterns. Continuous variables are presented as mean and standard deviation (SD), and categorical variables are presented as frequency and percentage. For participants without CVD and with complete data at baseline ($n = 14,163$), we estimated the association between CVH status and risk of CVD. Using the low CVH group as the reference group, Cox proportional risk models were used to estimate the association between CVH status and risk of CVD. Model 1 was adjusted for age, sex, and race/ethnicity. Model 2 was further adjusted for Townsend deprivation index, education level, family history of CVD, alcohol consumption status, and depression status. We also used restricted cubic spline (5 knots) to estimate the exposure-response association between baseline LE8 score and risk of CVD, and the model was adjusted for covariates included in Model 2.

Two strategies were used to evaluate the association between changes in CVH status and incident CVD. First, we treated CVH status as a categorical variable. Participants were classified into nine possible CVH change patterns, including consistent low ($n = 148$), low to moderate ($n = 171$), low to high ($n = 1$), consistent moderate ($n = 4,861$), moderate to high ($n = 493$), moderate to low ($n = 179$), consistent high ($n = 746$), high to moderate ($n = 595$), and high to low ($n = 0$). Low to high and high to low groups were excluded due to the extremely small sample size. Using the consistent low group as a reference category, Cox proportional risk models were used to calculate the hazard ratio (HR) and the corresponding 95 % confidence interval (95 % CI) for each group. Since consistent moderate is the most common pattern, we also calculated the relevant HRs (95 % CIs) using this group as a reference group. Second, CVH status was analyzed as a continuous variable (**Supplementary Figure 2**): 1) Participants were classified into four groups according to the quartiles of absolute change in LE8 score. Cox proportional risk models were used to evaluate the association between change in LE8 score and incident CVD using the first quartile as the reference group. 2) We calculated the HRs and 95 % CIs by adding the absolute change of the LE8 score as a continuous variable in the Cox proportional risk models. 3) A restricted cubic spline with five knots was used to analyze the exposure-response association between absolute change in LE8 score and incident CVD. Two different models were used to estimate the association between change in CVH and incident CVD. Model 1 was adjusted for age, sex, race/ethnicity, and baseline LE8 score (only when CVH was analyzed as a continuous variable). Model 2 was further adjusted for Townsend deprivation index, education level, family history of CVD, alcohol consumption status, and depression status.

We performed three sensitivity analyses to test the robustness of the results. First, we excluded participants who experienced CVD or death events within 1 year of follow-up. Second, we excluded participants with cancer before the start of the follow-up. Third, the change in CVH was

Table 1
Characteristics of participants included in the main analyses.

