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What stole Chinese older adults' life satisfaction? Integrating medical statistics and machine learning with a life-course perspective using CHARLS data

Jing Zhao^{1*†}, Yaya Wang^{2†}, XiaoFei Du³, ShaoPeng Wang¹ and Jun Lin⁴

Abstract

Background As China enters a rapidly aging era, understanding the determinants of life satisfaction among older adults has become a pressing research and policy concern. Life satisfaction in later life is shaped not only by current psychosocial and material conditions but also by accumulated experiences across the life course. Despite increasing attention to healthy aging, few studies have systematically examined how these factors jointly influence life satisfaction.

Methods Using data from 4,627 individuals aged 60 and above drawn from the 2020 wave of the China Health and Retirement Longitudinal Study (CHARLS) merged with the 2014 Life History Survey, this study applied a stage-specific and integrated analytical framework. Generalized Ordered Logit Regression (GOLR) was combined with the XGBoost machine learning algorithm to capture both linear and nonlinear associations, as well as perform individual-level prediction of life satisfaction. This mixed-method approach enabled identification of key determinants across satisfaction levels while allowing for variable interactions and heterogeneity analysis.

Results The results show factors' heterogeneity across satisfaction levels. At lower levels, present-day psychosocial and material conditions including depressive symptoms, self-rated health, intergenerational relationships, and access to utilities play dominant roles. As satisfaction level increases, early-life factors become increasingly important. Two variables, satisfaction with children relationship and depressive symptoms, consistently influence life satisfaction across all stages. The transition to very satisfaction involves all five domains of predictors, while the highest level of satisfaction is explained by a smaller group of enduring psychological and intergenerational factors.

Conclusion This study provides an integrated and stage-specific understanding of life satisfaction among older Chinese adults. The findings deepen the theoretical understanding of life course influences, social support, and psychological resilience in later life. The study also suggests the need for tailored policy interventions that prioritize

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mental health care, social engagement, and basic living conditions at lower satisfaction levels, and incorporate early-life experiences and emotional connectedness for those with higher satisfaction.

Keywords Life satisfaction, Older adults, GOLR, XGBoost algorithm, Determinants, Stage-specific analysis, Life course perspective

Introduction

Life satisfaction, a core component of subjective well-being, is increasingly recognized as a key indicator of meaningful and healthy ageing [1–3]. Older adults with greater life satisfaction will experience fewer depressive symptoms, slower cognitive decline, and better management in chronic disease [4, 5]. According to the World Health Organization, low subjective well-being is widespread among older adults worldwide [6]. Acknowledging its importance at the global level, the “United Nations Decade of Healthy Ageing (2021–2030)” has placed subjective well-being and life satisfaction at the heart of ageing with dignity and purpose [7]. In China, the “Healthy China 2030 Planning Outline” explicitly calls for improving older people’s “sense of gain, happiness, and security”, positioning life satisfaction not only as a psychological goal but also as a key component of national policy [8].

China is undergoing a profound demographic transition, with the ageing population as an increasingly urgent concern. In 2023, over 297 million individuals were aged 60 and above in China, representing 21.1% of total population [9], and this proportion will reach 33% by 2050 [10]. This demographic shift positions China becoming a super-aged society. In this context, promoting the life satisfaction of older adults has become both a social and policy priority. However, nationally representative data from the China Health and Retirement Longitudinal Study (CHARLS) reveals a concerning reality: over 62% of older adults report only “somewhat satisfied” or lower levels, while fewer than 37% report being “very” or “extremely” satisfied [11]. This shows that a majority of older adults remain in the middle or lower level of life satisfaction. The discrepancy between national policy goals and the reality of life satisfaction among older adults rises a critical question: What has influenced the life satisfaction of older adults in China?

Many research has examined the determinants of life satisfaction among older adults, revealing influencing factors across socio-demographic, health, psychological, social, material, and early-life domains. Good physical health and functional independence are consistently associated with higher levels of life satisfaction, whereas poor mental health, such as depression and loneliness, has shown detrimental effects [12, 13]. Social and interpersonal relationships, including intergenerational relationships, emotional support, and community participation, have all been identified as strong predictors of life satisfaction in later life [12, 14, 15]. Material and

environmental resources, particularly physical infrastructure and living conditions, are also significant linked to elders’ life satisfaction [16, 17]. Additionally, a growing number of studies have highlighted the long-term impact of early-life conditions and adversity, namely household dysfunction, financial strain, or exposure to hunger, on life satisfaction in later years, suggesting that life satisfaction in old age is shaped not only by present circumstances but also by life course experiences [18–20].

As a core dimension of subjective well-being, life satisfaction has been widely studied, alongside happiness and quality of life; yet some critical gaps remain. First, many studies have focused on isolated domains, such as health, social support, or economic status, without integrating these factors into a comprehensive analytical framework [12, 14, 16]. This fragmented approach limits the ability to understand multidimensional determinants in shaping life satisfaction. Second, many researchers have converted life satisfaction into binary outcomes, resulting in the loss of valuable gradational information and reducing analytical precision [21]. Third, while some studies employed ordered logit models, they often failed to test the proportional odds assumption, or incorrectly turned to multinomial logistic regression when considering the violation, leading to inaccurate estimations or the loss of the ordinal nature of the data [22, 23]. Fourth, most studies rely solely on a single regression, without testing the robustness of their results through alternative methods [21, 22]. This raises concerns about the credibility of findings. Finally, little attention was paid to potential interaction between multidimensional determinants or to individual-level prediction, both of which are crucial for targeted policy interventions [15].

To address these gaps, this study will use a comprehensive and methodologically rigorous approach. First, it integrates determinants across five key domains, including socio-demographic characteristics, health status and functional limitations, social and interpersonal relationships, material and environmental resources, and early-life adversities into a unified analytical framework. This integration is theoretically supported by life-span developmental psychology [24], which proposes that psychological development is lifelong, multidimensional, multidirectional, plasticity, and contextual. From this perspective, combining these domains is theoretically essential to holistic understanding of life satisfaction in later life. Second, the study employs the Generalized Ordered Logit Regression (GOLR), which can relax the

proportional odds assumption, at the same time keeping the ordinal nature of the life satisfaction, thereby enhancing the accuracy of estimation and interpretation. Third, the analysis is supplemented by the XGBoost algorithm, a machine learning technique that not only serves as a robustness check but also captures non-linear relationships and interaction effects among predictors [25, 26]. Furthermore, XGBoost enables individual-level prediction of life satisfaction, providing practical insights for precision-oriented ageing policy design. Collectively, these innovations will strengthen the study's empirical reliability.

Method

Sampling

This study employed a cross-sectional design based on the nationally representative data from the 2020 wave of CHARLS merged with retrospective life course information from the CHARLS Life History Survey conducted in 2014. CHARLS is a longitudinal survey targeting Chinese residents aged 45 years and older, utilizing a multistage stratified probability-proportional-to-size (PPS) random sampling strategy to ensure national representativeness. The baseline survey in 2011 covered 150 counties and 450 villages or urban communities across 28 provinces, with subsequent follow-ups conducted every two years. The 2014 Life History Survey collected detailed retrospective data, including early-life adversities, residence history, and education experience for all surviving respondents from the 2011 and 2013 waves. In the 2020 wave, CHARLS successfully followed up participants through structured interviews, and full informed consent was obtained prior to data collection in compliance with the Declaration of Helsinki. Ethical approval for the CHARLS project was granted by the Institutional Review Board at Peking University (IRB00001052-11015).

In this study, we focused exclusively on individuals aged 60 years and above in the 2020 wave, excluding those younger than 60. Besides that, cases with missing values, logically inapplicable responses, or extreme outliers were also removed. In particular, for the key variable "satisfaction with relationship with children", the CHARLS questionnaire included an additional category "6 = No child", selected by only 21/19,367 (0.11%) respondents. Given this minimal proportion, these cases were excluded. Based on missing completely at random (MCAR) test [27, 28], the results did not reject the MCAR assumption. Therefore, the cases with missing values were excluded, leaving 4627 individuals with complete data on both current and life course variables, and Fig. 1 shows the framework of this study, which begins with data integration and cleaning and proceeds through assumption testing and modeling.

Variables

This study included variables from five theoretical domains, each guided by a distinct body of literature relevant to aging, well-being, and life course research.

Predisposing and Socio-demographic factors

This domain is grounded in Andersen's Behavioral Model [29], which posits that health-related outcomes and subjective well-being are influenced not only by individual needs but also by predisposing characteristics and enabling resources. Predisposing factors include demographic attributes such as age, gender, and education, which shape individuals' attitudes, health beliefs, and perceptions of well-being across the life course. In the context of this study, these characteristics represent foundational social positions that affect access to both tangible and intangible resources necessary for later-life satisfaction.

Based on this framework, we include the following variables: age, gender, marital status, educational, residence, family size, average income, and financial support from children. To reduce the influence of magnitude-related disparities, both average income and financial support from children were transformed using natural logarithms.

