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The effects of physical exercise on subjective well-being among older adults based on Bio-Psycho-Social chain Model

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Abstract

Amid the rapid socioeconomic transformations underway in contemporary China, the older adults SWB has become a pivotal indicator for evaluating societal progress. Physical exercise, recognized as a health investment encompassing preventative, proactive, and social aspects, has substantially progressed beyond its traditional function of merely improving physical strength and fitness. Utilizing data from the 2023 China General Social Survey, this study investigates the effects of physical exercise on the older adults SWB within the framework of the Bio-Psycho-Social model. Employing an ordered logit model, the analysis reveals that physical exercise positively impacts the older adults SWB. Furthermore, the results demonstrate that physical health, mental health, and social interaction function as parallel mediators and collectively exhibit a sequential mediating effect, as evidenced through generalized structural equation modeling. This research contributes novel insights into the pathways by which physical exercise affects the older adults SWB and offers important policy implications for addressing the biopsychosocial challenges associated with population aging.

Introduction

The aging of the population constitutes a widespread global phenomenon that is progressively intensifying across the world. According to the United Nations' 2022 World Population Prospects, the global population is projected to attain 10 billion individuals by the year 2058, with its peak anticipated to occur in 2086 [1]. The aging of the population in China is occurring at an unprecedented rate on a global scale. As of the end of 2023, the population of individuals aged 60 and above in China amounted to 297 million, constituting 21% of the nation's total population [2]. By the year 2035, the proportion of China's population aged 60 and older is projected to surpass 30%, thereby officially designating the nation as a society experiencing advanced aging. The increasing number of the older individuals poses substantial challenges to economic and social development, as well as to the current institutional structures. In 2024, Chinese policy underscored the importance of ensuring that older adults benefit from societal development, experience a fulfilling retirement, and progressively realize the public’s aspirations for an improved quality of life [3]. Amidst the swift socioeconomic changes occurring in contemporary China, the subjective well-being (SWB) of its population has emerged as a crucial metric for assessing societal advancement. SWB constitutes an individual's comprehensive evaluation of their overall quality of life. It encompasses more than personal wellbeing, functioning as a fundamental basis for social cohesion and sustainable development. At the national level, the collective aspiration for an improved quality of life has emerged as the central focus of our efforts, with the experience of happiness in everyday life serving as the most immediate and tangible indicator of this objective at the individual subjective level. In this perspective, the study demonstrated that SWB serves as a significant predictor of health outcomes, lifespan, ethical conduct, and overall performance [4]. Concurrently, as the Healthy China 2030 strategy is progressively implemented, the significance of physical exercise as a proactive approach to health promotion is becoming increasingly apparent.

Physical exercise, regarded as a health investment characterized by its preventative, proactive, and social dimensions, has significantly evolved beyond its conventional role of solely enhancing physical strength and fitness. A substantial body of cross-sectional research and longitudinal data has consistently demonstrated

that individuals who engage regularly in physical exercise tend to report elevated levels of life satisfaction and overall well-being [5]. The older adults SWB reflects the quality of life, encompassing material conditions, physical health, mental and social well-being [6]. Social surveys underscore the advantages of physical activity among middle-aged and older adults, emphasizing the significance of consistent and prolonged exercise for this demographic [7]. Moreover, this study offers an empirical foundation for improving the quality of life among middle-aged and elderly individuals, thereby partially addressing the challenges associated with the increasing demographic of older adults. Although prior research has demonstrated a positive association between physical exercise and SWB, the majority of studies tend to concentrate exclusively on physiological health and psychological health mechanisms or do not sufficiently account for the and intricate sociological variables. It is important to recognize that health is often conceptualized holistically, which may obscure the unique and interactive roles of its physiological, psychological, and social components. The World Health Organization (WHO) emphasizes the preservation of intrinsic capacity, encompassing physical, psychological, and social dimensions, across the lifespan. Drawing upon social network theory, collective participation in sporting activities offers a platform for social interaction that positively influences life satisfaction among older adults [8]. This underscores the necessity of incorporating the mediating effects of social interaction into the relationship between physical exercise and life satisfaction. Nevertheless, there is presently a limited body of research investigating the underlying mediating mechanisms by which physical exercise influences physical and psychological health, as well as social interaction, ultimately affecting SWB.

Based on these findings, physical exercise may impact the older adults SWB by concurrently enhancing physical health, improving mental health, and facilitating social engagement. Which pathway holds greater significance? Alternatively, do all three pathways collectively form a comprehensive explanatory framework? Nonetheless, the precise mechanisms by which physical exercise impacts the older adults SWB have yet to be comprehensively elucidated. To elucidate the relationship among the three variables, this study developed a mediation model and sought to enhance the understanding of the impact of physical exercise on the older adults SWB.

