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ORIGINAL ARTICLE

Associations of psychosocial factors with cardiovascular health in aging: insights from the Inlife-Aging Project

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Abstract Life's Essential 8 (LE8) provides a multidimensional framework to assess cardiovascular health (CVH) in aging populations. The objective of this study was to describe LE8 component scores and their variation by age, sex, and psychosocial factors in middle-aged and older adults from Cádiz, Spain. Cross-sectional data were analyzed from 495 adults aged 50–79 years (59.4% women; 34.7% ≥ 65 years). LE8 scores were calculated following American Heart Association guidelines. Group comparisons used t-tests, ANOVA, and chi-square tests to explore differences across demographic and psychosocial variables. Age- and sex-adjusted linear regressions were fitted for CVH, health behaviors (HB), and health factors (HF). Most participants showed moderate CVH, HB, and HF scores (76.6%; 53.1%; 62.2%). Diet quality had the lowest mean (40.8 ± 31.7), while physical activity and sleep health were the highest (88.3 ± 30.6 and 85.0 ± 22.2). Middle-aged adults presented higher CVH and HF scores (mean differences [MD]: 2.5 ± 0.3; 7.8 ± 1.5), whereas older adults scored better in HB (MD: 2.8 ± 1.4). Women exhibited higher CVH, HB, and HF scores than men (MD: 3.6 ± 0.3; 2.8 ± 0.4; 4.4 ± 0.4), with middle-aged women showing the most favorable CVH profile (73.0 ± 10.5) and older men the least favorable (66.4 ± 11.0). Higher self-rated health (β = 0.240; R2 = 0.096) and educational attainment (β = 0.235;

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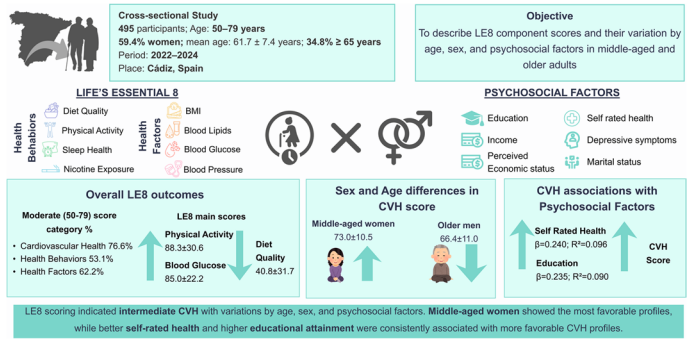
R2 = 0.090) were the strongest correlates of CVH (both $P < 0.001$). LE8 scoring revealed an intermediate CVH profile, with disparities by age, sex, and psychosocial context. Middle-aged women showed the most favorable profiles, while self-rated health and educational attainment emerged as key psychosocial markers for CVH assessment.

Graphical Abstract



Keywords Cross-sectional study · Cardiovascular health · Life's essential 8 · Psychosocial factors · Aging population · Sex differences

Introduction

Aging is fundamentally characterized by a progressive loss of physiological integrity, which often results in impaired function and increased vulnerability to multi-systemic decline [1]. Within the geroscience framework, these processes are understood as reflecting the biological hallmarks of aging, which act as a common underlying basis for chronic diseases, including cardiovascular disease (CVD) and other geriatric syndromes [1]. Demographic projections estimate that the proportion of the aging population will rise to nearly 28% by 2041 [4], in the context of a growing global burden of CVD [5]. CVD and aging-related pathologies are increasingly interpreted as expressions of the cumulative accumulation of molecular and cellular damage over time, together with age-related changes in the organism's capacity to maintain physiological integrity [2]. Consequently, prioritizing cardiovascular prevention strategies tailored to older adults is imperative not only to mitigate

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clinical risk but also to preserve functional capacity and to maximize healthspan [3].

In response to this growing burden, the American Heart Association (AHA) introduced *Life's Essential 8* (LE8) a composite cardiovascular health (CVH) score comprising diet quality, physical activity, nicotine exposure, sleep health, body mass index (BMI), blood lipids, blood glucose, and blood pressure [6]. Beyond its traditional utility as a conventional epidemiological risk metric, the LE8 can be conceptualized as an integrated marker capturing subclinical cardiovascular aging and interindividual differences in physiological maintenance capacity [2]. This distinction is relevant because, while chronological age measures the linear passage of time, biological age reflects the actual rate of physiological decline shaped by the dynamic interplay between damage accumulation and the body's repair mechanisms [4]. In this context, higher LE8 scores may reflect more favorable aging trajectories and have been associated with improved healthspan-related outcomes [3, 5]

The AHA also highlights the importance of psychosocial factors in shaping CVH across the lifespan [6]. Within a geroscience perspective, these factors can be understood as social determinants that influence biological aging processes, contributing to interindividual variability in CVH trajectories [7]. In Spain, structural factors such as educational attainment, income, healthcare accessibility, and social support influence CVD prevalence and related risk behaviors in older adults [8]. These psychosocial dimensions may function as markers of aging heterogeneity, reflecting the cumulative allostatic load or physiological 'wear and tear' sustained over the life course [9]. Higher educational attainment often provides a buffer against harmful behaviors and environmental stressors, thereby supporting biological resilience mechanisms [10]. Conversely, negative self-perception and depressive symptoms often coexist with multisystem health impairments and may be associated with underlying biological processes linked to chronic inflammation and dysregulated stress responses [5, 11].