Health and psychological factors

This domain captures physical health, functional limitations, and emotional well-being, based on the Disablement Process Model [30] and the Subjective Well-being Theory [31]. Variables include self-rated health, sleep duration, functional limitations (ADL), number of chronic diseases, the number of physical pain sites, and depressive symptoms (CES-D10). Functional limitations were assessed using ADL score, six ADL items were summed to create a score from 0 to 6, with higher scores indicating greater dependency [32]. The CES-D10 scale provides a continuous measure of depressive symptoms [33]. Together, these variables reflect the physical and psychological foundations that shape older adults' ability to function independently and maintain life satisfaction.

Children and social support factors

This domain is grounded in Social Support Theory [34], which highlights the protective role of social relationships in promoting psychological well-being and mitigating stress, especially in later life. In this study, two variables were used to measure these dimensions: the perceived quality of the relationship with children and the number of different types of social activities participated in during the past month. The first variable reflects emotional closeness and intergenerational support, representing a core aspect of familial social ties. The second variable captures the scope of an individual's broader

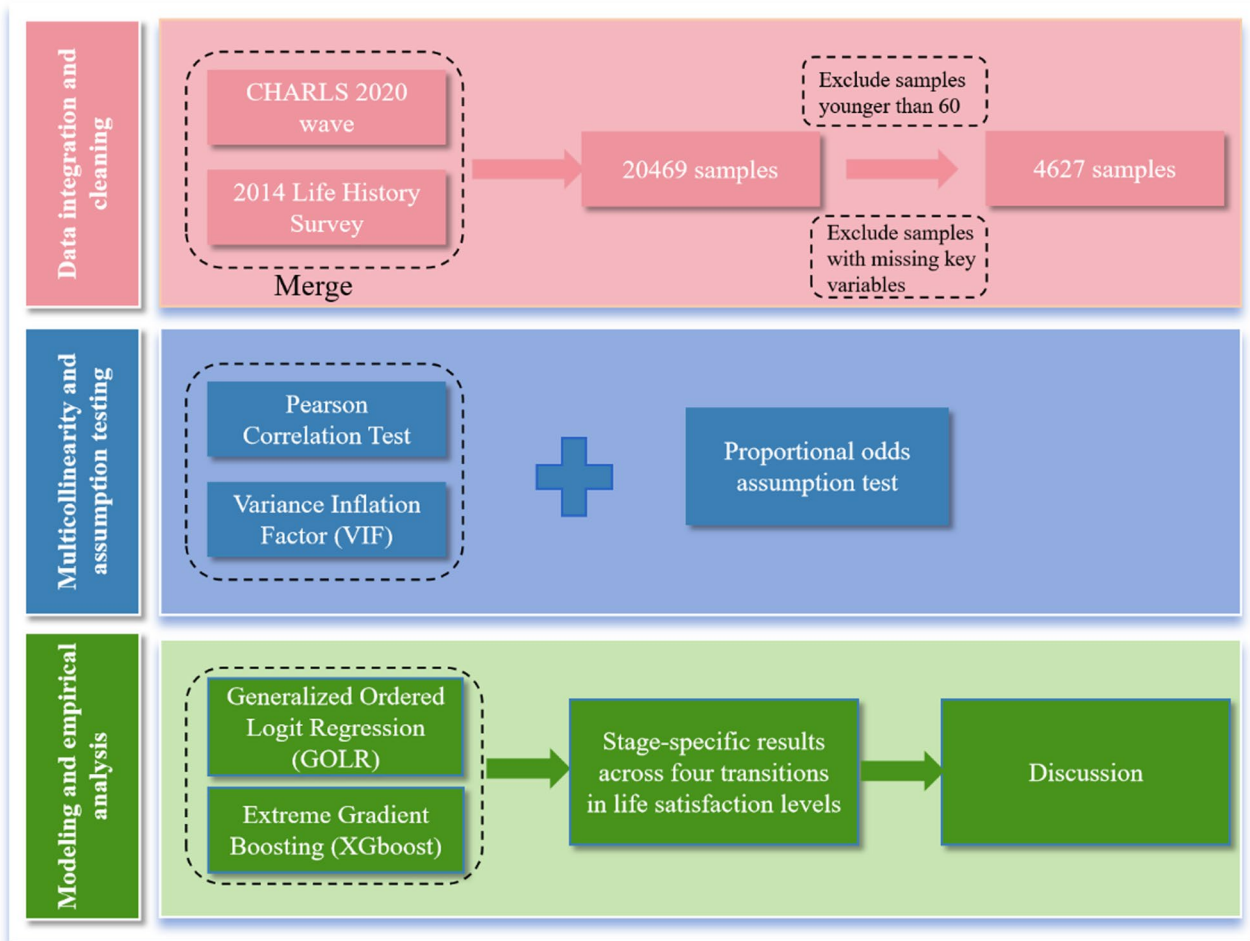


Fig. 1 Framework of This Study

social engagement, indicating the degree of interaction with the community and peers. Together, these variables serve as key indicators of social integration, which may enhance psychological resilience, reduce loneliness, and ultimately contribute to greater life satisfaction in later life [35, 36].

Housing and material condition factors

This domain reflects environmental and infrastructural conditions, supported by the Capability Approach [37] and Environmental Gerontology [38]. Included variables measure housing area, access to utilities such as electricity, tap water, internet, and gas, as well as indoor ground condition. These indicators reflect both physical security and symbolic dignity. A supportive physical environment enhances autonomy, reduces daily stress, and contributes to a sense of life satisfaction [39, 40].

Childhood adversity and Early-life experience

Based on the Life Course Perspective [41] and the Adverse Childhood Experience (ACE) Framework

[42], which emphasize that early-life conditions and experience exert lasting effects on psychological and socio-emotional development throughout the lifespan. According to Evans et al. [43], early adversities affecting individual development include four domains: family, peer, community, and society. Guided by this framework, nine variables were selected to capture multidimensional aspects of early adversities. Family adversity includes family income (ranging from 1 = much better off to 5 = much worse off), caregiving effort by the female guardian (ranging from 1 = a lot to 4 = none), relationship quality with the male guardian (ranging from 1 = excellent to 5 = poor), and relationship quality between parents (ranging from 1 = excellent to 5 = poor), reflecting household economic conditions and family functioning. Emotional loneliness due to lack of friends (ranging from 1 = never to 4 = often) captures peer exclusion. Community adversity comprises perceived neighborhood safety at night (ranging from 1 = very safe to 4 = not safe at all), cleanliness (ranging from 1 = very clean to 4 = not clean at all), and closeness (ranging from 1 = very close-knit to 4 = not

at all), which together indicate neighborhood quality and cohesion. Societal adversity is measured by childhood hunger (0 = no, 1 = yes), referring specifically to the experience of the Great Chinese Famine (1959–1961), which reflects broader social and structural hardship. Consistent with the cumulative risk model [43], early-life adversities from different domains can be summed to reflect the overall burden of exposure. Following prior studies [44], each childhood adversity indicator was first normalized to a 0–1 scale to reduce scale heterogeneity, then summed and averaged to construct cumulative childhood adversity index (CCAI).

Summary statistics and detailed coding of all variables are presented in Table 1.

Statistical analysis

Multicollinearity diagnostics

To evaluate the multicollinearity among the explanatory variables, we examined the pairwise Pearson correlation matrix and calculated the Variance Inflation Factor (VIF) for each variable. Correlation coefficients exceeding 0.80 are typically considered as high collinearity, while VIF values greater than 5 suggest moderate multicollinearity and values above 10 indicate severe multicollinearity [45].

The correlation matrix revealed no excessively high pairwise correlations as shown in Fig. 2, all correlation coefficients were below 0.80. In addition, the VIF values ranged from 1.01 to 1.55, with a mean of 1.25, indicating that multicollinearity is not a concern in this dataset. Therefore, all variables were retained for subsequent models.

Statistical analysis and machine learning algorithms

To examine the determinants of life satisfaction among older adults while addressing the ordinal nature of dependent variable and potential violations of proportional odds assumption, we employed the Generalized Ordered Logit Regression (GOLR) model. Unlike ordered logit model, which assumes constant effects across outcome thresholds, the GOLR model allows for the coefficients of explanatory variables to vary across different satisfaction levels [46]. This flexibility is particularly suitable for modeling life satisfaction, measured on a five-point ordinal scale ranging from 1 (“Not at all satisfied”) to 5 (“Extremely satisfied”), as it enables the identification of heterogeneous effects across different satisfaction levels.

The XGBoost machine learning algorithm was applied to confirm feature importance, explore potential interactions among predictors, and generate individual predictions [25]. In this study, we constructed XGBoost models based on cumulative life satisfaction levels in order to model the ordinal nature of the outcome variable. To further enhance the interpretability of the results, Shapley Additive Explanations (SHAP) is employed to analyze the

marginal and interactive effects of features on life satisfaction level. To ensure reproducibility, a random seed of 123 was set, and the model was trained on 70% of the dataset, with the remaining 30% used for testing.