Characteristics	Change in CVH						
	Consistent low	Low to moderate	Consistent moderate	Moderate to low	Moderate to high	Consistent high	High to moderate
Number (n,%)	148 (2.1)	171 (2.4)	4861 (67.6)	179 (2.5)	493 (6.94)	746 (10.4)	595 (8.3)
Age (Mean, SD)	61.1 (6.4)	62.5 (6.9)	62.5 (7.1)	62.3 (7.0)	61.1 (7.6)	57.8 (7.8)	60.6 (7.7)
Female (n,%)	55 (37.2)	62 (36.3)	2302 (47.4)	71 (39.7)	263 (53.3)	494 (66.2)	364 (61.2)
White (n,%)	147 (99.3)	171 (100.0)	4759 (97.9)	172 (96.1)	482 (97.8)	734 (98.4)	588 (98.8)
Townsend deprivation index (Mean, SD)	−1.4 (2.9)	−1.3 (3.1)	−2.2 (2.6)	−1.5 (3.2)	−2.2 (2.5)	−2.2 (2.5)	−2.1 (2.8)
Non/moderate alcohol consumption (n,%)	80 (54.1)	94 (55.0)	2482 (51.1)	105 (58.7)	291 (59.0)	426 (57.1)	334 (56.1)
Education level (n,%)							
Low	81 (54.7)	102 (59.6)	3136 (64.5)	106 (59.2)	355 (72.0)	542 (72.7)	424 (71.3)
Moderate	25 (16.9)	36 (21.1)	831 (17.1)	31 (17.3)	70 (14.2)	113 (15.1)	86 (14.5)
High	42 (28.4)	33 (19.3)	894 (18.4)	42 (23.5)	68 (13.8)	91 (12.2)	85 (14.3)
Family history of CVD (n,%)	104 (70.3)	115 (67.3)	3275 (67.4)	124 (69.3)	322 (65.3)	443 (59.4)	403 (67.7)
Depression (n,%)	41 (27.7)	34 (19.9)	624 (12.8)	41 (22.9)	59 (12.0)	93 (12.5)	70 (11.8)
LE8 score at baseline (Mean, SD)							
Diet	30.1 (18.8)	34.1 (18.0)	46.4 (19.4)	42.2 (18.6)	50.1 (19.1)	58.8 (18.6)	58.0 (19.0)
Physical activity	28.8 (37.8)	24.7 (32.3)	75.7 (35.0)	70.3 (36.9)	76.0 (35.2)	94.5 (15.2)	94.7 (15.6)
Nicotine exposure	43.9 (39.7)	55.7 (36.4)	79.7 (27.9)	57.7 (37.2)	88.8 (20.8)	94.5 (13.3)	91.9 (17.2)
Sleep health	76.2 (26.3)	82.5 (21.8)	90.9 (16.6)	89.2 (19.4)	91.8 (15.0)	96.5 (9.7)	96.1 (11.0)
BMI	35.7 (25.4)	39.6 (25.4)	70.3 (25.6)	49.4 (27.0)	83.7 (20.0)	94.3 (12.4)	90.3 (15.6)
Blood lipids	31.2 (25.9)	31.5 (26.1)	42.9 (25.5)	40.3 (27.2)	49.5 (26.1)	75.3 (26.6)	69.0 (27.8)
Blood glucose	77.2 (26.9)	77.6 (25.5)	93.0 (16.9)	83.9 (25.1)	96.7 (11.3)	98.9 (6.5)	98.6 (7.6)
Blood pressure	20.3 (22.1)	19.1 (18.9)	37.4 (29.4)	34.9 (27.6)	51.0 (30.2)	76.3 (24.8)	69.9 (27.8)
Total	42.9 (5.6)	45.6 (4.3)	67.0 (7.3)	58.5 (6.3)	73.4 (5.2)	86.1 (4.3)	83.6 (3.3)
LE8 score at repeat visit (Mean, SD)							
Diet	29.8 (18.7)	41.5 (18.2)	45.7 (18.8)	33.3 (17.5)	59.0 (18.3)	57.2 (18.3)	49.0 (17.9)
Physical activity	31.6 (36.3)	72.5 (35.6)	78.6 (32.9)	30.3 (36.9)	96.8 (10.0)	96.0 (12.1)	79.3 (33.5)
Nicotine exposure	48.4 (37.8)	65.9 (31.0)	82.0 (25.1)	56.5 (36.5)	93.1 (14.6)	94.9 (12.6)	90.6 (19.3)
Sleep health	76.1 (27.4)	90.6 (15.9)	90.5 (16.9)	76.0 (24.5)	95.5 (11.7)	95.8 (11.0)	91.8 (15.8)
BMI	35.2 (25.5)	47.7 (28.3)	70.2 (25.7)	40.7 (25.6)	91.1 (14.3)	94.1 (12.6)	84.0 (19.7)
Blood lipids	35.1 (27.8)	42.9 (30.4)	42.7 (26.3)	29.8 (27.3)	61.9 (27.1)	70.1 (27.4)	50.7 (25.1)
Blood glucose	68.9 (27.1)	80.6 (25.6)	90.6 (18.9)	73.5 (27.4)	97.8 (9.7)	98.2 (8.2)	94.8 (13.9)
Blood pressure	19.2 (20.8)	33.0 (25.6)	35.0 (29.2)	20.6 (19.9)	67.7 (28.3)	75.1 (26.4)	50.4 (30.3)
Total	43.0 (5.4)	59.3 (7.0)	66.9 (7.1)	45.1 (4.5)	82.9 (3.0)	85.2 (4.1)	73.8 (4.9)

CVH: cardiovascular health. SD: standard deviation. LE8: Life's Essential 8. CVD: cardiovascular disease. BMI: body mass index. Education level: high level: College or University degree, NVQ or HND or HNC or equivalent; middle level: A levels/AS levels or equivalent, Other professional qualifications (e.g.: nursing, teaching); low level: O levels/GCSEs or equivalent, CSEs or equivalent. CVH level: high group: LE8 score ≥80, moderate group: 50≤LE8 score<80; low group: LE8 score <50. Low to high ($n = 1$) and high to low ($n = 0$) groups were excluded here due to the extremely small sample size.

limited to 3–5 years. All data analyses were performed using R version 4.1.3, and two-tailed $P < 0.05$ was considered statistically significant.