However, current evidence on LE8 does not fully address several relevant aspects. Previous LE8 studies have typically examined psychosocial factors in isolation, with limited integration of structural, subjective, and clinical dimensions [13–16, 26]. In the Spanish context, large cohorts have primarily focused on characterizing CVH distributions and socioeconomic gradients, with less emphasis on the integrated psychosocial dimensions in relation to CVH [9, 18–20]. In addition, existing evidence relies mainly on objective socioeconomic indicators, limiting the ability to capture the lived experience of socioeconomic conditions [8, 15, 20], or the utilization of brief screening tools like the Patient Health Questionnaire-9 (PHQ-9) lacking a more robust clinical characterization of symptom severity in aging cohorts [14, 21, 22]. Most studies also focus on the global LE8 score, with limited evaluation of domains and individual components [17, 23], and frequently assess LE8 in relation to downstream outcomes, providing limited insight into upstream psychosocial factors [12, 14, 24–26]. These limitations are particularly relevant in aging populations, which remain underrepresented despite the heterogeneity of CVH across later adulthood [14, 27]. The present study aims to address these gaps.

Therefore, the present study aims to describe the distribution of LE8 scores and examine age- and sex-related differences, as well as the associations of psychosocial factors with CVH, in a cohort of middle-aged and older adults from the province of Cádiz (Spain). By focusing on upstream psychosocial factors in relation to CVH and by adopting a multidimensional assessment of LE8, this study seeks to provide a more detailed and context-sensitive characterization of CVH variability in aging populations, with potential to inform targeted prevention strategies.

Methods

Procedure

This study was conducted within the framework of the Inlife-Aging Project. Participants were recruited between January 2022 and June 2024 in Cádiz, Spain, through community centers, senior associations, and primary healthcare facilities. All participants received information about the study objectives and procedures and provided written informed consent prior to enrolment. The study was conducted in accordance with the Declaration of Helsinki (2024 revision) [28, 29] and was approved by the Clinical Research Ethics Committee of Hospital Universitario Puerta del Mar, Cádiz, Spain (approval no. 0653-N-20).

During a clinical assessment visit, participants completed sociodemographic and psychosocial questionnaires and underwent standardized physical examinations. Anthropometric measurements and blood pressure assessments were performed following established protocols. Venous blood samples were collected after an overnight fast of at least 8 h and following 48 h of abstention from alcohol and caffeine intake. Laboratory analyses were carried out at the Biochemistry Unit of Hospital Universitario Puerto Real according to standard procedures.

Study sample

A total of 524 participants aged 50–79 years were recruited. Eligible individuals were those able to communicate effectively, capable of understanding the study aims, provide informed consent and had no major physical illness that could limit participation. Moreover, exclusion criteria included acute or terminal illness, history of cerebral infarction, epilepsy, brain tumor, or alcohol or drug abuse.

After applying inclusion and exclusion criteria, the final analytical sample comprised 495 participants (mean age: 61.7 ± 7.4 years; 59.4% women; 34.7% aged ≥ 65 years). For analytical purposes, participants were categorized into middle-aged adults (50–64 years) and older adults (65–79 years).

Measurements

Outcome variables

The CVH score comprises eight components grouped into two domains: health behaviors (HB)—diet quality, physical activity, nicotine exposure, and sleep health—and health factors (HF)—BMI, blood lipids, blood glucose, and blood pressure. Each component was scored on a 0–100 scale according to the AHA guidelines [28]. HB components were assessed using self-reported questionnaires, whereas HF components were derived from standardized clinical and laboratory measurements. All measurements were obtained after an 8-h overnight fast and 48 h of abstention from alcohol and caffeine. Serum and plasma samples were processed and analyzed according to standard procedures at the Biochemistry Unit of Hospital Universitario Puerto Real. Detailed information on measurement tools and scoring procedures for each LE8 component is provided in Online Resource 1, TableS1. The CVH score was computed as the unweighted mean of the eight component scores. HB and HF domain scores were calculated by an unweighted mean of their components. All LE8 composite was categorized into low (< 50), moderate (50–79), and high (≥ 80) levels following AHA recommendations, as previously described [6]. In addition, criterion variables were derived from the LE8 framework and included CVH, HB, and HF scores, as well as the individual LE8 components. These variables were defined a priori as outcome (dependent) variables in all analyses, including age- and sex-stratified comparisons, and in association analyses with psychosocial factors.

Explanatory and sample characterization variables

Psychosocial factors and comorbidities were used to characterize the study sample and were described across age- and sex-stratified groups. Psychosocial factors were additionally considered as explanatory (independent) variables in the association analyses with CVH outcomes, whereas comorbidities were included for descriptive purposes and to contextualize the clinical profile of the sample.

Psychosocial status included socioeconomic status, household income, educational level, and marital status obtained through a self-reported questionnaire specifically designed for this study; as well as self-perceived health status, assessed using the corresponding item from the Spanish National Health Survey (Encuesta Nacional de Salud de España) [30], and depressive symptoms, measured using the Beck Depression Inventory-II (BDI-II), with scores ≥ 14 classified as clinically relevant depressive symptoms [31]. All psychosocial factors were dichotomized into binary indicators according to predefined criteria. Detailed information on measurement tools and classification procedures for each psychosocial factor is provided in Online Resource 1, Table S2.

Comorbidities were evaluated by a physician during a clinical consultation. Individuals with elevated fasting glucose levels (> 125 mg/dL) or elevated HbA1c (> 6.4%) without a history of diabetes were treated as cases of undiagnosed diabetes and included in the diabetes group, as described elsewhere [32].

Statistical analysis

To describe the distribution of LE8 scores, continuous variables were summarized as mean ± standard deviation (SD) and mean differences (MD) ± standard error (SE), and categorical variables as frequencies and percentages. Age-related differences were examined between middle-aged (50–64 years) and older (65–79 years) adults. MD were tested using Student's t-tests for sex or age comparisons. Categorical variables were compared using Pearson's chi-square tests and one-way ANOVA for combined sex-age categories, with Bonferroni post hoc adjustments when appropriate.