All statistical analyses, including regression modeling, were conducted using Stata MP18.0, while the XGBoost algorithm was implemented in RStudio 4.4.2. The detailed explanations of the two models are provided in the Supplementary Material.

Results

Generalized ordered logit regression results

Test for proportional odds assumption

The results of the proportional odds assumption test indicate the assumption is violated (Table 2). The likelihood ratio test has a Chi^2 value of 375.9 ($P=0.000$), and the Wolfe-Gould test showed a Chi^2 value of 372.4 ($P=0.000$), both rejecting the parallel assumption. Additionally, the Wald test result and Brant test further confirms the inconsistency of coefficients across different life satisfaction levels. These results suggest the need for a GOLR model to account for varying relationships between independent variables and life satisfaction levels.

Results for GOLR

Table 2 presents the results from GOLR. The results show that the factors vary across different life satisfaction levels, further validating the appropriateness of GOLR in this study.

As shown in Table 2, only two variables, satisfaction with children relationship and CES-D10 consistently demonstrate statistically significant effects across all satisfaction thresholds, suggesting their persistent and stable influence on life satisfaction. Notably, the OR value for satisfaction with children relationship becomes progressively larger as life satisfaction level improves, and remains significant at the 1% level. This pattern indicates a particularly strong effect of intergenerational emotional closeness in shaping higher levels of life satisfaction. However, other factors vary in significance across thresholds, indicating heterogeneous influences at different levels of life satisfaction.

Specifically, in the transition from “not at all satisfied” to “higher levels” (Threshold 1), ten variables are significant. These include: education (95% CI=0.999–1.708, P value<0.1), financial support from children (95% CI=0.962–1.615, P value<0.1), self-rated health (95% CI=1.406–2.376, P value<0.01), sleep time (95% CI=1.010–1.220, P value<0.05), pain (95% CI=0.812–0.994, P value<0.05), CES-10 (95% CI=0.866–0.937, P value<0.01), relationship with children (95% CI=2.053–3.251, P value<0.01), social activity participation (95% CI=1.168–2.225, P value<0.01), electricity access (95% CI=1.074–21.39, P value<0.05), and tap water access

Table 1 Measurement, coding, and descriptive statistics of key variables

Variable	Explanation of variable	Mean (SD)	Frequency (Percentage)	Min	Max
Satlife	Life satisfaction			1	5
	1 = Not at all satisfied		140(3.02%)		
	2 = Not very satisfied		347(7.49%)		
	3 = Somewhat satisfied		2411(52.13%)		
	4 = Very satisfied		1520(32.84%)		
	5 = Extremely satisfied		209(4.52%)		
Age	Age(years)	70.045 (7.201)		60	120
Gender	0 = Male		2231(48.22%)	0	1
	1 = Female		2396(51.78%)		
Edu	Highest education level			1	4
	1 = Below Primary		2419(52.29%)		
	2 = Primary		936(20.23%)		
	3 = Secondary		750(16.20%)		
	4 = Upper Secondary and Above)		522(11.28%)		
Marry	Marital status			0	1
	0 = Not currently married, including never married, divorced, and widowed		1046(22.61%)		
	1 = Currently married		3581(77.39%)		
Residence	Type of residence			0	1
	0 = Urban		1859(40.17%)		
	1 = Rural/semi-rural/other		2768(59.83%)		
Fam_size	Number of household members	2.783 (1.612)		1	16
log_income_Avg	Log of per capita household income	8.919 (1.406)		-1.099	13.624
log_fcamt	Log of financial support from children	9.398 (0.894)		3.584	13.116
Self_rp	Self-rated health			1	5
	1 = Very poor		343(7.41%)		
	2 = Poor		965(20.85%)		
	3 = Fair		2324(50.23%)		
	4 = Good		530(11.46%)		
	5 = Very good		465(10.04%)		
Slptime	Average nightly sleep duration in past month (in hours)	5.836 (2.318)		0	24
ADL	ADLscore based on Katz Index(0–6)	0.659 (1.333)		0	6
ChroDis	Number of chronic diseases	2.626 (2.049)		0	13
Pain	Number of pain sites	2.538 (3.498)		0	15
CES_D10	Depressive symptoms score (0–30)	9.143 (6.538)		0	30
Chld_relation	Satisfaction with relationship with children			1	5
	1 = Not satisfied at all		76(1.62%)		
	2 = Slightly satisfied		181(3.92%)		
	3 = Moderately satisfied		1913(41.35%)		
	4 = Very satisfied		2167(46.84%)		
	5 = Extremely satisfied		290(6.26%)		
SocAct	Number of types of social activities participated in	0.669 (0.919)		0	6
log_House_area	Log-transformed housing area(sq m)	4.680 (0.722)		0.000	7.664

Table 1 (continued)

Variable	Explanation of variable	Mean (SD)	Frequency (Percentage)	Min	Max
Electricity	Electricity access			0	1
	0=No		30(0.65%)		
	1=Yes		4597(99.35%)		
Tap_water	Tap water access			0	1
	0=No		455(9.84%)		
	1=Yes		4172(90.16%)		
Internet	Internet access			0	1
	0=No		2263(48.91%)		
	1=Yes		2364(51.09%)		
Gas_supply	Access to piped gas or natural gas			0	1
	0=No		2921(63.14%)		
	1=Yes		1705(36.86%)		
Ground_cond	Floor condition			1	3
	1=Uneven floor		2823(61.01%)		
	2=Cement floor		1553(33.56%)		
	3=Finished floor		251(5.43%)		
CCAI	Cumulative Childhood Adversity Index (0–1)	0.364 (0.126)		0	1

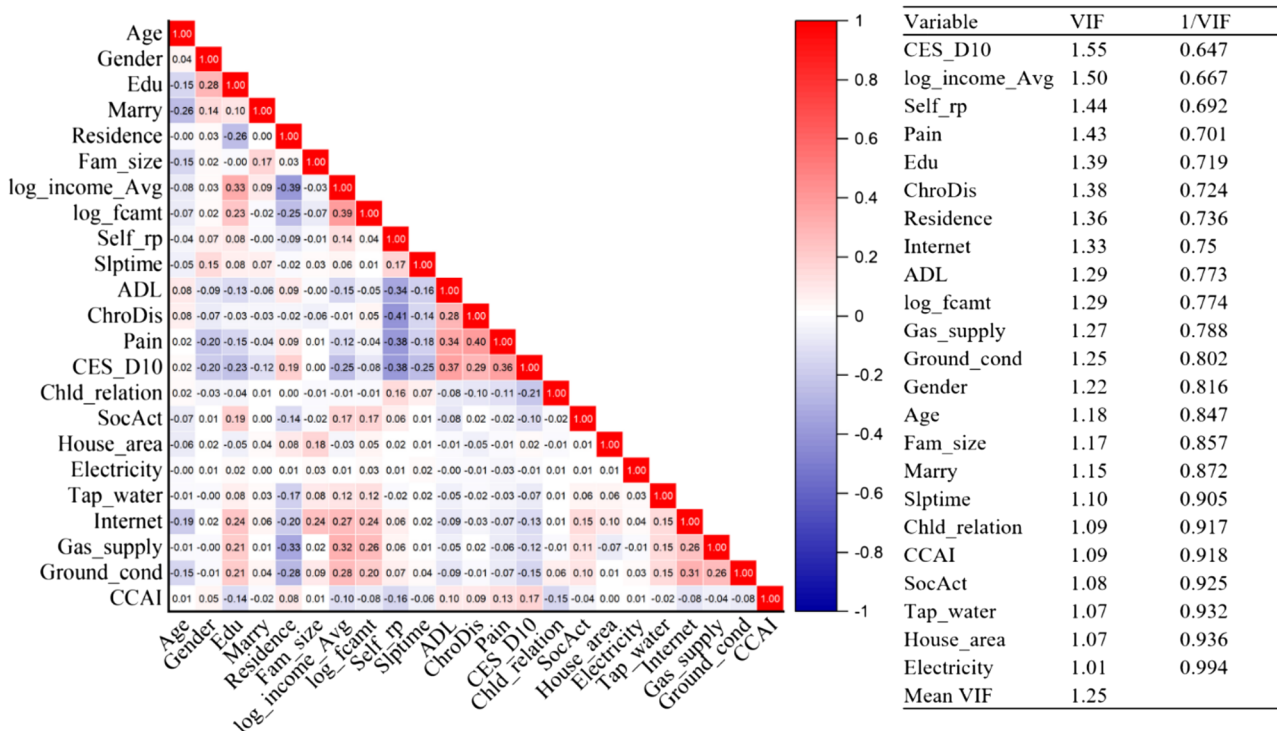


Fig. 2 Combined Correlation Heatmap and VIF Analysis of Key Variables

(95% CI=1.039–3.177, P value<0.05). These findings suggest at the lowest level of life satisfaction, both social support and material availability are important, and fewer depressive symptoms is a significant factor in helping individuals move out of complete dissatisfaction. It is also noteworthy that cumulative childhood adversity index is not statistical significance at this threshold,

indicating that childhood experiences not directly affect the initial shift from complete dissatisfaction to higher satisfaction.