Review of literature and theoretical framework

Older adults SWB and physical exercise: establishing the core relationship

SWB constitutes a fundamental concept within the domain of positive psychology. It encompasses six key constructs: mood, loneliness, life satisfaction, happiness, self-esteem, and overall SWB. The study and understanding of SWB have become an increasingly prominent area of interest globally [9, 10], which pertain to an individual's subjective experiences and assessments of their own life, representing a holistic self-concept that develops progressively throughout the life span. It is defined as an individual's evaluation of their life satisfaction, in conjunction with the balance between positive and negative emotions, only positive affect among the SWB components showed a significant association with longevity [4]. This concept reflects an individual's subjective perceptions and cognitive interpretations of life [11], represents a growing subject of interest around the world for psychologists, economists, philosophers, and politicians [12]. Well-

being constitutes a fundamental objective in life, sought after by both individuals and nations [13]. Furthermore, nations globally are committed to investigating the fundamental nature of well-being and actively striving to enhance the well-being of their entire populations.

Engagement in regular physical activity has been reported to exert a positive influence on SWB [14], junior high school students [15], all-aged chinese adult population [16] and middle-aged office workers [17]. Provinces exhibit variation, and distinct demographic characteristics are often correlated with SWB [18]. The influence of physical exercise on life satisfaction among the elderly may be moderated by several factors, including demographic variables such as gender, educational attainment, and marital status [19]. Notably, based on the 2021 China General Social Survey (CGSS) databse, the study reveals that exercisers were found to have greater SWB than did those who did not exercise after controlling for relevant variables [20]. Notably, Tai Chi practice has been shown to have a beneficial impact on the older adults SWB [21]. Additionally, a cross-sectional survey was conducted, physical exercise directly affected the older adults SWB [22]. The aging process constitutes a critical phase that lays the groundwork for an individual's physical, cognitive, emotional, social, and economic well-being. The older adults SWB encompasses the self-assessment regarding their physical and mental health, social engagement, emotional support, and overall quality of life [23]. It assesses their overall living status and cognitive state from both subjective and objective perspectives [24]. That is to say that the older adults SWB relates to their pursuit of both material comfort and spiritual fulfillment, as well as the processes involved in attaining these objectives. It evolves with the decline in physiological function, shifts in social roles, and changes in economic circumstances. Entering old age, the end of professional life, reduced economic income, decreased personal communication, diminished self-care ability due to declining health, increased loneliness, and reduced social participation all contribute to weakened social adaptability. Alterations in lifestyle, communication patterns, and self-perception have engendered a range of challenges for older adults, consequently affecting their physical and mental well-being. This has resulted in a reduction in their overall well-being and self-esteem. In recent years, academic research examining the factors influencing the older adults SWB, both within national contexts and globally, has expanded and deepened considerably. The extant literature suggests that individual attributes, familial contexts, and broader social environments each exert significant influence on the older adults SWB. Regarding individual attributes, the older adults SWB tends to diminish as they advance in age [25, 26]. More research is needed in the future to explore the underlying mechanisms that affect the older adults SWB.

The favored approach to health promotion is physical exercise, which encompasses participation in diverse physical activities designed to enhance bodily health, improve physical fitness, offer both mental and physical benefits, and contribute to the enrichment of leisure time. Physical exercise is not only a means for the older adults to maintain health, but also an effective way to enhance their subjective sense of bodily control, strengthen their sense of social integration and self-worth, and shape a sense of life happiness [27]. Previous research has demonstrated a positive correlation between the extent of physical exercise engagement among older adults and their SWB, life satisfaction, perceived life expectancy, and overall quality of life in later years [28]. According to data from the China Health and Nutrition Survey, engagement in physical exercise constitutes a significant factor in enhancing life satisfaction among the elderly population [29]. As evidenced by the foregoing, investigations into the effects of physical exercise on the

older adults SWB are continually being refined. It is necessary to point out here that physical exercise is not only an effective means for the older adults to maintain physical and mental health, but also may serve as a unique form of social participation, enhancing the well-being of the elderly through multi-dimensional mechanisms such as health promotion, emotional regulation, social network expansion, and a positive view of aging. Therefore, based on this, this study will provide a theoretical basis for guiding the older adults to participate in physical exercise through empirical testing. Policymakers should consider the role of physical exercsie participation when developing measures to improve retirees' quality of life refers to their SWB.