3. Results

Among 7,194 participants, the mean (SD) age was 61.7 (7.4) years, and 3,611 (50.2 %) were females. Table 1 shows the baseline characteristics of the participants. The change in CVH showed that most of the participants 4,861 (67.6 %) remained in the consistent moderate group, 664 (9.2 %) participants experienced an increase in CVH level, and 774 (10.8 %) experienced a decrease in CVH level. Participants in the consistent low group not only had a higher prevalence of family history of CVD and depression but were also more likely to be male and have a low education level than those in the consistent high group.

Compared to the high CVH group at baseline, the risk of CVD was increased in the moderate and low CVH group, the fully-adjusted HRs (95 % CIs) were 1.56 (1.31, 1.87) and 2.14 (1.66, 2.76), respectively (**Supplementary Table 5**). We also documented a linear exposure-response association between baseline LE8 score and risk of CVD ($P_{overall}<0.01$, $P_{non\text{-}linear}=0.99$) (**Supplementary Figure 3**). During a median of 10.3 years of follow-up, CVD events were observed in 597 participants. Compared to the consistent low group, the risk of CVD decreased in the other groups, except for the moderate to low group. The multivariable-adjusted HRs (95 % CIs) were 0.40 (0.21, 0.77) [low to moderate], 0.46 (0.30, 0.69) [consistent moderate], 0.41 (0.25, 0.70) [moderate to high], 0.35 (0.21, 0.59) [consistent high], and 0.35 (0.21, 0.59) [high to moderate] for each pattern, respectively (Fig. 1A). When using the consistent moderate group as the reference group, the moderate to low group was associated with about 128 % increased risk of CVD (HR: 2.28; 95 % CI: 1.61, 3.23), and the relevant HR (95 % CI) was 2.19 (1.46, 3.29) for the consistent low group (Fig. 1B). Although protective effects were observed in other groups, the results were not statistically significant (Fig. 1B).

The mean (SD) LE8 score was 69.6 (11.2) at baseline and 69.3 (10.8) at the first repeat assessment visit. Compared to the first quartile, the risk of CVD decreased by 23 % for the third quartile (HR: 0.77; 95 % CI: 0.61, 0.99), and no statistically significant associations were observed in the second and fourth quartiles (Table 2). When the change in LE8 score was analyzed as a continuous variable, per 5-point increase in LE8 score was associated with a 6 % decreased risk of CVD (HR: 0.94; 95 % CI: 0.93, 0.95). The restricted cubic spline analysis results (Fig. 2) showed that there was no statistically significant exposure-response association between absolute change in LE8 score and incident CVD ($P = 0.15$).