In the transition from “low satisfaction” to “moderate to high” (Threshold 2), eleven variables are significant. These include: age (95% CI=1.009–1.054, P value<0.01), average household income (95%

Table 2 Odds ratios (ORs) and 95% confidence intervals from the generalized ordered logit model for life satisfaction

Variables	OR 1 (95%CI)	OR 2 (95%CI)	OR 3 (95%CI)	OR 4 (95%CI)
<i>Predisposing and Socio-demographic Characteristics</i>				
Age	1.032 (0.993–1.074)	1.031*** (1.009–1.054)	1.021*** (1.008–1.033)	1.040*** (1.014–1.067)
Gender	1.352 (0.841–2.174)	1.085 (0.839–1.405)	0.897 (0.770–1.044)	0.877 (0.626–1.229)
Edu	1.306* (0.999–1.708)	1.089 (0.952–1.246)	0.761*** (0.705–0.821)	1.08 (0.912–1.278)
Marry	1.41 (0.829–2.397)	1.23 (0.904–1.673)	0.826* (0.677–1.008)	0.885 (0.583–1.344)
Residence	0.883 (0.499–1.560)	1.243 (0.935–1.651)	1.218** (1.036–1.432)	0.991 (0.688–1.427)
Fam_size	0.979 (0.838–1.144)	1.033 (0.949–1.124)	1.035 (0.984–1.088)	1.041 (0.924–1.173)
log_income_Avg	1.038 (0.855–1.262)	1.169*** (1.060–1.288)	1.051 (0.989–1.116)	0.999 (0.872–1.145)
log_fcamt	1.246* (0.962–1.615)	1.01 (0.876–1.165)	0.953 (0.870–1.045)	0.931 (0.759–1.141)
<i>Health Status and Functional Limitations</i>				
Self_rp	1.828*** (1.406–2.376)	1.334*** (1.153–1.544)	1.388*** (1.279–1.505)	1.046 (0.880–1.244)
Slptime	1.110** (1.010–1.220)	1.005 (0.950–1.064)	0.992 (0.957–1.029)	0.936* (0.868–1.010)
ADL	0.918 (0.801–1.053)	0.899** (0.822–0.983)	1.013 (0.936–1.096)	0.977 (0.819–1.167)
ChroDis	0.959 (0.869–1.058)	1.058* (0.997–1.123)	1.044** (1.004–1.086)	1.054 (0.970–1.146)
Pain	0.931** (0.812–0.994)	0.995* (0.964–1.008)	0.983 (0.958–1.007)	0.977 (0.923–1.036)
CES_D10	0.901*** (0.866–0.937)	0.863*** (0.846–0.881)	0.934*** (0.921–0.947)	0.972* (0.942–1.003)
<i>Children and Social Support Factors</i>				
Chld_relation	2.584*** (2.053–3.251)	2.912*** (2.472–3.431)	3.942*** (3.496–4.446)	5.684*** (4.340–7.445)
SocAct	1.582*** (1.156–2.164)	1.129* (0.977–1.305)	1.018 (0.946–1.095)	1.151* (0.989–1.339)
<i>Housing and Material Condition Factors</i>				
House_area	1.001 (0.999–1.003)	1.000 (0.999–1.001)	1.000 (1.000–1.001)	0.999 (0.997–1.001)
Electricity	4.792** (1.074–21.39)	1.904 (0.641–5.649)	1.085 (0.454–2.594)	1.35 (0.159–11.46)
Tap_water	1.817** (1.039–3.177)	1.006 (0.706–1.434)	1.046 (0.821–1.333)	1.592 (0.833–3.040)
Internet	0.867 (0.532–1.415)	1.194 (0.919–1.552)	0.887 (0.758–1.039)	0.873 (0.611–1.247)
Gas_supply	0.741 (0.395–1.391)	1.353* (0.970–1.886)	1.166* (0.980–1.387)	0.966 (0.670–1.393)
Ground_cond	1.256 (0.889–1.776)	1.133 (0.928–1.384)	1.051 (0.924–1.196)	1.301* (0.956–1.770)
<i>Early-life Conditions and Adversities</i>				
CCAI	0.588 (0.130–2.656)	0.299*** (0.120–0.747)	0.182*** (0.102–0.324)	0.961 (0.266–3.471)
Number of obs	4627			

Table 2 (continued)

Variables	OR 1 (95%CI)	OR 2 (95%CI)	OR 3 (95%CI)	OR 4 (95%CI)
LR chi ² (92)	2026.40			
Prob > chi ²	0.000			
Log likelihood	-4054.358			
Pseudo R ²	0.200			
Wolfe Gould:	Chi ² = 372.4	P > Chi ² = 0.000		
Brant:	Chi ² = 342.2	P > Chi ² = 0.000		
Score:	Chi ² = 379.4	P > Chi ² = 0.000		
Likelihood ratio:	Chi ² = 375.9	P > Chi ² = 0.000		
Wald:	Chi ² = 379.6	P > Chi ² = 0.000		

OR1 to OR4 refer to thresholds between adjacent life satisfaction levels estimated from a Generalized Ordered Logit Model. ***, **, and * indicate significant level at 0.01, 0.05, and 0.1, respectively

CI = 1.060–1.288, P value < 0.01), self-rated health (95% CI = 1.153–1.544, P value < 0.01), ADL score (95% CI = 0.822–0.983, P value < 0.05), the number of chronic diseases (95% CI = 0.997–1.123, P value < 0.1), pain (95% CI = 0.995, P value < 0.1), CES-D10 (95% CI = 0.846–0.881, P value < 0.01), relationship with children (95% CI = 2.472–3.431, P value < 0.01), social activity participation (95% CI = 0.977–1.305, P value < 0.1), gas supply (95% CI = 0.970–1.886, P value < 0.1), and cumulative childhood adversity index (95% CI = 0.120–0.747, P value < 0.01). Both current health status and early-life experiences play significant roles in shaping individuals' moderate to high levels of life satisfaction. Additionally, fewer depressive symptoms and closer intergenerational relationships remain strong protective factors, while adverse childhood experiences exert lasting and strong negative effects in later life.

In the transition from “Low to moderate” to “High satisfaction” (Threshold 3), ten variables are significant. These include: age (95% CI = 1.008–1.033, P value < 0.01), education (95% CI = 0.705–0.821, P value < 0.01), marital status (95% CI = 0.677–1.008, P value < 0.1), residence type (95% CI = 1.036–1.432, P value < 0.05), self-rated health (95% CI = 1.279–1.505, P value < 0.01), the number of chronic diseases (95% CI = 1.004–1.086, P value < 0.05), CES-D10 (95% CI = 0.921–0.947, P value < 0.01), relationship with children (95% CI = 3.496–4.446, P value < 0.01), gas supply (95% CI = 0.980–1.387, P value < 0.1), and cumulative childhood adversity index (95% CI = 0.102–0.324, P value < 0.01). These findings confirm the continued significance of intergenerational relationships and CES-10 across all thresholds, with the influence of satisfaction with children relationship becoming even stronger. Early-life adversities show increasing negative influence, suggesting a lasting impact on later-life well-being. Notably, education plays a negative role in this stage, possibly reflecting a mismatch between expectations and reality in highly educated older adults.

In the transition from “Less than extremely satisfied” to “Extremely satisfied” (Threshold 4), only six

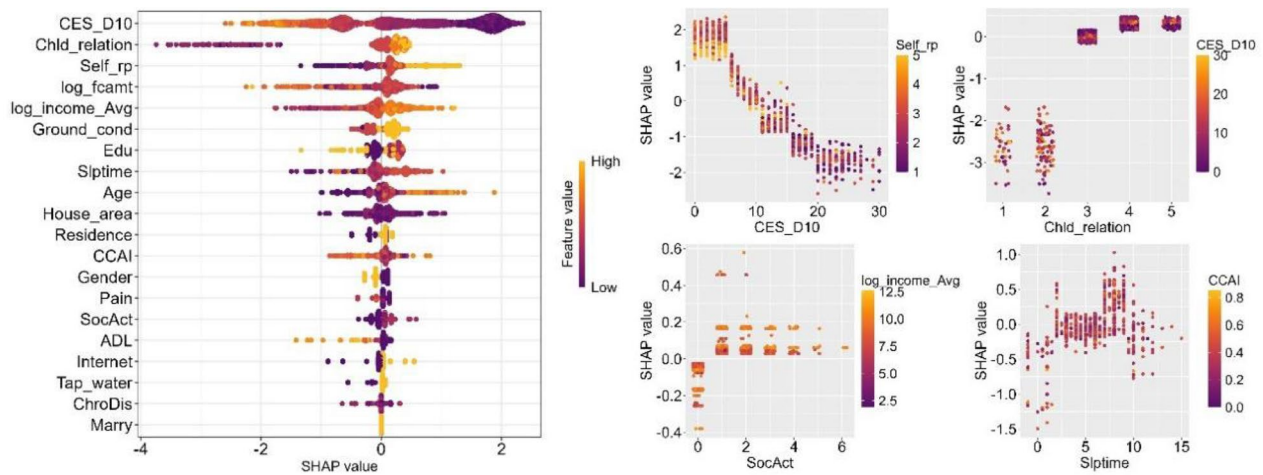
variables remain statistically significant. These include: age (95% CI = 1.014–1.067, P value < 0.01), sleep time (95% CI = 0.868–1.010, P value < 0.1), CES-D10 (95% CI = 0.942–1.003, P value < 0.1), satisfaction with children relationship (95% CI = 4.340–7.445, P value < 0.01), social activity participation (95% CI = 0.989–1.339, P value < 0.1), ground condition (95% CI = 0.956–1.770, P value < 0.1). This pattern suggests that as satisfaction reaches its highest point, the range of influential factors narrows, leaving only those with enduring effects, such as strong child relationships, lower depressive symptoms, social activity, and physical conditions, still playing a role. These results highlight that at the highest satisfaction level, emotional closeness, psychological resilience play decisive roles in shaping life satisfaction.