***Hypothesis* 1:** physical exercise can enhance the older adults SWB.

Health as a mediator: Bio-Psycho-Social Model

Compared with general well-being, the older adults SWB pays more attention to the needs in areas such as health services, daily care, and social participation. It is related not only to an individual's objective economic foundation, policy guarantees, status and other factors, but also to an individual's sense of self-worth, efficacy and control over the social situation they are in. Health improvement policies must consider SWB, a better perceived health status is associated with higher SWB [18]. However, a single theoretical mechanism is difficult to clearly explain how physical exercise enhances the older adults SWB. Therefore, this study will take sociological theory as the perspective to distill the possible mediating mechanisms by which physical exercise enhances the well-being of the elderly, thereby constructing a comprehensive analytical framework.

Biological pathway: physical health promotion effect

The concept of health promotion was first proposed in the Ottawa Charter issued by the World Health Organization (WHO) in 1986, and it has since evolved into a global public health campaign with a clear action framework and strategy. In the 1990s, a large number of epidemiological studies proved that physical activity is an important factor in reducing the risk of chronic diseases such as coronary heart disease, obesity and diabetes. According to Bandura's self-efficacy theory, there are four sources of self-efficacy: past experience, vicarious experience, verbal persuasion, and perception of physical states, subjective health had significant direct effects on self-efficacy, which fan infer that physical exercise can enhance an individual's health self-efficacy [30]. An analysis utilizing data from the 2018 China Family Panel Studies (CFPS) demonstrates that engagement in physical exercise substantially enhances both subjective and objective health outcomes among residents, with findings exhibiting considerable robustness [31]. As a holistic representation of an individual's self-assessment of their physical health, it functions as the primary conduit linking objective physical exercise to SWB [32]. In addition, the association between physical exercise and SWB among Chinese adults was found to be fully mediated by both the perception of physical health and the frequency of social interactions [20]. There is a research initiative: regular physical activity to improve their SWB among middle-aged and elderly womenin in particular based on the data from the 2014 and 2018 CFPS [33]. Currently, physical exercise is widely acknowledged on a global scale as a crucial method for enhancing health. Consequently, numerous nations have integrated physical exercise or physical

activities into the structure of their national health promotion strategies. In this context, physical exercise, by virtue of its health-enhancing properties, has the potential to diminish the risk of physical illnesses and disabilities among older adults, improve their capacity for physical activity, and extend their duration of healthy life. This study posits the hypothesis that both subjective and objective health conditions are favorable and, to some extent, contribute to the enhancement of SWB among older adults.

***Hypothesis* 2:** physical exercise enhances SWB through physical health-promoting effect.

Psychological pathway: mental health promotion effect

Physical exercise, as a positive and healthy lifestyle, can promote metabolism and release neurotransmitters such as endorphins, playing a positive role in improving mental or psychological health. A large number of studies have confirmed that physical activity is closely linked to positive emotions and can alleviate depressive symptoms and reduce negative emotions [27, 34, 35]. In additin, based on the positive emotion expansion-construction theory, physical exercise can stimulate positive emotions, and positive emotions can expand an individual's thinking and action scope, finally build lasting personal resources, and they will spiral upward to enhance SWB. The older adults can relieve their feelings of depression, tension, and anxiety through physical exercise, and form a positive psychological state [36]. Studies with healthy senior suggest that physical exercise can help improve cognition and quality of life, which is also found from physical exercise training leads to improved cognitive functioning and psychological well-being in frail older adults [37]. Also, long-term adherence to physical exercise can relieve psychological stress, prevent older adults depression, and improve life happiness and satisfaction [38]. Consistent with the findings of the 2018 CGSS, there exists a robust positive correlation between physical exercise and mental health [39]. Physical exercise improves emotional states and enhances psychological well-being through neuroendocrine mechanisms, constituting an affective pathway influencing happiness [40]. Current research data confirms that a strong positive relationship between physical exercise and life satisfaction and verified the mediating effect of positive emotion on this relationship among chinese college students [41]. Alleviate symptoms of depression, tension, and anxiety, thereby fostering a positive psychological state. The physical exercise process assists older adults in interpreting stressful life events through a more constructive cognitive framework, ultimately enhancing their SWB. Consequently, drawing upon the foregoing analysis, this study posits the hypothesis that physical exercise may contribute to the enhancement of the older adults SWB through the improvement and regulation of negative emotional states.