Comorbidities and psychosocial factors were examined across the four sex-age categories using Pearson's chi-square tests. When applicable, pairwise comparisons used Bonferroni-adjusted *P*-values. Associations between dichotomized psychosocial factors and CVH were assessed using Student's t-tests. Independent effects were evaluated with age- and sex-adjusted linear regression models for overall CVH, HB, and HF scores. For each outcome, separate models were fitted for each psychosocial factor, but only factors significant in bivariate analyses were analyzed. Although psychosocial factors were dichotomized, regression models used the most informative measurement scale available to maximize precision. Factors measured on a continuous scale (e.g., educational years, BDI-II) were modelled in their original metric, and factors with ordered categories (self-rated health, economic status, income category) were modelled as ordinal variables assuming a monotonic linear trend across levels. Multicollinearity was assessed using variance inflation factors (VIF), and no evidence of problematic multicollinearity was observed (all VIFs < 1.1). Standardized beta coefficients (β), two-sided *P*-values, and model fit statistics were reported. Given that all regression models included the same number of predictors, model fit was summarized using R2 and Huber-White robust standard errors were applied.

Statistical significance was set at $P < 0.05$. Analyses were performed using Stata SE 14.2 (StataCorp, College Station, TX, USA) and R version 4.4.1 (R Core Team) via RStudio 2024.12.0 (Posit Software). The GPT-4o model of ChatGPT (OpenAI, USA; accessed in November 2024) was used to assist with troubleshooting R and Stata code. All analyses and final decisions were performed by the researchers.

Results

Sample characteristics

Table 1 summarizes the participants' sociodemographic and clinical characteristics. Comorbidities such as dyslipidemia, hypertension, diabetes and CVD were more prevalent among older men (> 21%, all $P < 0.05$).

Psychosocial characteristics showed marked sex- and age-related differences. Older women had the highest prevalence of low income (< 1000 €; 25.2%) and living without a partner (43.0%), as well as the lowest levels of higher education (≥ 12 years; 42.1%) and self-rated health (65.4%), all $P < 0.05$. In contrast, middle-aged men reported the most favorable profiles across these indicators, all $P < 0.05$.

Clinically relevant depressive symptoms were most frequent among middle-aged women (22.5%) and least common among men in both age groups (all $P < 0.05$).

Distribution of LE8 components

Figure 1 presents mean scores for all LE8 components and their distribution across categories (low, moderate, high). Diet quality showed the lowest mean scores (40.8 ± 31.7), whereas physical activity (88.3 ± 30.6) and sleep health (85.0 ± 22.2) reached the highest. The majority of participants fell within the moderate category for overall CVH (76.6%), HB (53.1%), and HF (62.2%).

Comparisons by age revealed consistent disparities in CVH. Middle-aged adults showed higher overall CVH and HF scores (MD, 2.5 ± 0.3; $P = 0.020$ and 7.8 ± 1.5; $P < 0.001$), with particularly higher values for BMI, blood glucose, and blood pressure (MD, 6.7 ± 0.5; 9.4 ± 0.5; and 13.2 ± 0.5; all $P < 0.001$) than older adults. In contrast, older adults achieved higher HB scores (MD, 2.8 ± 1.4; $P = 0.049$), mainly due to better sleep health (MD, 7.2 ± 0.4; $P < 0.001$).

Regarding sex, women showed significantly higher scores in overall CVH, HB, and HF (MD, 3.6 ± 0.3; $P < 0.001$; 2.8 ± 0.4; $P = 0.045$; and 4.4 ± 0.4; $P = 0.003$), with particularly higher values

Table 1 Comorbidities and psychosocial characteristics of sample population by sex and age

Variables	Total	Middle-aged Adults (50-64y) (n = 323)		Older Adults (65-79y) (n = 172)	
		Men	Women	Men	Women
Number of participants (%)	495	136 (27.5)	187 (37.9)	65 (13.1)	107 (21.6)
Age, y, Mean (SD)	61.7 (7.4)	57.5 (4.4)	57.1 (4.3)	70.3 (3.5)	69.9 (4.0)
Comorbidities, frequency (%)					
Dyslipidemia		a	bc	ab	c
	184 (37.2)	44 (32.4)	55 (29.4)	35 (53.9)	50 (46.7)
Hypertension		ac	bd	ab	cd
	167 (33.7)	38 (27.9)	45 (24.1)	35 (53.9)	49 (45.8)
Diabetes Mellitus		a	b	abc	c
	55 (11.1)	16 (11.8)	12 (6.4)	15 (23.1)	12 (11.2)
Cardiovascular Disease			a	a	
	46 (9.3)	11 (8.1)	8 (4.3)	14 (21.5)	13 (12.2)
Peripheral arterial disease	7 (1.4)	2 (1.5)	1 (0.5)	0 (0.0)	4 (3.7)
Neurological disease	21 (4.2)	6 (4.4)	9 (4.8)	2 (3.1)	4 (3.7)
Gastrointestinal disease	28 (5.7)	5 (3.7)	12 (6.4)	3 (4.6)	8 (7.5)
Self-reported psychosocial factors, frequency (%)					
Economic status					
• Financial Hardship	131 (26.5)	37 (27.2)	58 (31.0)	9 (13.9)	27 (25.2)
• Financial ease	364 (73.5)	99 (72.8)	129 (69.0)	56 (86.2)	80 (74.8)
Net Household Income		a		b	ab
• Below the minimum wage (< 1000€)	79 (16.0)	13 (9.6)	34 (18.9)	5 (7.7)	27 (25.2)
• At or above the minimum wage (≥ 1000€)	416 (84.0)	123 (90.4)	153 (81.8)	60 (92.3)	80 (74.8)
Educational Level		ab	a		b
• Secondary or low (0–12 years)	206 (41.6)	36 (26.5)	78 (41.7)	30 (46.2)	62 (57.9)
• Superior (> 12 years)	289 (58.4)	100 (73.5)	109 (58.3)	35 (53.9)	45 (42.1)
Marital Status		ac	a	b	bc
• Not in a relationship	144 (29.1)	23 (16.9)	64 (34.2)	11 (16.9)	46 (43.0)
• In a relationship	351 (70.9)	113 (83.1)	123 (65.8)	54 (83.1)	61 (57.0)
Health Perception		ab	a		b
• Poor-Fair	138 (27.9)	24 (17.6)	62 (33.2)	15 (23.1)	37 (34.6)
• Good	357 (72.1)	112 (82.4)	125 (66.8)	50 (76.9)	70 (65.4)
Depressive symptoms		a	ab	b	
• DS (≥ 14 points)	76 (15.4)	10 (7.4)	42 (22.5)	4 (6.2)	20 (18.7)
• No DS (< 14 points)	419 (84.7)	126 (92.7)	145 (77.5)	61 (93.9)	87 (81.3)