Result of XGBoost algorithm

Results for transition from “Not at all satisfied” to “Higher levels”

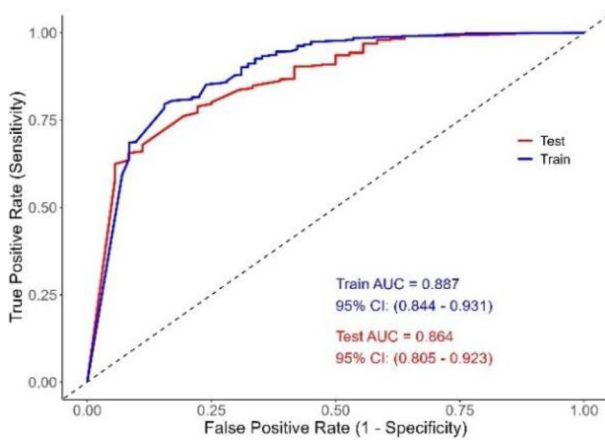
Consistent with the results of GOLR, the XGBoost analysis validates the robustness of the findings by identifying key factors influencing the transition from “Not at all satisfied” to “Higher levels”. The SHAP (Shapley Additive Explanations) plot (Fig. 3a) shows each variable's contribution to this initial transition from the perspectives of both the direction and extent of their effects.

In the SHAP plot, positive SHAP values on the right-hand side indicate a positive contribution to higher levels, while negative values on the left reflect a negative relation. The color gradient represents variable's feature value, with yellow meaning higher values and purple indicating lower values. In Fig. 3a, the SHAP plot highlights CES-D10, relationship with children, self-rated health and sleep time as the top four most influential predictors of life satisfaction among older adults. Social activity participation, tap-water access, pain and education also show considerable predictive importance though to a lesser extent relative to the top four variables. These findings are almost consistent with those from the GOLR model, where eight out of these ten variables were

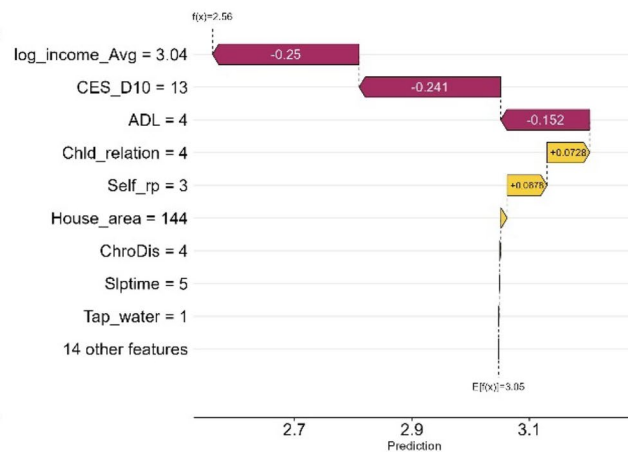


(a). SHAP Plot of Feature Importance

(b). SHAP Dependence Plots



(c). ROC Curve



(d). Waterfall Plot for Individual Prediction

Fig. 3 Interpretation of XGBoost Using SHAP: From “Not at all satisfied” to “Higher levels”

statistically significant. CES-D10 consistently exhibits the largest and predominantly negative SHAP values. Better intergenerational relationships and self-rated health, higher levels of social activity participation, less pain sites promote the transition from “Not at all satisfied” to “Higher levels”. The consistency across econometric and machine learning approaches enhances robustness and reliability of the findings.

Figure 3b presents the SHAP dependence plot with interaction coloring. Overall, in the transition from “Not at all satisfied” to “Higher levels”, no major interaction effects were observed across the SHAP dependence plots. However, a weak interaction emerged between CES-D10 and self-reported health. Specifically, among individuals with low CES-D10 scores (0–6), those reporting better self-rated health showed slightly lower SHAP values,

suggesting that when depressive symptoms are minimal, additional improvements in perceived physical health contribute less to life satisfaction.

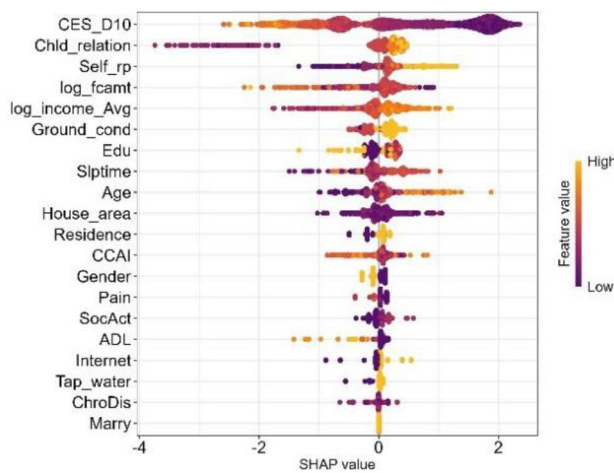
Except capturing feature importance, non-linear relationships, and interactions, XGBoost also demonstrated excellent prediction. The model achieved an AUC of 0.887 on the training set and 0.864 on the testing set, as illustrated by the ROC curve in Fig. 3c. Figure 3d presents the SHAP waterfall plot for the prediction of a randomly selected individual (row 1). Key features such as average income, CES-D10, ADL, relationship with children, self-reported health, house area, chronic disease, sleep time and tap-water access exert the most significant influence in the prediction. These results demonstrate the model’s robustness and its strong interpretability at the individual level.

Results for transition from “Low satisfaction” to “Moderate to high”

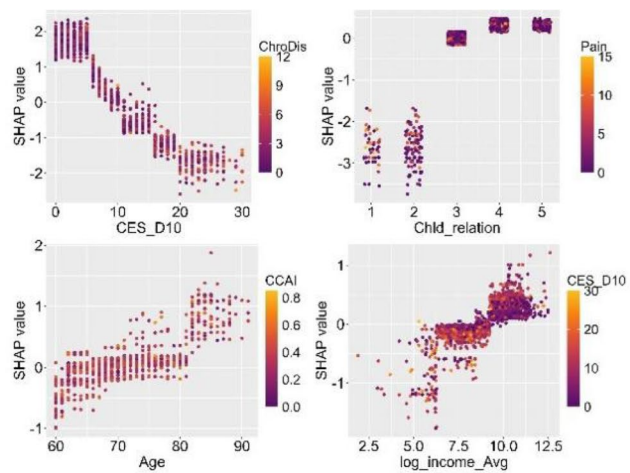
Building on the previous analysis, XGBoost was further applied to examine the factors associated with the transition from “Low satisfaction” to “Moderate to high” levels. As shown in the SHAP feature importance plot (Fig. 4a), among the eleven significant variables identified in the GOLR analysis, nine remained influential in the XGBoost results, including age, average household income, self-rated health, ADL score, pain, CES-D10, relationship with children, social activity participation, and cumulative childhood adversity index. However, the number of chronic diseases and gas supply, previously significant in the GOLR model, did not demonstrate importance

in the SHAP feature importance plot. Notably, the relative importance cumulative childhood adversity index increased in this stage, suggesting that early-life factors begin to play a prominent role in the transition from “Low satisfaction” to “Moderate to high”.