***Hypothesis* 3:** Physical exercise enhances the older adults SWB through emotional regulation effect.

Sociological pathway: social interaction enhancing effect

When refers to social interaction, older people social interactions gradually decrease, and their sense of isolation increases significantly. Physical exercise is an activity with strong social attributes. During the process of participating in physical exercise, people can not only enhance their physical fitness, but also expand their social networks, increase their participation in civil society, and cultivate social capital [42]. Through the positive emotional experiences associated with physical exercise and the development of

strong social relationships, older adults can increase social interaction, which collectively improves their quality of life [43, 44]. Social interaction theory holds that physical exercise can be regarded as a platform for people to build social networks, which can attract and unite participants from different backgrounds. In particular, engaging in physical exercise within a group setting offers individuals the opportunity to interact and socialize with others. In this process, individuals can learn to effectively handle interpersonal relationships, ease conflicts, and demonstrate abilities such as support, empathy, and social emotions in interacting with others [45]. Furthermore, when the older adults withdraw from the social labor field, the non-institutional social network resources they possess play a significant role in providing for their elderly care. To a certain extent, they can help individuals gain social respect and spiritual support, thereby establishing a positive and healthy attitude towards life. Consequently, drawing upon the aforementioned literature, this study hypothesizes that physical exercise facilitates increased social engagement, enhances self-efficacy, and subsequently promotes improved the older adults SWB.

***Hypothesis* 4:** Physical exercise enhances the older adults SWB through social interaction effect.

The chain mediating role of biopsychosocial indicators between physical exercise and SWB

Health and illness are influenced by a multifaceted interaction of biological, psychological, and social factors, rather than being attributable exclusively to a single domain. It emphasizes that these components are interconnected and influence each other in a dynamic system, impacting an individual's overall well-being and response to life circumstances. Physical health, mental health, and social interaction seem to be antecedent variables of SWB. Previous research indicates that social interactions serve as important mediating factors in the relationship between mental health and subsequent physical health outcomes [46]. In other words, there is a chain-like mediating effect of mental health-social interaction-physical health. Practically, the study indicates social connections can enriching emotional experiences, promoting community engagement and mental health [47]. That is, there exists a chain-like mediating effect of social interaction on mental health. In addition, there is a strong link between mental health and physical health, but little is known about the pathways from one to the other [48]. A meta-analysis indicated that physical exercise has a positive impact on improving the physical and mental health of older adults, particularly in enhancing physical health, psychological well-being, and social interactions [42]. Therefore, It is worth noting that physical exercise has been mentioned as an important predictor variable of physical health, mental health, and social interaction, so whether physical exercise can influence the older adults SWB through the chain-mediated effect? Therefore, this study proposes a chain-mediated hypothetical model to clarify the relationships among physical exercise, physical health, mental health, social interaction, and SWB among the the older adults, and presents the following research hypotheses:

***Hypothesis* 5:** Physical health, mental health and social interaction are chained mediators in the relationship between physical exercise and SWB among the older adults.

Research design

Data source

The dataset utilized in this study is the most recent 2023 CGSS data, which was officially released for public access on June 21, 2025. The data are distributed in 16 provinces and 199 communities, covering more than 400 refined variables such as education, economy, behavior and attitude. According to the research topic, stata 18.0 was used for data cleaning. The sample age selected in this paper are old adults people aged 60 and above. After screening and processing the missing values of key variables, 1848 valid samples were determined.

Variable setting

Dependent Variable

The dependent variable of this study is the older adults SWB (Table 1). In the questionnaire, SWB was assessed using the item : " Overall, do you feel your life is happy? " The options were, in order: 1 = "Very unhappy", 2 = "Relatively unhappy", 3 = "Unhappy", 4 = "Relatively happy" and 5 = "Very happy". Higher scores correspond to greater levels of SWB.

Table 1
Descriptive characteristics of variables

Type	Variable	Variable declaration
Dependent variable	Subjective well-being	Very unhappy = 1; Relatively unhappy = 2; Unhappy = 3; Relatively happy = 4; Very happy = 5
Independent variable	Physical exercise	Participate in physical exercise = 1; Do not participate in physical exercise = 0
Mediating variables	Physical health	Very unhealthy = 1; Relatively unhealthy = 2; General = 3; Relatively healthy = 4; Very healthy = 5
	Mental health	Always = 1; Often = 2; Sometimes = 3; Rarely = 4; Never = 5
	Social interaction	Not very close = 1; Not close = 2; General = 3; Close = 4; Very close = 5
Control variables	Gender	Male = 1; Female = 0
	Household registration	Non-agricultural household registration = 1; Agricultural household registration = 0
	Marriage	Married = 1; Unmarried = 0
	Educational attainment	Unedcated = 1; Elementary School = 2; Middle School = 3; Higher Education = 4
	Region	Eastern Region = 1; Central Region = 2; Western Region = 3
	Elder care obligations	Mainly responsible by the children/mainly responsible by the elderly themselves (Internalize responsibility) = 1; Mainly responsible by the government/responsibility of the three parties are shared (Externalize responsibility) = 0
	Social hierarchy	1 point = 1; 2 points = 2; 3 points = 3; 4 points = 4; 5 points = 5; 6 points = 6; 7 points = 7; 8 points = 8; 9 points = 9; 10 points = 10
	Socioeconomic status	Lower level = 1; Lower middle level = 2; Middle level = 3; Upper middle level = 4; Upper level = 5
	Housing	Homeownership = 1; Non-homeownership = 0

Independent variable

Based on the design of the CGSS questionnaire and relevant existing literature, this study identified physical exercise as the independent variable. Specifically, the item from the CGSS survey utilized was: "In the past 1 year, how often did you participate in physical exercise ?" The options 1 to 5 of the item represent: "every day," "several times a week," "several times a month," "several times a year or less," and "never," respectively. The values of "every day," "several times a week," "several times a month," and "several times a year or less" are collectively referred to as "participation in physical exercise" is 1, and "never" is 0, forming a binary variable.