The table presents a comparison of comorbidities and self-reported psychosocial factors across different age and sex groups. Values are expressed as absolute numbers (n) and percentages (%). Differences by sex and age combined, with significant differences ($P < 0.05$) between groups indicated by "a", "b", and "c". *DS:* Depressive Symptoms

for diet quality, blood glucose, and blood pressure (MD, 10.9 ± 0.5; $P < 0.001$; 4.8 ± 0.5; $P = 0.029$; and 12.7 ± 0.5; $P < 0.001$) compared with men.

Figure 2 illustrates the combined effects of age and sex on LE8 scores. Middle-aged women exhibited the highest overall CVH scores, particularly compared with both middle-aged and older men (MD, 4.4 ± 1.2; $P = 0.004$; 5.8 ± 1.6; $P = 0.002$), and the highest HF scores compared with middle-aged men, older men, and older women (MD, 5.2 ± 1.7; $P = 0.018$; 12.4 ± 2.2; $P < 0.001$; 8.6 ± 1.9; $P < 0.001$). They also scored highest for BMI, blood glucose, and blood

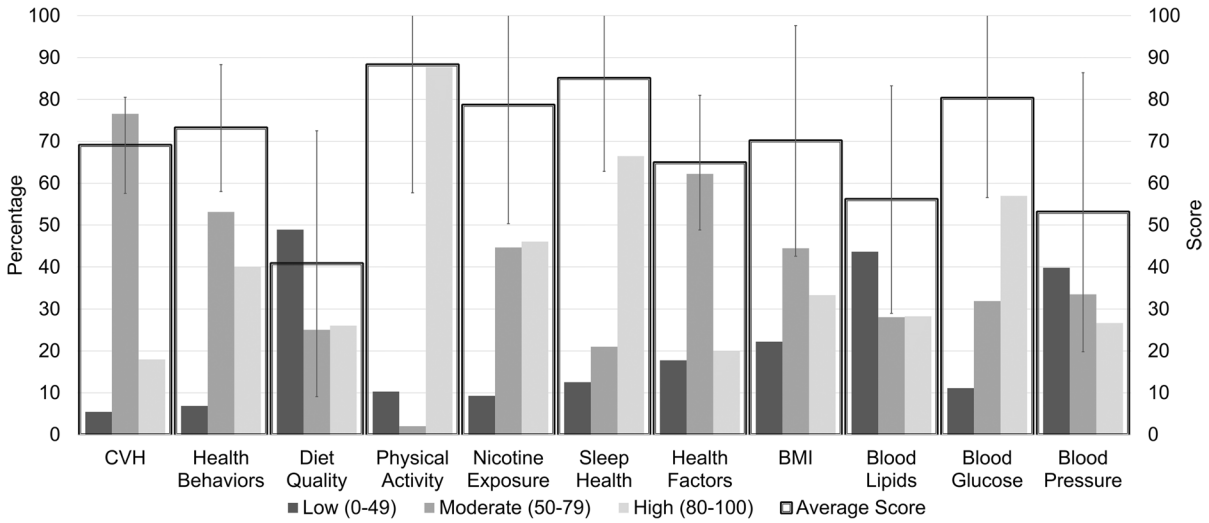

Fig. 1 Distribution of LE8 scores and category percentages**.** LE8 scores by overall mean and percentage of each score category (low, moderate and high). Colored bars represent the different score categories, while semi-transparent black gradient bars indicate overall mean values, with error bars representing standard deviation. Categories are coded as low (<50), moderate (50–79), and high (80–100). *CVH:* Cardiovascular Health, *BMI:* Body Mass Index

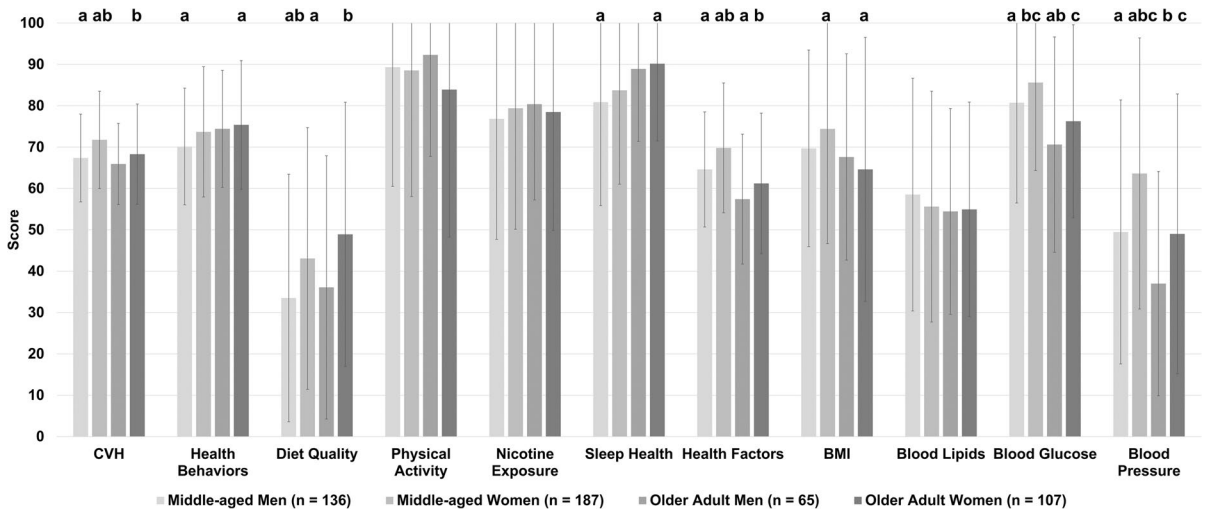

Fig. 2 Differences in LE8 by sex and age combined**.** Significant differences between groups indicated by "a", "b", and "c". *BMI:* Body Mass Index, *CVH:* Cardiovascular Health, *LE8:* Life's Essential 8