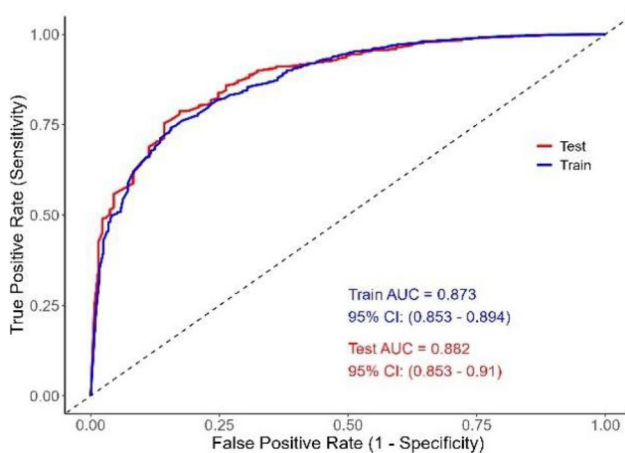
No significant interaction effects were detected in the SHAP dependence plots (Fig. 4b), but there exists a nonlinear positive relationship between age and life satisfaction. For individuals aged 60 to 80, the SHAP values remain relatively stable around zero, indicating that age itself contributes little to variations in life satisfaction once other factors are controlled. However, beyond 80-year-old, SHAP values increase noticeably, suggesting that age becomes a stronger positive contributor to



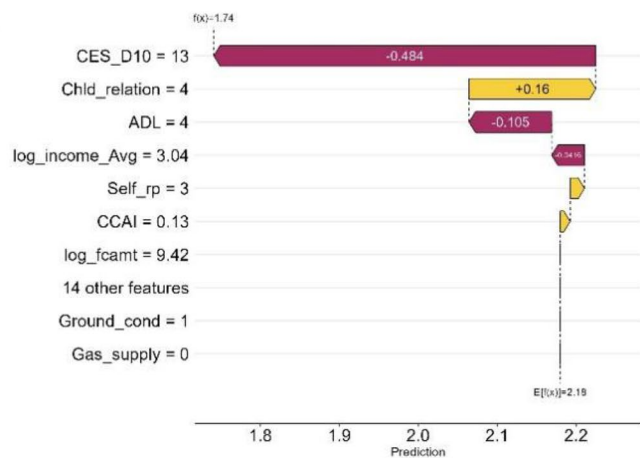
(a). SHAP Plot of Feature Importance



(b). SHAP Dependence Plots



(c). ROC Curve



(d). Waterfall Plot for Individual Prediction

Fig. 4 Interpretation of XGBoost Using SHAP: From “Low satisfaction” to “Moderate to High”

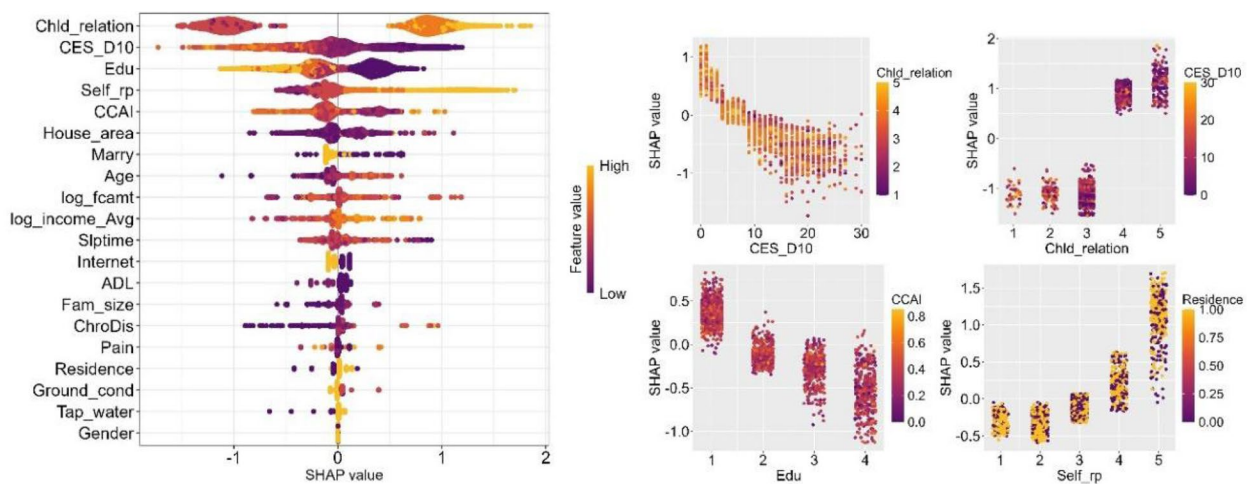
life satisfaction in very old age. The ROC curve (Fig. 4c) shows an AUC of 0.873 in training set and 0.882 in test set, demonstrating the model’s robustness and generalizability. Furthermore, the SHAP waterfall plot for an individual case (row 1) (Fig. 4d) further demonstrates the key predictors combine to influence the prediction outcome at this stage.

Results for transition from “Low to moderate” to “High satisfaction”

To further advance staged analysis, XGBoost was employed to explore the determinants contributing to the transition from “low to moderate” to “High satisfaction”. According to the SHAP feature importance plot (Fig. 5a),

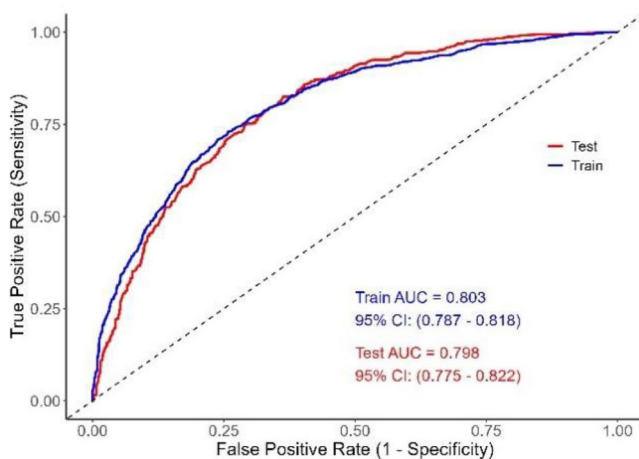
among the ten variables identified as significant in the GOLR model, nine remained influential in the XGBoost results. These include: age, education, marital status, residence type, self-rated health, the number of chronic diseases, CES-D10, relationship with children, gas supply, and cumulative childhood adversity index. However, gas supply, which were significant in the GOLR results, did not exhibit notable importance in the XGBoost model.

The SHAP dependence plots (Fig. 5b) did not reveal obvious interaction effects overall. However, relationships with children showed clear nonlinear relationship with life satisfaction. The SHAP values remain negative and relatively stable at lower satisfaction levels (1–3), indicating that weak or moderate relationships with children

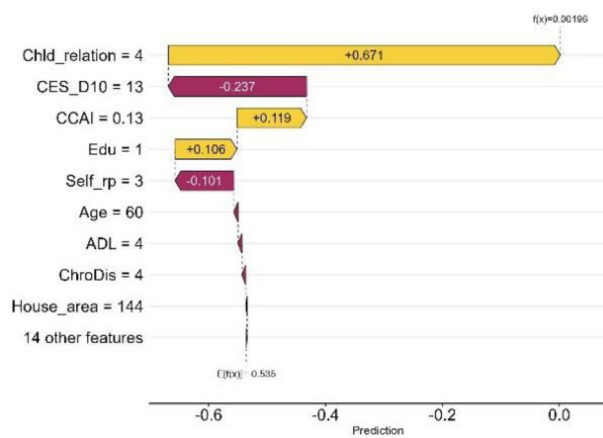


(a). SHAP Plot of Feature Importance

(b). SHAP Dependence Plots

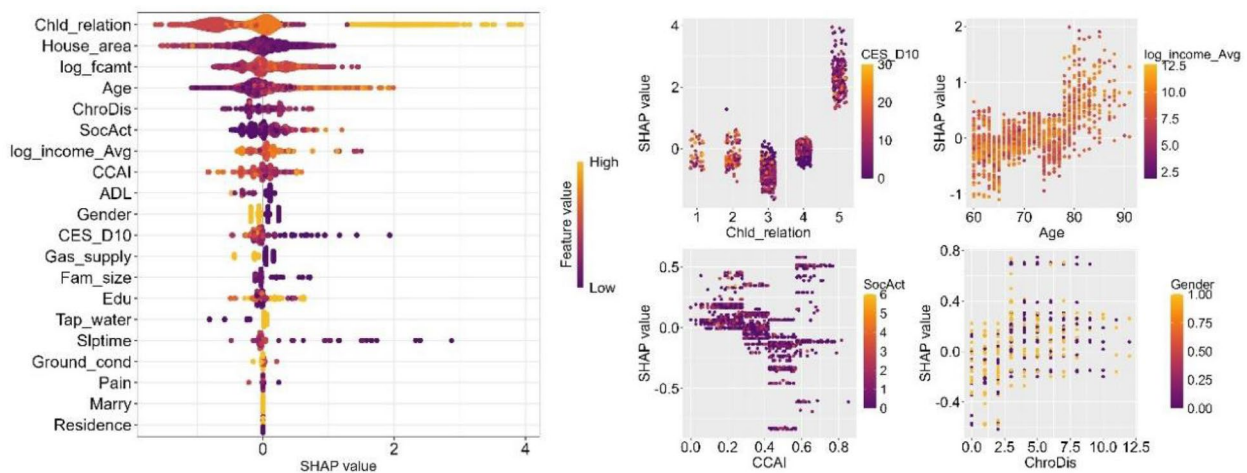


(c). ROC Curve



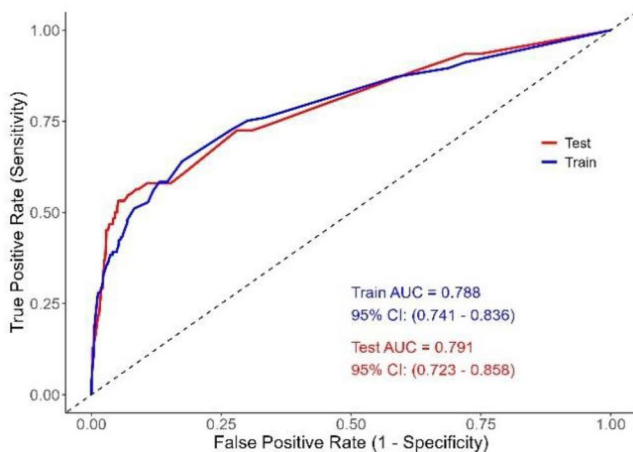
(d). Waterfall Plot for Individual Prediction