The results of sensitivity analysis were consistent with those of the

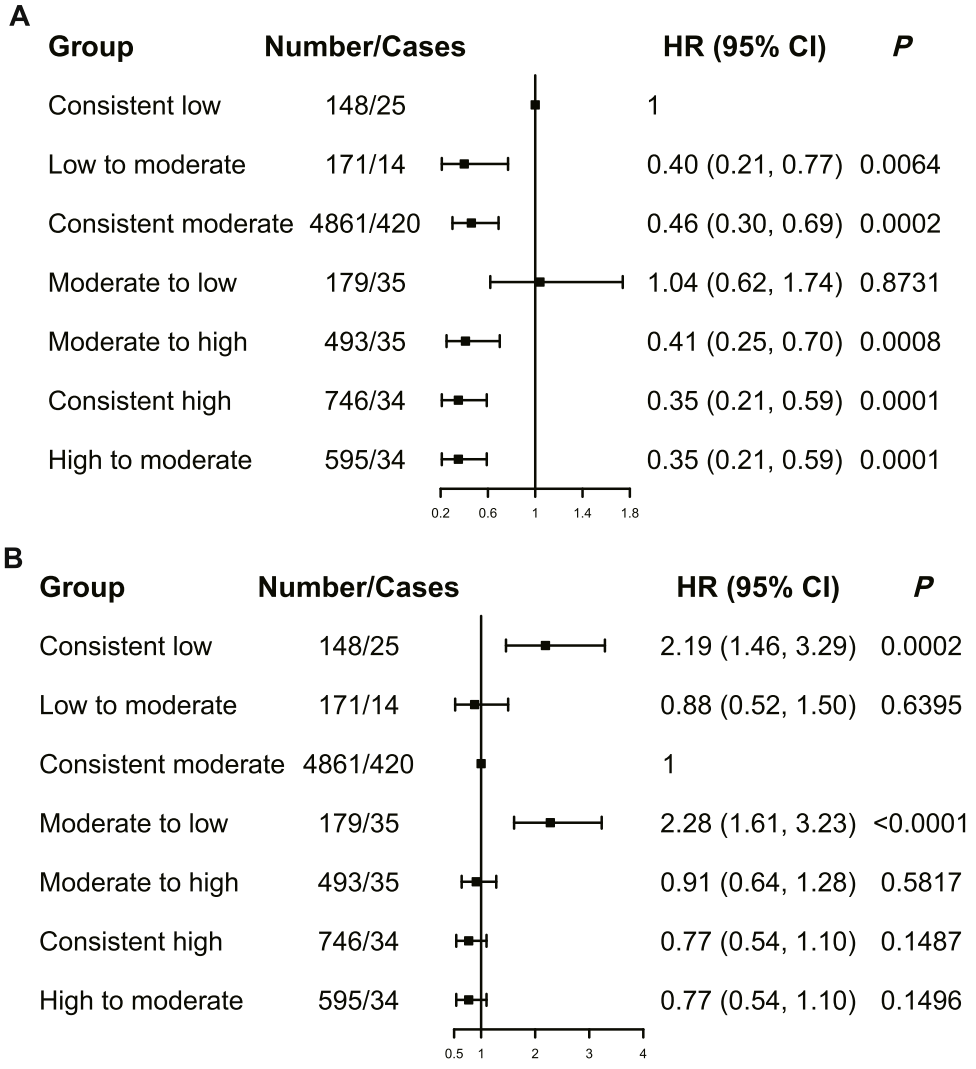


Fig. 1. Association between CVH change patterns and CVD incidence.
A: using the consistent low group as the reference group; B: using the consistent moderate group as the reference group; CVH: cardiovascular health; CVD: cardiovascular disease; HR: hazard ratio; 95 % CI: 95 % confidence interval; low to high ($n = 1$) and high to low ($n = 0$) groups were excluded here due to extremely small sample size.

Table 2
Hazard ratios (95 % CIs) of CVD with an absolute change of CVH.

Models	Absolute change of LE8 score, HR (95 % CI)					
	Categorical variable				Continuous variable	
	Quartile 1	Quartile 2	Quartile 3	Quartile 4	Per 5-point increase	Per 10-point increase
Model 1	1 [Reference]	0.96 (0.76, 1.21)	0.77 (0.60, 0.98)	0.86 (0.67, 1.09)	0.94 (0.93, 0.95)	0.88 (0.87, 0.89)
Model 2	1 [Reference]	0.97 (0.77, 1.22)	0.77 (0.61, 0.99)	0.87 (0.68, 1.10)	0.94 (0.93, 0.95)	0.89 (0.88, 0.90)

HR: hazard ratio; 95 % CI: 95 % confidence interval; CVH: cardiovascular health; LE8: life's essential 8; Model 1 was adjusted for age, sex, race/ethnicity, and LE8 score at baseline; Model 2 was further adjusted for Townsend deprivation index, education level, family history of CVD, alcohol consumption and depression status.

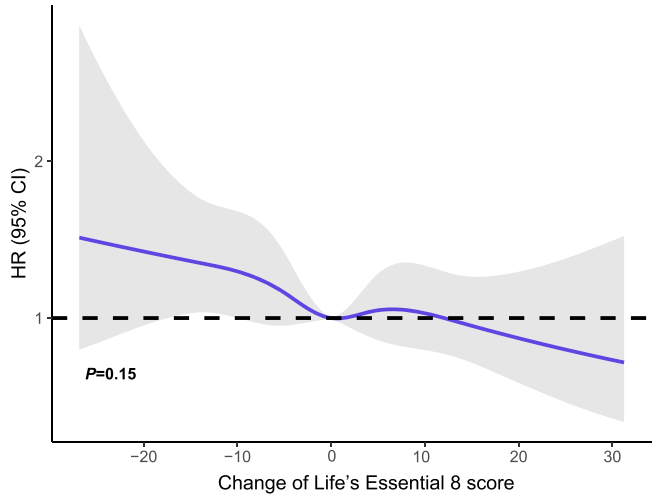


Fig. 2. Exposure-response association between change of CVH score and CVD incidence.
CVH: cardiovascular health; CVD: cardiovascular disease; HR: hazard ratio; 95 % CI: 95 % confidence interval

main analysis. Compared to the consistent low group, changes in CVH patterns were associated with a decreased risk of incident CVD (HRs, 0.27–0.50), except for the moderate to low group (Table 3). When the change in LE8 score was analyzed as a continuous variable, per 5-point increase in LE8 score was associated with 5 %, 7 %, and 7 % decreased risk of CVD in the sensitivity analysis, respectively.