pressure ($P=0.024$; $P<0.01$; $P<0.002$). In contrast, older women showed the highest HB scores, particularly compared with middle-aged men (MD, 5.2 ± 1.9; $P=0.044$), and the highest scores for sleep health and diet quality ($P=0.007$ and $P<0.05$).

For overall CVH, a greater proportion of middle-aged women reached the high category (≥25%), whereas men were predominantly classified within the moderate category regardless of age (≥81%; $P=0.002$). Regarding HF, middle-aged women were more frequently classified in the high category (30.5%) compared with other groups (<16%; $P<0.001$). No significant differences were observed for HB categories ($P=0.535$). Detailed distributions

for each individual LE8 component are presented in Online Resource 1, Figures S1, S2 and S3.

Association between psychosocial factors and LE8 components

Table 2 summarizes the associations between psychosocial factors and LE8 components. Self-rated health emerged as the most influential factor: participants reporting good health showed significantly higher scores in overall CVH, HB, and HF (MD, 4.4 ± 1.1; $P < 0.001$; 5.4 ± 1.5; $P < 0.001$; 3.3 ± 1.6; $P = 0.040$), as well as in physical activity, nicotine exposure, BMI, and blood glucose ($P = 0.001$; $P = 0.033$; $P < 0.001$; $P = 0.016$).

Education was also a major determinant of CVH. Participants with ≥ 12 years of education had higher CVH and HF scores (MD, 5.2 ± 1.0; 7.7 ± 1.4; both $P < 0.001$), along with better BMI, blood glucose, blood pressure, and diet quality scores ($P < 0.001$; $P < 0.001$; $P = 0.020$; $P = 0.009$).

Depressive symptomatology was negatively associated with CVH scores (MD, 3.4 ± 1.4; $P = 0.019$), and lower HB scores (MD, 8.1 ± 1.9; $P < 0.001$) mainly through poorer performance in physical activity, nicotine exposure, and sleep health ($P = 0.003$; $P = 0.008$; and $P = 0.024$).

Participants reporting greater perceived economic status or income above the minimum threshold showed higher CVH scores (MD, 2.9 ± 1.2; $P = 0.012$; 3.2 ± 1.4; $P = 0.023$). Only higher perceived economic status was additionally associated with better HB scores (MD, 4.5 ± 1.5; $P = 0.004$), whereas BMI, physical activity, and blood glucose scores were also independently associated (all $P < 0.05$).

Finally, marital status was associated with specific LE8 components. Participants living with a partner showed higher nicotine exposure ($P = 0.007$) but lower blood pressure scores ($P = 0.039$).

Age- and sex-adjusted linear associations of psychosocial factors with CVH, HB, and HF

In age- and sex-adjusted linear regression models, better perceived health was consistently related to higher CVH (β = 0.240; $P < 0.001$; R2 = 0.096), HB (β = 0.182; $P < 0.001$; R2 = 0.049), and HF (β = 0.171; $P < 0.001$; R2 = 0.118) scores. More years of education with better CVH (β = 0.235; $P < 0.001$; R2 = 0.090) and HF (β = 0.202; $P < 0.001$; R2 = 0.126) scores. Greater depressive symptoms burden were associated with lower CVH (β = −0.154; $P = 0.002$; R2 = 0.062) and HB (β = −0.212; $P < 0.001$; R2 = 0.060) scores. Higher income category with higher CVH (β = 0.153; $P < 0.001$; R2 = 0.061) and HB (β = 0.108; $P = 0.021$; R2 = 0.028) scores. And a more favorable economic status perception was positively related to higher CVH (β = 0.178; $P < 0.001$; R2 = 0.070) score. Figure 3 represents the main results of the article.

Discussion

This study described LE8 component scores and examined the influence of age, sex, and psychosocial factors on CVH in middle-aged and older adults from Cádiz, Spain. Overall, participants exhibited an intermediate CVH profile, with the majority of the sample classified within the moderate range for both behavioral and clinical components. Diet quality, blood lipids, and blood pressure emerged as the areas showing the least favorable scores, identifying them as relevant indicators of CVH in this group. Furthermore, the observations reveal that structural (net household income, educational level and marital status), subjective (economic status and health perception) and clinical (depressive symptoms) psychosocial factors were consistently associated with CVH, displaying distinct patterns of association across different age and sex groups. Rather than implying direct causality, these results highlight a significant degree of variation in cardiovascular profiles within the population studied.

Our results are consistent with national and international evidence on LE8. Data from the Spanish ENRICA cohort, the Swedish SCAPIS, and the U.S. NHANES studies also reported low adherence to ideal CVH, with diet quality and blood pressure among the lowest-scoring components [17, 33–35]. These associations suggest that the cardiovascular configuration in our cohort reflects aging patterns shared with other adult populations, where the higher physical activity scores likely reflect methodological differences in the GPAQ tool [36] rather than distinct biological profiles as SCAPIS used accelerometry [34] and ENRICA and NHANES assessed only leisure-time activity [17, 33].