Mediating variables

The mediating variables of the study include physical status, psychological status and social interaction. Among them, physical status is measured by physical health. The title is: "You feel that your current physical condition is?" The response options for the item range from 1 to 5, corresponding respectively to "Very unhealthy," "Relatively unhealthy," "General," "Relatively healthy," and "Very healthy." These options are scored on a scale from 1 to 5 points. A higher score indicates a better state of health. Secondly, psychological status pertains to mental health and is assessed by the question: "In the past four weeks, How often have you felt depressed or down? " The response options range from 1 to 5, corresponding to "Always," "Often," "Sometimes," "Rarely," and "Never," respectively. Scores ranging from 1 to 5 were allocated, with higher values indicating a more positive evaluation. Ultimately, interpersonal communication is manifested through social interaction. The subject under consideration is: "What is the current state of communication and interaction between yourself and your relatives and friends?" The response options consist of "Not very close," "Not close," "General," "Close," and "Very close," which are respectively scored from 1 to 5 points. A higher score indicates a greater degree of social closeness.

Control variables

In addition, in order to avoid endogenous problems, demographic and socioeconomic status variables (including gender, household registration, marriage, education attainment, region, elder care obligations, social hierarchy, socioeconomic status and housing) that have been selected as control variables in the analysis. Based on previous studies, this paper sets the individual characteristics, family characteristics and socioeconomic characteristics of the older adults as control variables. Individual characteristics include gender, household registration, marital status and educational attainment. Gender is a dichotomous variable, with female as a reference. the household registration is a dichotomous variable, with the agricultural household registration as a reference. The classification is divided into three categories according to administrative regions: the eastern region is designated as 1, the central region as 2, and the western region as 3. Marriage is categorized based on the respondent's actual situation, divided into unmarried (0) and married (1). Educational attainment was assessed using the item, "Your current highest level of education is?" Responses were categorized into four groups as follows: Uneducated (coded as 1), Elementary School (coded as 2), Middle School (coded as 3), and Higher Education (coded as 4).

Socioeconomic characteristics include: social hierarchy, socioeconomic status the elder care obligations and housing. Social hierarchy can be examined through the following inquiry: "In our society, some people are in the upper level of society, some people are in the lower level of society, in general, in this society, which level of society are you in ?" Options 1 through 10 correspond to a hierarchical spectrum ranging from the lowest to the highest social strata. Socioeconomic status was assessed using the following item: "Generally speaking, in the current society, your own socioeconomic status belongs to?" The response options provided were: "Lower level," "Lower middle level," "Middle level," "Upper middle level," and "Upper level," which were coded with values ranging from 1 to 5, respectively. The responsibility for elder care is assessed using the item: "Who do you think should be responsible for the pension of the elderly with

children?" The options include: "mainly responsible by the government", "mainly responsible by the children", "mainly responsible by the elderly themselves" and "the government, children and the elderly themselves share the responsibility". The "mainly responsible by the children" and "mainly responsible by the elderly themselves" are merged into "internalized responsibility", with an assignment of 1. The "mainly responsible by the government" and the "responsibility of the three parties are shared" are merged into "external responsibility", assigned to 0, and the external responsibility is the reference item. The housing issue serves as an indicator of the extent to which an individual's living conditions are constrained. Based on the survey item, "At present, do you own (including co-ownership with others) property (property rights) ?" homeownership is coded as 1, while non-homeownership is coded as 0.

Empirical analysis method

Ordered Logit model

An ordered logit model (Ologit) was conducted to test the impact of physical exercise on the older adults SWB. A series of nested models were constructed to test the effects of key mediators.

The general specification for the latent variable SWB* underlying the observed ordinal outcomes is as follows:

$$SWB^* = \beta X + \epsilon$$

where *SWB** represents the unobserved continuous propensity for higher SWB, X is the vector of explanatory variables, *β* is the vector of coefficients to be estimated, and ϵ follows a standard logistic distribution. The observed ordinal variable *SWB* with *J* categories is linked to the latent variable through a set of cutpoints (thresholds) $\tau 1 < \tau 2 < \ldots < \tau J - 1$, such that:

$$SWB = j \, if \, \tau_{j-1} < SWB^* \leq \tau_j$$

The cumulative probability is given by:

$$P(SWB \leq j \mid X) = \frac{1}{1 + \exp[-(\tau 1 - (\beta_1 X_1 + \ldots + \beta_P X_P))]} (x + a)^n = \sum_{k=0}^{n} \binom{n}{k} x^k a^{n-k}$$

The following nested model specifications were estimated:

Model 1: includes the core independent variable and demographic/socioeconomic controls.