Fig. 5 Interpretation of XGBoost Using SHAP: From “Low to moderate” to “High satisfaction”

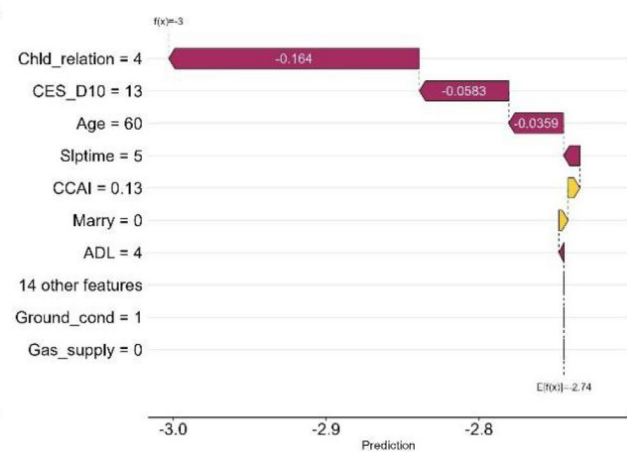


(a). SHAP Plot of Feature Importance

(b). SHAP Dependence Plots



(c). ROC Curve



(d). Waterfall Plot for Individual Prediction

Fig. 6 Interpretation of XGBoost Using SHAP: From “Less than extremely satisfied” to “Extremely satisfied”

are consistently associated with lower life satisfaction. However, a sharp increase in SHAP values was observed between levels 3 and 4, followed by a further rise at level 5, suggesting a threshold effect. This nonlinearity implies that improvements in child relationships at lower levels have limited effects, whereas once the relationship quality reaches a high or very high level, it will show a strong positive impact. Figure 5c is the ROC curve, the AUC is 0.803 in the training set and 0.798 in the test set, indicating appropriate predictive performance. The SHAP waterfall plot for the first individual (Fig. 5d) further illustrates how key predictors jointly contribute to the final prediction, reinforcing the model’s reliability and its capacity for individualized interpretation.

Results for transition from “Less than extremely satisfied” to “Extremely satisfied”

To complete the final phase of the staged analysis, XGBoost was employed to identify key predictors driving the transition from “Less than extremely satisfied” to “Extremely satisfied”. As shown in the SHAP feature importance plot (Fig. 6a), five out of six variables identified as significant in the GOLR model remained important in the XGBoost analysis. These include age, sleep time, CES-D10, satisfaction with children relationship, social activity participation. This consistency across methods reinforces the robustness of these variables in explaining the highest level of life satisfaction.

The SHAP dependence plots (Fig. 6b) did not reveal major interaction effects, while both age and satisfaction

with children relationship exhibited nonlinear patterns similar to those observed previously. The ROC curve (Fig. 6c) confirms the model's reasonable predictive performance at this transition stage, with an AUC of 0.788 for the training set and 0.791 for the test set. Although the AUC values are slightly lower than in previous stages, the performance remains acceptable and shows no clear signs of overfitting. The SHAP waterfall plot (Fig. 6d) further illustrates how individual-level predictions (row 1) are driven by multiple features. This visualization enhances the interpretability of the model, revealing both positive and negative influences that jointly determine the predicted outcome for individual.

Discussion

Stage-Specific drivers of life satisfaction

This study offers a staged analytical framework to examine how determinants vary across different levels of life satisfaction among older adults in China. The integration of GOLR and XGBoost algorithm not only confirms the robustness of findings but also reveals stage-specific patterns that were overlooked by previous research.

4.1.1 Transition from “Not at all satisfied” to “Higher levels”: Driven by Present-Day Psychosocial and Material Conditions.

In the transition from the lowest level of life satisfaction to higher levels, eight variables were identified as significant across both GOLR and XGBoost models: education, self-rated health, sleep time, pain, CES-D10, relationship with children, social activity participation, tap-water access. These variables involve health, psychosocial, behavioral, and material domains, suggesting the multifaceted nature of life satisfaction at its lowest level.

The dominant role of CES-D10 reflects the substantial negative association of depressive symptoms, which not only reduce subjective well-being but also constrain psychological capacity for upward transition in satisfaction levels [47, 48]. Similarly, strong intergenerational emotional ties reinforce the core influence of familial networks, consistent with Intergenerational Solidarity Theory [49]. Social activity participation highlights the role of social connectedness. By reducing loneliness, strengthening psychological resilience, and facilitating information exchange through social networks, participation in social activities helps older adults move out of extreme dissatisfaction [36–51]. Meanwhile, self-rated health reflects subjective health perception rather than objective functional limitation. Its strong and significant influence at this stage suggests that perceived health confidence and self-evaluation dominate life satisfaction formation under severe dissatisfaction, consistent with the psychological appraisal perspective of self-rated health, whereby individuals integrate bodily sensations, emotional states, and

future health expectations in forming overall life evaluations [52, 53].

Importantly, the appearance of sleep time and tap-water access as significant factors points to the continued relevance of basic physiological and environmental conditions. The result for tap-water access supports the logic of Maslow's hierarchy of needs [54, 55], which emphasizes that foundational safety and comfort must be secured before individuals can pursue higher-order emotional fulfillment. The fact that tap-water becomes insignificant in subsequent stages signals a threshold-limited utility, crucial for escaping the bottom level but not for sustaining higher levels of satisfaction.

Notably, cumulative childhood adversity index wasn't significance at this threshold, indicating that transition from complete dissatisfaction is primarily contingent on present-day conditions. This contrasts with later transitions where childhood experience becomes increasingly relevant. Thus, interventions for the most dissatisfied older adults should focus on mental health screening and treatment, improving daily living conditions, ensuring utility access, promoting structured social activity, and strengthening intergenerational emotional support.

4.1.2 Transition from “Low satisfaction” to “Moderate to high”: The Emergence of Early-Life Influence alongside Current Well-being Factors.

Building on the first stage, this transition represents a structural shift in the composition of significant predictors: for the first time, early-life adversities appear alongside current psychosocial and health factors, marking the beginning of a cumulative life-course influence. Nine variables remained significant across both GOLR and XGBoost models: age, average household income, self-rated health, ADL score, pain, CES-D10, relationship with children, social activity participation, and cumulative childhood adversity index. The continued significance of CES-D10 and relationship with children highlights their persistent foundational role. At the same time, the emergence of cumulative childhood adversity index illustrates the lasting psychological imprint of early-life adversities. These findings echo the logic of the Cumulative Advantage/Disadvantage Theory, which posits that early advantages or disadvantages accumulate over time and shape later-life outcomes [56, 57]. Furthermore, functional and physical health remains central: the significance of ADL score and self-rated health reinforces the need for maintaining functional independence to support upward transitions in life satisfaction.

The appearance of age as a significant positive predictor may reflect a shift in life perspective as individuals grow older. In this study, a non-linear pattern was observed, where life satisfaction remained relatively stable between ages 60 and 80 but increased markedly beyond 80,

suggesting that very old age strengthens the positive association between age and well-being. This pattern partially corresponds to the latter half of a U-shaped curve in previous research, where life satisfaction tends to rebound at older ages [58, 59], possibly due to greater acceptance, emotional regulation, and recalibrated expectations, all of which contribute to enhanced life satisfaction [60, 61]. Average household income becomes significant as it supports material security and access to health services, enabling higher levels of satisfaction [62].

These findings support a dual-pathway interpretation of life satisfaction at this stage. On one hand, modifiable factors such as functional capacity and material resources continue to exert immediate and tangible effects. On the other hand, latent influences from early-childhood begin to shape older adults' subjective evaluation of current experiences. The interaction between these two pathways suggests that present-focused policies (functional rehabilitation based on ADL limitations, income stabilization) must be complemented by developmentally-informed interventions aimed at addressing long-standing psychosocial vulnerabilities.