Table 2 Differences in life's essential 8 scores by psychosocial factors

	Economic Status		Net Household Income		Educational Level		Marital Status		Health Perception		Depressive Symptoms	
LE8 Variable, score mean (SD)	Financial Hardship	Financial Ease	Below MW (< 1000€)	At or above MW (≥ 1000€)	Secondary or lower (≤ 12 years)	Superior (> 12 years)	Not in a relationship	In a relationship	Poor-Fair	Good	DS (≥ 14 points)	No DS (< 14 points)
Cardiovascular Health		*		*		**				**		*
	66.9 (11.3)	**69.8 (11.5)**	**66.3 (10.9)**	**69.5 (11.5)**	**66.0 (11.3)**	**71.1 (11.1)**	68.7 (12.3)	69.2 (11.2)	**65.9 (11.8)**	**70.3 (11.2)**	**66.2 (12.7)**	**69.6 (11.2)**
Health Behaviors		*								**		**
	69.9 (15.8)	**74.4 (14.7)**	70.9 (17.4)	73.6 (14.7)	71.7 (15.1)	74.2 (15.1)	71.3 (17.8)	74.0 (13.8)	**69.3 (16.3)**	**74.7 (14.4)**	**66.3 (17.4)**	**74.4 (14.4)**
Diet Quality						*						
	37.1 (31.0)	42.1 (31.9)	40.4 (30.4)	40.9 (32.0)	**36.3 (29.6)**	**43.9 (32.8)**	43.2 (32.2)	39.8 (31.5)	39.4 (32.1)	41.4 (31.6)	36.3 (31.2)	41.6 (31.8)
Physical Activity				*						*		*
	84.5 (34.5)	89.6 (28.9)	**77.7 (40.2)**	**90.3 (28.0)**	85.2 (33.9)	90.5 (27.8)	84.4 (34.6)	89.8 (28.7)	**81.1 (37.4)**	**91.0 (27.1)**	**78.5 (39.8)**	**90.0 (28.3)**
Nicotine Exposure								*		*		*
	75.0 (32.2)	80.0 (26.7)	78.2 (31.4)	78.7 (27.7)	79.4 (28.2)	78.0 (28.4)	**73.3 (32.2)**	**80.8 (26.3)**	**74.3 (30.9)**	**80.3 (27.1)**	**70.7 (33.8)**	**80.1 (27.0)**
Sleep Health												*
	83.0 (24.1)	85.8 (21.4)	87.3 (22.3)	84.6 (22.2)	85.8 (22.3)	84.5 (22.2)	84.2 (24.0)	85.4 (21.5)	82.4 (25.0)	86.0 (21.0)	**79.7 (26.6)**	**86.0 (21.2)**
Health Factors						**				*		
	63.9 (15.7)	65.3 (16.2)	61.8 (14.3)	65.5 (16.4)	**60.4 (16.0)**	**68.1 (15.4)**	66.1 (16.2)	64.4 (16.1)	**62.5 (16.5)**	**65.8 (15.8)**	66.1 (15.9)	64.7 (16.1)
BMI		*		*		**				**		
	65.6 (28.3)	**71.7 (27.1)**	**62.0 (29.4)**	**71.7 (26.9)**	**61.4 (29.2)**	**76.4 (24.6)**	68.8 (28.6)	70.6 (27.1)	**61.6 (30.0)**	**73.4 (25.8)**	67.9 (29.3)	70.5 (27.2)
Blood Lipids												
	56.2 (29.4)	56.1 (26.3)	59.2 (27.4)	55.5 (27.1)	57.8 (26.9)	54.9 (27.3)	56.4 (26.5)	56.0 (27.4)	57.8 (28.2)	55.5 (26.7)	56.6 (28.4)	56.0 (26.9)
Blood Glucose				*		*				*		
	79.7 (25.4)	80.5 (23.1)	**74.6 (24.7)**	**81.4 (23.4)**	**73.6 (25.0)**	**85.0 (21.6)**	81.3 (23.9)	79.9 (23.7)	**76.2 (25.0)**	**81.9 (23.0)**	80.9 (24.2)	80.2 (23.6)
Blood Pressure						**		*				
	54.1 (31.1)	52.7 (34.0)	51.3 (28.6)	53.4 (34.1)	**48.9 (31.9)**	**55.9 (33.9)**	**57.9 (32.1)**	**51.1 (33.6)**	54.5 (33.3)	52.6 (33.3)	59.0 (33.4)	52.0 (33.2)

This table presents the mean and SD values of LE8 score components across different psychosocial factors, including economic status, net household income, educational level, marital status, health perception, and depressive symptoms. Significant differences (*, $P < 0.05$) and highly significant (**, $P < 0.001$) differences are shown between groups within the same factor. *DS:* Depressive Symptoms, *LE8:* Life's ssential 8, *MW*: Minimum Wage, *SD:* Standard Deviation