Latent variable specification:

$$SWB^* = \beta_1 (PE) + \sum_{k=2}^{10} \beta_k (Control_k) + \epsilon$$

Model 2: extends Model 1 by incorporating physical health as a potential pathway.

$$SWB^{*} = Model\,1 + \beta_{11}(PH) + \epsilon$$

Model 3: extends Model 1 by incorporating mental health as a potential pathway.

$$SWB^{*} = Model\,1 + \beta_{12}(MH) + \epsilon$$

Model 4: extends Model 1 by incorporating social interaction as a potential pathway.

$$SWB^{*} = Model\,1 + \beta_{13}(SI) + \epsilon$$

Model 5: extends Model 1 by simultaneously including all three hypothesized mediators.

$$SWB^{*} = Model\,1 + \beta_{14}(PH) + \beta_{15}(MH) + \beta_{16}(SI) + \epsilon$$

Physical exercise serves as the primary independent variable, SWB as the ordinal dependent variable, and the additional variables in Models 2–5 are included to examine potential mediating pathways. The vector of control variables (Gender, Household registration, Marriage, Educational attainment, Region, Elder care obligations, Social hierarchy, Socioeconomic status, and Housing) accounts for potential confounding demographic and socioeconomic factors. The coefficients β represent the change in the log-odds of being in a higher SWB category (versus all lower categories combined) associated with a one-unit increase in the corresponding explanatory variable, holding other variables constant. The threshold parameters τj determine the boundaries between the observed ordinal categories on the latent scale. The proportional odds assumption underlying these models was tested and confirmed using appropriate diagnostic tests.

Structural Equation Modeling

Generalised Structural Equation Model (gSEM) was established to explore the impact of physical exercise on the older adults SWB. Compared with the stepwise method traditionally used to test and estimate mediating effects, gSEM can simultaneously handle multiple dependent variables and perform path analysis.

The mediator equations (representing paths from the independent variable to each mediator):

Model 6: $M_{1i}(PH) = \alpha_{10} + a_1 PE_i + \varvec{\alpha}_{1c}^{\varvec{'}} control_i + \epsilon_{1i}$

Model 7: $M_{2i}(MH) = \alpha_{20} + a_2 PE_i + \varvec{\alpha}_{2c}^{\varvec{'}} control_i + \epsilon_{2i}$

Model 8: $M_{3i}(SI) = \alpha_{30} + a_3 PE_i + \varvec{\alpha}_{3c}^{\varvec{'}} control_i + \epsilon_{3i}$

The representing paths from all predictors to the latent outcome variable.

$$SWB_i^{*} = c'\,PE_i + b_1 PH + b_2 MH + b_3 SI + \varvec{\delta}^{\varvec{'}}\,\varvec{C}_i + \sigma_i$$

Linking latent propensity to observed categories.

$$SWB_i = j\ if\ \tau_{j-1} < SWB_i^{*} \le \tau_j\ for\ j = 1, 2, \ldots, 5$$

Among them, direct Effect of physical exercise: c'; Indirect Effects: $a1b1$ (via physical health), $a2b2$ (via mental health), $a3b3$ (via social interaction); Total Effect: $c' + a1b1 + a2b2 + a3b3$. Further use the Bootstrap method to test the chain mediating effect of physical health, mental health, and social interaction.

Results and analysis

Descriptive statistics

Overall, the proportion of the older adults who are satisfied with their current life (77.76%) is significantly higher than the proportion of the older adults who are not satisfied with their life (22.24%), and the average SWB of the older adults is 3.92 (Table 2). Regarding the primary independent variable of physical exercise, 51.57% of older adults report never engaging in physical exercise, representing a slight increase compared to the 48.43% of elderly individuals who do participate in such activities. Concerning the mediating variables, 593 respondents (32.09%) rated their health as "general," while 684 respondents (37.01%) reported never experiencing feelings of depression or discouragement in relation to their mental health. Social interaction was evaluated, yielding a mean score of 3.24 (SD = 0.93), indicative of moderate levels of social engagement among the elderly population. With respect to the control variables, the sample of older adult participants consisted of individuals aged over 60 years. Of this group, approximately 48.16% are female and 51.84% are male. Additionally, 1,779 participants, representing 96.27% of the total sample, are married. Concurrently, it is observed that the agricultural population constitutes a larger proportion compared to the non-agricultural population. The educational levels of older adults are primarily concentrated within the elementary and middle school categories. Approximately 36.42% lived in eastern region, 29.60% in central region and 33.98% in western region. Most older adults perceive their social hierarchy and socioeconomic status as belonging to the lower middle stratum, with only a minority identifying themselves within the upper middle stratum. Additionally, 31.22% are homeownership, and 68.78% are non-homeownership.