Transition from “Low to moderate” to “High satisfaction”: the most complex pattern of predictors

At this stage, life satisfaction reached its most complex pattern of determinants, with significant predictors spanning all five domains: socio-demographic characteristics, health status and functional limitations, children and social support factors, housing and material condition factors, and early-life conditions and adversities. The key predictors identified across both models include age, education, marital status, residence type, self-rated health, the number of chronic diseases, CES-D10, relationship with children, gas supply, and the cumulative childhood adversity index. The continuing influence of CES-D10 and relationship with children across all thresholds underscores their foundational importance in shaping life satisfaction.

Notably, the negative association between education and satisfaction may reflect the expectation-disconfirmation theory, where better-educated individuals may perceive greater dissatisfaction when actual circumstances fall short of earlier expectations, especially following retirement and reduced role identity [63, 64]. In contrast, during the transition from “not at all satisfied” to higher satisfaction levels, education exerts a positive effect. This finding is fully consistent with the evidence reported by the Bennett Institute for Public Policy at the University of Cambridge [65], which showed that education has a strong positive impact at the lower end of the life satisfaction distribution, becomes negligible at the middle, and turns negative at the upper end using large-scale UK panel data.

The significance of residence type and marital status highlights the influence of contextual structural conditions, including regional infrastructure, access to public services, and formal family status, on older adults' evaluation of life satisfaction [66, 67]. In addition, the persistent effects of the cumulative childhood adversity index confirm the cumulative continuity principle, where disadvantages experienced earlier continue to shape present well-being [68].

This phase reflects a turning point from mid-level to high satisfaction, where all five domains are activated simultaneously. It emphasizes that achieving higher satisfaction requires a holistic accumulation of advantages across time. From a policy perspective, single-dimensional interventions are limited. Instead, comprehensive strategies that simultaneously address early-life deprivation and current health and structural vulnerabilities are essential to promote the upward shifts in subjective well-being.

Transition to “Extremely satisfied”: A convergence toward fewer but stronger predictors

At the highest threshold, life satisfaction appears around a small but powerful enduring predictors. Five variables identified in the GOLR model remained significant in XGBoost: age, sleep time, CES-D10, satisfaction with children relationship, social activity participation.

Among the relationship with children emerges as the strongest and most consistent determinant across all stages. Its odds ratio increases progressively, reaching its maximum at this stage. This upward trend indicates a cumulative enhancement of its predictive strength and reinforces the enduring importance of intergenerational emotional ties in shaping well-being in later life. In the Chinese cultural context, this finding resonates with the normative role of filial piety and emotional reciprocity between generations [69]. Although positive parent-child relationships also enhance older adults' well-being in the United States, their influence is weaker because of the stronger individualistic ideology with respect to kinship ties [70]. In Europe, intergenerational relationships remain important, but their strength varies regionally, relationships are generally closer in Southern than in Northern Europe, and this closeness has a more direct association with older adults' life satisfaction [71, 72].

Notably, the effect of CES-D10, a dominant predictor in earlier transitions, declines in statistical strength at this threshold. The reduction in effect may suggest that depressive symptoms become less central in distinguishing the “extremely satisfied” group. This may reflect a form of psychological adaptation or emotional regulation among older adults who have reached higher satisfaction levels, consistent with Socioemotional Selectivity Theory [73].

In summary, this stage reflects a concentration of explanatory power in a few deeply embedded variables, rather than the addition of new ones. Life satisfaction at its highest level depends less on the breadth of factors and more on the depth of psychological integration and socioemotional coherence. This implies that further improvements in subjective well-being require interventions that promote emotional continuity, secure living environments, and strengthen close and supportive relationships between older adults and their children.

Integrative analysis across satisfaction transitions

Findings across the four satisfaction levels transitions reveal a compelling trajectory of determinant evolution. At the lowest level of satisfaction, life satisfaction is shaped primarily by current and material conditions. However, as individuals' life satisfaction progress upward, the influence of early-life experience becomes increasingly significant.

Two variables, CES-D10 and the relationship with children, consistently emerged as significant across all four transitions, affirming their role as foundational determinants of older adults' well-being. These results offer strong empirical support for intergenerational solidarity theory and mental health resilience models. They also suggest that promoting psychological well-being and maintaining satisfying intergenerational relationships should be regarded as central intervention strategies across satisfaction levels. At the same time, these findings raise concerns about older adults without children, highlighting the need to strengthen community and neighborhood-based emotional support systems, or to foster alternative social networks that can partially substitute for intergenerational emotional bonds.

By contrast, stage-specific variables, such as tap-water access (significant only in the first transition) and cumulative childhood adversity index (emerging only in the second and third transitions), reveal certain factors exert their influence only under specific emotional or contextual conditions. The third transition, which involves all five domains, illustrates the peak complexity in the formation of life satisfaction and reflects dynamics of cumulative inequality and identity re-evaluation.

This layered transformation from tangible factors to psychological and ultimately existential dimensions carries important policy implications. Programs targeting those with the lowest satisfaction should focus on mental well-being, basic needs fulfillment, and social participation. For moderately satisfied individuals, dual-track strategies that address both present conditions and early-life adversity are essential. At the highest tier, sustaining satisfaction requires personalized and emotionally interventions.

Overall, this study highlights the importance of differentiated and stratified aging policies tailored to individuals' life satisfaction levels. Effective interventions must consider individual's past experience as well as what they currently endure.

Theoretical implications

These stage-specific findings support and extend several theoretical frameworks. The persistent influence of child relationship across all thresholds validates the social support theory [34] and intergenerational solidarity theory [49]. The strong and consistent role of CES-D10 reinforces psychological vulnerability models that posit depressive symptoms as a central threat to subjective well-being. Moreover, the growing prominence of early-life adversity in later thresholds echoes the cumulative inequality theory [56], suggesting that disadvantage is not simply additive but becomes increasingly constraining over time.

Importantly, the negative association between education and satisfaction when transferring to "high satisfaction" may indicate a mismatch between personal expectations and social rewards in later life, warranting further theoretical investigation into post-retirement identity theory and expectation-disconfirmation frameworks.

Practical and policy implications

These findings carry strong implications for targeted and stratified policy design. For individuals at the lowest satisfaction level, interventions should focus on immediate and modifiable conditions: mental health screening, improving sleep quality, strengthening social activity opportunities, and enhancing basic utilities. For those in the mid-satisfaction range, a combined strategy addressing both present deficits and unresolved early-life adversity is needed. Potential approaches may include life review therapy, trauma-informed care, and structured family counseling.

At higher thresholds, strategies should be more individualized, focusing on promoting harmonious intergenerational relationship. In addition, the findings support a life course-oriented policy that acknowledges the enduring impact of early childhood experience on later-life well-being, and accordingly prioritizes investment not only in elder care but also in early developmental conditions.

Limitations and future directions

Several limitations should be noted. First, our findings are limited to older adults with children as childless respondents (0.11%) were excluded when answering the question on their relationship with children. However, this group also requires greater research attention because the absence of children means the loss of

support through intergenerational relationships. Second, this study is based on cross-sectional data from the 2020 wave of CHARLS. Future research could extend this work by using the longitudinal CHARLS to examine temporal dynamics. Third, although CHARLS provides sampling weights adjusted for death, survivorship and attrition biases may still exist across waves. Fourth, childhood adversity data were collected retrospectively in 2014, which may involve recall bias, and the six-year interval between 2014 and 2020 may also cause a temporal mismatch to some extent. Finally, given the cultural and regional diversity within China, generalizability may be limited. Future research should test the findings across subgroups or international settings.

Conclusion

This study provides a stage-specific and methodologically robust analysis of life satisfaction among older Chinese adults with GOLR and XGBoost models. The results reveal that the determinants of life satisfaction evolve across thresholds: material and health-related factors such as mental health, sleep, and utility access dominate at lower satisfaction levels, early-life adversities and socio-emotional dimensions gain prominence in higher tiers. Intergenerational emotional bonds and CES-D10 consistently emerge as the most influential predictors throughout all stages. The transition to very satisfaction involves all five domains of predictors, while the highest level of satisfaction is explained by a smaller group of enduring psychological and intergenerational factors. These findings extend theoretical understandings of aging, social support, and life course inequality, and highlight the need for stratified interventions that address both current vulnerabilities and long-term psychosocial histories.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12877-026-07000-0>.

Supplementary Material 1.

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Informed consent

All respondents provided written informed consent prior to their participation in the survey.

Authors' contributions

Jing Zhao and Yaya Wang framed the study, contributed to methodology and statistical validation, wrote the main manuscript text and supervised the overall project. Xiaofei Du, Shaopeng Wang, and Jun Lin contributed to methodology, statistical validation, and revisions. All authors reviewed and approved the final manuscript.

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Data availability

The datasets in this study are available from the CHARLS repository at <http://charls.pku.edu.cn>.

Declarations

Ethics approval and consent to participate

All procedures involving human participants were conducted in accordance with relevant CHARLS guidelines, regulations and the Declaration of Helsinki. All participants joined CHARLS voluntarily and signed a consent form before participation. For all the CHARLS waves was granted from the Institutional Review Board at Peking University. The IRB approval number for the main household survey (including anthropometric data) is IRB00001052–11015.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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