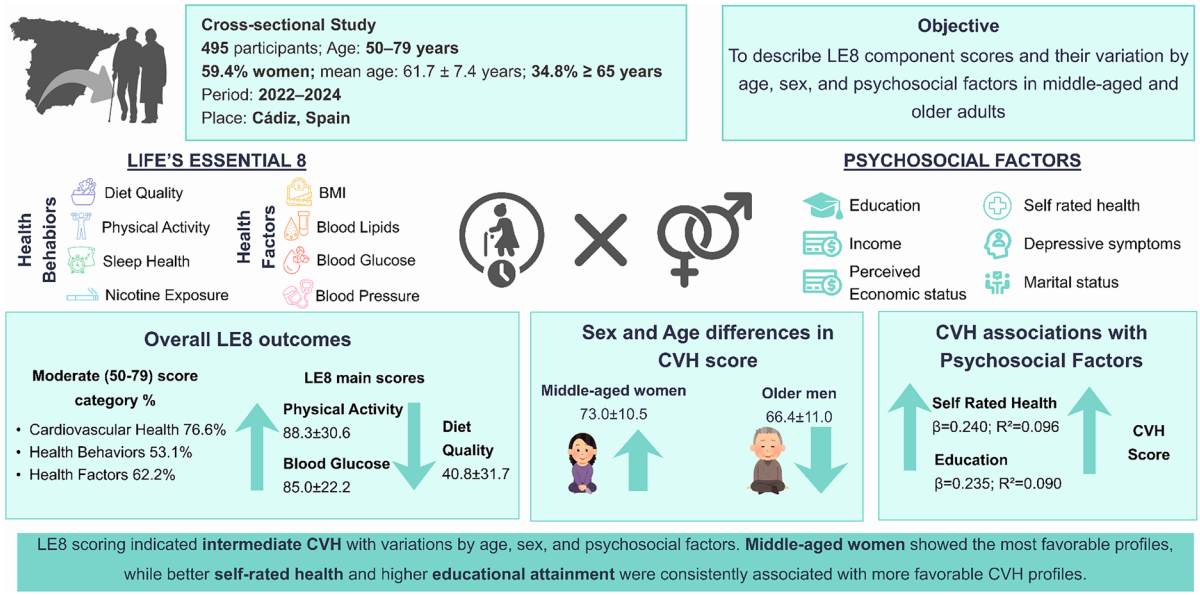

Fig. 3 Central illustration**.** Summary of LE8 components, overall CVH scores, key sex-related differences in LE8, and CVH associations with psychosocial factors in 495 adults aged 50–79 years from Cádiz, Spain. *BMI:* Body Mass Index; *CVH:* Cardiovascular Health; *LE8:* Life's Essential 8

Age- and sex-related differences in LE8 scores were consistent with patterns reported in international literature [33, 34], as well as in national studies, including the Seniors-ENRICA subsample and the high-risk PREDIMED cohort 8, 33–35 . Moreover, national data from the Instituto Nacional de Estadística report higher prevalence of CVD, hypertension and diabetes among older adults, together with comparable dyslipidemia patterns across sexes, supporting the representativeness of our cohort and suggesting that LE8 distributions were not biased by comorbidity burden [37].

These variations highlight the heterogeneity in cardiovascular aging trajectories, where chronological age provides a temporal framework for the emergence of differences in functional health [2, 4]. This variability was not uniform across all LE8 components in our data. While blood pressure and glucose showed clearer age-related differences, other components such as blood lipids remained relatively stable. This suggests that individual LE8 domains may reflect distinct biological pathways and temporal dynamics, rather than a single, homogeneous aging process, in line with evidence that cardiovascular risk factors evolve differently across the life course due to diverse aging mechanisms [3, 36]. This heterogeneity may be partly expressed through age-related vascular stiffening, endothelial dysfunction, and impaired metabolic regulation, which are closely linked to less favorable blood pressure, glucose, and lipid profiles [3, 38]. However, given the cross-sectional design of the present study, these observations should be interpreted as a snapshot of CVH distribution across age groups, and no inferences can be made regarding longitudinal trajectories or causal relationships.

These patterns are also consistent with sex-related differences in cardiovascular aging, where men tend to exhibit a steeper decline in metabolic and vascular function during later adulthood [39]. Such differences may reflect a greater cumulative burden of physiological dysregulation over time, contributing to less favorable CVH profiles in older men [38].

Beyond biological and behavioral domains, our findings revealed consistent associations between the psychosocial context and the configuration of CVH. While other large-scale studies have explored these links, our results align with and extend evidence from the Swedish SCAPIS project, which also identified self-rated health as a potent indicator of LE8 adherence [40]. Similarly, the association found in our cohort between financial hardship and poorer CVH mirrors findings from the MESA study, where

subjective financial strain was linked to adverse cardiovascular profiles [20]. However, the Inlife-Aging Project distinguishes itself from previous Spanish cohorts, such as ENRICA or PREDIMED, which have primarily focused on objective socioeconomic gradients (income, education) without incorporating the subjective lived experience or clinical mental health dimensions into a single integrative framework [3, 39]. From a geroscience perspective, this multidimensionality is crucial, as self-rated health and perceived economic difficulty act as proximal markers of physiological reserve and allostatic load [3, 41].

Mechanistically, these factors trigger the weathering process, where chronic psychosocial stressors, common in groups with lower educational attainment and high financial hardship, accelerate biological aging through inflammaging and the accumulation of senescent cells [38]. By demonstrating that these associations hold in a regional aging cohort from Southern Spain, we provide a more context-sensitive characterization of CVH, suggesting that individual LE8 domains are not just risk factors, but reflections of the failure of the body's physiological maintenance capacity under cumulative stress [40, 42].

Despite these vulnerabilities, older women maintained higher scores in behavioral components, and middle-aged women in biological ones, an observation also reported in SCAPIS and SWAN [3, 42]. These findings suggest potential behavioral and contextual resilience [43, 44]. Women, particularly in midlife, tend to engage more consistently in protective behaviors, including healthier dietary patterns, greater healthcare utilization, and lower tobacco exposure [16, 45]. However, this resilience is often offset by greater psychosocial vulnerability, characterized by higher prevalence of depressive symptoms, poorer perceived health, and increased caregiving burdens, all of which are associated with less favorable CVH profiles, potentially through behavioral and stress-related processes [40]. By integrating this broader set of factors, our approach underscores the central role of education and self-rated health as indicators of interindividual variability in aging-related health profiles [2, 46–48].