Table 2
Descriptive Statistics

Variable	Classification	Freq	Percent(%)	Cum	mean	std.dev.	min	Max
Subjective well-being	Very unhappy	34	1.84	1.84	3.92	0.88	1	5
	Relatively unhappy	108	5.84	7.68				
	Unhappy	269	14.56	22.24				
	Relatively happy	993	53.73	75.97				
	Very happy	444	24.03	100.00				
Physical exercise	Do not participate in physical exercise	953	51.57	51.57	0.48	0.50	0	1
	Participate in physical exercise	895	48.43	100.00				
Physical health	Very unhealthy	197	10.66	10.66	3.01	1.13	1	5
	Relatively unhealthy	413	22.35	33.01				
	General	593	32.09	65.10				
	Relatively healthy	468	25.32	90.42				
	Very healthy	177	9.58	100.00				
Mental health	Always	72	3.90	3.90	3.79	1.18	1	5
	Often	227	12.28	16.18				
	Sometimes	407	22.02	38.20				
	Rarely	458	24.78	62.99				
	Never	684	37.01	100.00				
Social interaction	Not very close	56	3.03	3.03	3.24	0.93	1	5
	Not close	318	17.21	20.24				
	General	741	40.10	60.34				
	Close	590	31.93	92.26				
	Very close	143	7.74	100.00				
Gender	Female	890	48.16	48.16	0.52	0.50	0	1
	Male	958	51.84	100.00				

Variable	Classification	Freq	Percent(%)	Cum	mean	std.dev.	min	Max
Household registration	Agricultural household registration	1090	58.98	58.98	0.41	0.49	0	1
	Non-agricultural household registration	758	41.02	100.00				
Marriage	Unmarried	69	3.73	3.73	0.96	0.19	0	1
	Married	1779	96.27	100.00				
Educational attainment	Uneducated	421	22.78	22.78	2.28	0.87	1	4
	Elementary School	578	31.28	54.06				
	Middle School	756	40.91	94.97				
	Higher Education	93	5.03	100.00				
Region	Eastern region	673	36.42	36.42	1.98	0.84	1	3
	Central region	547	29.60	33.02				
	Western region	628	33.98	100.00				
Elder care obligations	Externalize responsibility	755	40.85	40.85	0.59	0.49	0	1
	Internalize responsibility	1093	59.15	100.00				
Social hierarchy	1 point	221	11.96	11.96	4.32	1.97	1	10
	2 points	128	6.93	18.89				
	3 points	241	13.04	31.93				
	4 points	257	13.91	45.83				
	5 points	615	33.28	79.11				
	6 points	207	11.20	90.31				
	7 points	74	4.00	94.32				
	8 points	54	2.92	97.24				
	9 points	14	0.76	98.00				
	10 points	37	2.00	100.00				
Socioeconomic status	Lower level	414	22.40	22.40	2.32	0.92	1	5

Variable	Classification	Freq	Percent(%)	Cum	mean	std.dev.	min	Max
	Lower middle level	584	31.60	54.00				
	Middle level	722	39.07	93.07				
	Upper middle level	108	5.84	98.92				
	Upper level	20	1.08	100.00				
Housing	Non-homeownership	577	31.22	31.22	0.69	0.46	0	1
	Homeownership	1271	68.78	100.00				

A statistical analysis is conducted on the SWB and physical exercise across various demographic groups. The findings indicate that significant differences exist in the SWB among older adults belonging to distinct characteristic groups. Older adults who self-report excellent health, have never experienced depression or low mood, frequently engage in social activities, are non-agricultural workers, possess higher education, belong to higher social classes, enjoy higher socioeconomic status, own their homes, and have internalized responsibility for their own care exhibit higher levels of SWB. Regarding physical exercise, men who self-assess their health as very good, have never experienced depression or low mood, engage frequently in social interactions, belong to non-agricultural populations, possess higher educational attainment, reside in eastern regions, occupy a middle social hierarchy, have an upper socioeconomic status, own their homes, and delegate eldercare responsibilities externally tend to exhibit higher levels of physical exercise (Table 3).