Table 3
Association between change in CVH and CVD incidence in sensitivity analyses.

Change in CVH	HR (95 % CI)		
	Sensitivity analysis 1	Sensitivity analysis 2	Sensitivity analysis 3
Categorical variable			
Low to moderate	0.38 (0.18, 0.78)	0.44 (0.22, 0.87)	0.33 (0.15, 0.76)
Consistent moderate	0.50 (0.32, 0.78)	0.46 (0.30, 0.72)	0.42 (0.25, 0.69)
Moderate to low	1.10 (0.63, 1.91)	0.99 (0.57, 1.72)	0.81 (0.42, 1.58)
Moderate to high	0.46 (0.27, 0.80)	0.42 (0.24, 0.72)	0.32 (0.17, 0.62)
Consistent high	0.38 (0.22, 0.66)	0.27 (0.15, 0.49)	0.29 (0.15, 0.57)
High to moderate	0.40 (0.23, 0.70)	0.36 (0.20, 0.62)	0.32 (0.17, 0.61)
Continuous variable			
Per 5-point increase	0.95 (0.94, 0.96)	0.93 (0.92, 0.94)	0.93 (0.92, 0.94)

HR: hazard ratio; 95 % CI: 95 % confidence interval; CVH: cardiovascular health; LE8: life's essential 8; Sensitivity analysis 1: we excluded participants who experienced CVD or death events within 1 year of follow-up. Sensitivity analysis 2: we excluded participants with cancer before the start of follow-up. Sensitivity analysis 3: the change of CVH was limited to 3 to 5 years. Models were adjusted for age, sex, race/ethnicity, and LE8 score at baseline, Townsend deprivation index, education level, family history of CVD, alcohol consumption, and depression status.

4. Discussion

In this study, consistent low and moderate to low groups were associated with a higher CVD risk than other CVH change patterns. No statistically significant exposure-response association between change in LE8 score and CVD incidence was documented.

Some previous studies have indicated that CVH status is under dynamic change. van Sloten et al. found that 42.1 % of participants experienced a change in CVH status in the Whitehall II study[9], and the proportion was about 41.4 % in the Kailuan cohort study[11]. However, limited empirical evidence exists on the association between CVH change and incident cardiovascular events. Most studies have indicated that improvement of CVH from low to moderate/high status is associated with a decreased risk of cardiovascular events, such as sudden cardiac death[14], stroke[12], and premature cardiovascular events [10]. Compared with the consistent low group, Gaye et al. showed that the risk of CVD was statistically decreased in the low to moderate/high group[20], whereas van Sloten et al. found that the risk of CVD was not significantly changed in the low to moderate and low to high groups[9]. Our study provides additional evidence on this topic, as we demonstrated that CVH improvement from the low to moderate group was associated with a 60 % decreased risk of CVD.

Additionally, to our knowledge, this is the first study to evaluate the change in CVH using LE8, which is more precise in evaluating CVH than LS7. Although most participants (77 %) were classified into a moderate level of CVH at baseline (**Supplementary Table 5**), consistent moderate group has been evaluated as a reference group in only one previous study[21]. This means that most people do not know how CVD risk will change if they maintain, decrease, or increase the LE8 score. In addition to previous studies, we provided insight into the association of change in CVH with CVD incidence by using both the consistent low group and the consistent moderate group as the reference group. Compared to the consistent moderate group, the results showed that the risk of CVD increased significantly in the consistent low group (HR: 2.19, 95 % CI: 1.46, 3.29) and the moderate to low group (HR: 2.28, 95 % CI: 1.61, 3.23). These results were consistent with those of the only previous study that revealed that the moderate to low group was associated with a 45 % increased risk of subclinical atherosclerosis when compared with the consistent moderate group[21]. The results from previous studies and ours should be carefully interpreted in clinical practice, as some differences exist between them. These differences could be explained by many possible reasons: 1) the definition of CVH was not exactly the same; 2) the definition of outcomes varied in studies; 3) the time interval used to evaluate changes in CVH varied widely; and 4) the data used in different studies were collected at different years. Further studies are needed to verify the association between changes in CVH status and CVD incidence.