Self-rated health should be interpreted as a global indicator of overall health status, which may be closely related to CVH and may partially reflect overlapping dimensions of health. Therefore, its association with CVH should be interpreted with caution, as it may capture, at least in part, similar aspects of health status rather than representing a fully independent explanatory factor. Nevertheless, it remains a useful integrative measure that may reflect individuals' physiological reserve, multisystem functioning, psychological disposition, perceived control, and readiness to engage in health-promoting behaviors [49, 50]. Closely related, educational attainment plays a pivotal role by enhancing health literacy, fostering better decision-making, and supporting adherence to medical recommendations [51]. Moreover, education facilitates access to healthier environments and provides a buffer against harmful health behaviors throughout the life course [52]. Together, these two factors, subjective and structural, interact with broader social conditions such as income, employment stability, and family structure, all of which shape individuals´ capacity to adopt and sustain behaviors that improve CVH, particularly in socially disadvantaged settings [9, 52]. Taken together, these findings suggest that the observed age- and sex-related differences in CVH reflects a multifactorial interaction between biological aging, health behaviors, and cumulative psychosocial context.

Although each LE8 component contributes to the overall CVH score, our results highlight specific indicators such as diet quality, blood pressure, and blood lipids as markers that may reflect aging heterogeneity, particularly among older men and individuals with lower educational attainment within the Spanish context. At the population level, addressing structural inequalities in education, income, and perceived health appear to be important contextual factors, as they may reflect cumulative allostatic load sustained over the life course [16, 53, 54]. In this context, mental health markers, particularly depressive symptoms, warrant consideration in relation to CVH, as they are frequently associated with less favorable physiological profiles and reduced functional reserve [16, 51, 52]. However, depressive symptoms should not be interpreted solely as upstream factors, as they may also reflect existing disease burden. This consideration is particularly relevant in cross-sectional analyses, where the directionality of associations cannot be established and reverse causation may partly explain the observed relationships. Ultimately, integrating population-wide health promotion with focused attention on vulnerable subgroups may help inform equity-oriented approaches to improve CVH outcomes,

especially in socioeconomically disadvantaged regions [3, 5, 36].

These observations also support a broader interpretation of CVH within a biological aging framework, in which LE8 reflects not only chronological aging, but also interindividual differences in biological aging trajectories. In this context, adverse psychosocial conditions, such as lower educational attainment, poorer self-rated health, and depressive symptoms, may contribute to a less favorable biological profile through cumulative physiological dysregulation, including stress-related and inflammatory pathways, as well as reduced physiological reserve [3, 5, 38]. These processes are consistent with mechanisms of vascular aging, metabolic dysregulation, and multisystem decline, which may be expressed in less favorable blood pressure, glucose, and lipid profiles [4, 7, 37]. Conversely, more favorable psychosocial conditions may support adaptive stress responses, including more efficient regulation of the hypothalamic–pituitary–adrenal axis, balanced autonomic function, and lower chronic inflammatory activation, which are associated with improved metabolic and vascular homeostasis and promote a cardiovascular aging pattern that is more favorable than would be expected from chronological age alone [3, 8, 10]. From this perspective, LE8 may be interpreted not only as a CVH metric, but also as a clinically meaningful indicator of resilience or vulnerability in biological aging [7].

Strengths and limitations

This study offers a detailed regional characterization of CVH in southern Spain through the application of the LE8 framework in a community-based sample of middle-aged and older adults. A key strength is the integrated evaluation of structural, subjective, and clinical psychosocial factors alongside LE8, assessed at the level of the global score, domains, and individual components, with age- and sex-stratified analyses. This multidimensional approach allows a more attenuated interpretation of heterogeneity in CVH profiles across later adulthood and enhances the contextual understanding of CVH in a socioeconomically diverse setting.

Several limitations should be acknowledged. First, the cross-sectional design precludes causal inference and limits conclusions regarding the directionality of associations between psychosocial factors and CVH. Second, the modest sample size may constrain generalizability, and the volunteer nature of recruitment could introduce self-selection bias favoring healthier participants. In addition, the use of self-reported measures for physical activity and sleep health may also involve reporting bias, suggesting the need for objective assessments in future studies. Finally, the absence of data on passive smoking may have led to an underestimation of nicotine exposure.

Conclusion

The present findings indicate that most participants exhibited intermediate levels of CVH, with diet quality, blood pressure, and blood lipids emerging as the weakest components of the LE8 framework. Clear differences were identified by age and sex, with middle-aged women showing the most favorable profiles and older men the least favorable, particularly with respect to HF components. In addition, psychosocial factors, especially self-rated health and education, were consistently associated with more favorable CVH profiles across both behavioral and clinical domains. Overall, these results highlight the relevance of considering age-, sex-, and context-specific variability when characterizing CVH in aging populations and support the utility of the LE8 framework for identifying priority areas and social vulnerabilities within CVH assessment.

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Authors contributions **Iván H. Martín-Costa:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Writing—original draft. **Laura Martínez-Sánchez:** Data curation; Investigation; Methodology; Project administration; Supervision; Writing—review editing. **Verónica Mihaiescu-Ion:** Data curation; Formal analysis; Investigation; Methodology; Writing—review editing**. Sonia Ortega-Gómez**: Investigation, Methodology, Writing – review & editing. **Javier S. Morales**: Investigation, Methodology, Writing – review & editing. **José L. Andrey-Guerrero**: Resources, Investigation, Writing – review & editing. **María J. Pedrosa-Martínez**:

Resources, Investigation, Writing – review & editing. **Eulalio Valmisa**: Resources, Investigation, Writing – review & editing. **José D. Santotoribio**: Resources, Investigation, Writing – review & editing. **David Jiménez-Pavón**: Conceptualization; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Writing—review editing. **Ana Carbonell-Baeza**: Conceptualization; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Writing—review editing.

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Data Availability The data presented in this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy and ethical restrictions.

Declarations

Ethics This study was conducted in accordance with the principles of the Declaration of Helsinki and was reviewed and approved by the Clinical Research Ethics Committee of Hospital Universitario Puerta del Mar, Cádiz, Spain (approval no. 0653-N-20). All participants provided written informed consent prior to enrolment.

Competing interests 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.

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