The associations between absolute change in CVH score and incident cardiovascular events have also been evaluated in some previous studies, and all the results showed that both per 1 additional ideal metric and per 1-point increase in CVH score were associated with a decreased risk of cardiovascular events[9,10,13,14,21]. Lee et al. found that per

1-point increase in the CVH score based on LS7 (total 14 points) was associated with a 21 % decrease in the risk of premature cardiovascular events[10], and Yang et al. showed that per 1 additional ideal metric based on LS7 was associated with a 13 % decrease in the risk of total stroke[13]. These results were further confirmed in our study, and we found that per 5-point increase in CVH score based on LE8 (total of 100 points) was associated with a 6 % decrease in the risk of CVD. However, previous studies have never evaluated whether the association between the absolute change in CVH score and incident cardiovascular events was linear or nonlinear. This is the first study to evaluate the exposure-response association between absolute change in CVH score and CVD incidence, and no statistically significant exposure-response association between change in LE8 and risk of CVD was documented. This hinted that the estimated HR for per 1-point or per 1-additional ideal metric increase in CVH may be biased, and these results should be carefully implemented in clinical practice. The inconsistent results could be explained by several possible reasons: 1) there may be truly no exposure-response relationship between change in LE8 score and CVD incidence. Notably, participants were classified into four groups according to the quartiles of change in LE8 score, and no statistically significant change in CVD risk was observed in the second and fourth quartiles in this study when compared with the first quartile; 2) the risk of CVD may be not only determined by the status of CVH at two time points, but also influenced by how long participants were maintaining at each CVH status. However, this data was not collected in the UKB; 3) although we included 7,194 participants in this study, most of the participants were classified into the consistent moderate group (67.6 %), and the absolute change of LE8 score ranged from −10 to 10 for most participants (**Supplementary Figure 2**). This means that the sample may be not large enough in this study. The exposure-response association between change in CVH and CVD incidence should be further explored in other studies

Although the exact association between changes in CVH status and subsequent CVD incidence should be further evaluated in future researches, previous studies and our results showed that remaining at a low CVH status and changing from moderate to low CVH status were associated with an increased risk of CVD. This result means that strategies should be taken to ensure that participants maintain at least a moderate CVH status. As for this study, we found that the mean scores for blood pressure, blood lipids, BMI, diet, and physical activity were relatively low in the second measurement in the consistent low and moderate to low groups. Thus, corresponding strategies, such as increasing blood pressure control rates, enhancing physician education and training in nutrition, and improving the community-built environment to encourage an active lifestyle, could be implemented to improve CVH in this population[22–24].

This study had two strengths. First, the change in CVH was evaluated using LE8, which is more precise than LS7. Second, restricted cubic spline analysis was used to evaluate the exposure-response association between CVH change and incident CVD. This study also had some limitations. First, reverse causality was not considered because of the observational nature of the UKB. Second, a high proportion of missing data from LE8 score was documented in this study, and we documented statistically significant differences about some variables between participants with and without LE8 score, this may weaken the representativeness of the results. Third, two CVH change patterns (low to high group and high to low group) were excluded due to the extremely small number of participants in this study, the associations between the two CVH change patterns and CVD incidence should be further evaluated in other studies. Fourth, the time interval between the two measurements of CVH ranged from 2.1 to 6.1 years. However, the results remained unchanged when we limited the time interval to 3–5 years. Fifth, the CVH status was only evaluated at two fixed time points, and the duration for which participants maintained a certain CVH status was unclear. Finally, the generalizability of our results is limited by the selection bias of the participants in the UKB, and most of the participants were white.

5. Conclusions

Conclusively, our investigation of participants from the UKB demonstrated that change in CVH based on LE8 was associated with the risk of CVD, however, the relationship varied widely in different CVH change patterns. No statistically significant exposure-response association between change in LE8 score and CVD incidence was documented in this study. These results should be further verified in future studies.

Ethics approval and consent to participate

The study was approved by the North West Multi-center Research Ethics Committee (11/NW/0382). Informed consent was obtained from all individual participants included in the study.

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CRediT authorship contribution statement

Chao Song: Writing – review & editing, Writing – original draft, Visualization, Validation, Funding acquisition, Conceptualization. **Xunjie Cheng:** Writing – review & editing, Visualization, Software, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yongping Bai:** Writing – review & editing, Visualization, Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ajpc.2024.100668.

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