Table 3
Analysis of differences in variables related to subjective wellbeing and physical exercise

Variable	Classification	Subjective well-being	F	Physical exercise	F
Physical health	Very unhealthy	3.675 (1.146)	25.140***	0.244 (0.430)	25.690***
	Relatively unhealthy	3.697 (0.954)		0.385 (0.487)	
	General	3.924 (0.830)		0.519 (0.500)	
	Relatively healthy	4.062 (0.704)		0.564 (0.496)	
	Very healthy	4.350 (0.732)		0.655 (0.477)	
Mental health	Always	3.417 (1.172)	39.250***	0.319 (0.470)	17.720***
	Often	3.533 (1.122)		0.308 (0.463)	
	Sometimes	3.784 (0.867)		0.435 (0.496)	
	Rarely	3.906 (0.773)		0.489 (0.500)	
	Never	4.199 (0.733)		0.586 (0.493)	
Social interaction	Not very close	3.607 (1.139)	7.790***	0.321 (0.471)	9.680***
	Not close	3.786 (0.988)		0.358 (0.480)	
	General	3.877 (0.832)		0.506 (0.500)	
	Close	4.039 (0.803)		0.508 (0.500)	
	Very close	4.084 (1.003)		0.615 (0.488)	
Gender	Female	3.890 (0.930)	2.360	0.458 (0.499)	4.610*
	Male	3.953 (0.836)		0.508 (0.500)	
Household registration	Agricultural household registration	3.852 (0.926)	17.000***	0.361 (0.480)	178.530***

Variable	Classification	Subjective well-being	F	Physical exercise	F
	Non-agricultural household registration	4.024 (0.807)		0.662 (0.473)	
Marriage	Unmarried	3.913 (0.836)	0.010	0.536 (0.502)	0.770
	Married	3.923 (0.885)		0.482 (0.450)	
Educational attainment	Uneducated	3.841 (0.976)	2.680*	0.335 (0.473)	32.840***
	Elementary school	3.898 (0.896)		0.427 (0.495)	
	Middle school	3.974 (0.826)		0.583 (0.493)	
	Higher education	4.032 (0.773)		0.710 (0.456)	
Region	Eastern region	3.902 (0.888)	0.860	0.566 (0.496)	21.080***
	Central region	3.905 (0.889)		0.494 (0.500)	
	Western region	3.960 (0.873)		0.389 (0.488)	
Elder care obligations	Externalize responsibility	3.829 (0.919)	14.410***	0.514 (0.500)	4.480*
	Internalize responsibility	3.987 (0.852)		0.464 (0.499)	
Social hierarchy	1 point	3.498 (1.158)	18.130***	0.394 (0.490)	5.340***
	2 points	3.563 (0.962)		0.477 (0.501)	
	3 points	3.689 (0.957)		0.386 (0.488)	
	4 points	3.934 (0.800)		0.432 (0.496)	
	5 points	4.060 (0.743)		0.501 (0.500)	
	6 points	4.159 (0.689)		0.628 (0.485)	
	7 points	4.108 (0.751)		0.595 (0.494)	

Variable	Classification	Subjective well-being	F	Physical exercise	F
	8 points	4.241 (0.751)		0.648 (0.482)	
	9 points	4.500 (0.519)		0.571 (0.514)	
	10 points	4.486 (0.651)		0.486 (0.507)	
Socioeconomic status	Lower level	3.512 (1.046)	39.760***	0.365 (0.482)	9.290***
	Lower middle level	3.896 (0.816)		0.481 (0.500)	
	Middle level	4.126 (0.737)		0.546 (0.498)	
	Upper middle level	4.167 (0.902)		0.528 (0.502)	
	Upper level	4.550 (0.605)		0.600 (0.503)	
Housing	Non-homeownership	3.835 (0.969)	8.230**	0.421 (0.494)	13.480***
	Homeownership	3.962 (0.838)		0.513 (0.500)	
Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$					

Ologit model estimation

The findings from Ologit analysis indicate that Model 1 incorporates physical exercise alongside all relevant control variables. Subsequently, Models 2 through 5 extend Model 1 by integrating the mediating variables of physical health, mental health, and social interaction. Building upon Model 1, Model 5 simultaneously integrates all mediating variables into the analytical framework. The coefficient associated with physical exercise consistently demonstrates a positive and statistically significant relationship, suggesting that engagement in physical exercise exerts a substantial and favorable impact on the SWB of older adults (Table 4). Comparing the estimation results of models 1 to 5, it can be seen that the influence of physical exercise is significant regardless of whether the model adds mediating variables. This shows that the promotion effect of physical exercise on SWB is relatively stable. In addition, physical health, mental health and social intreaction have a positive impact on the older adults SWB. Specifically, the better the individual physical and mental health status, the closer the social intreaction, the higher the older adults SWB is.

Robustness analysis

To ensure the reliability of the benchmark regression results, this study conducted robustness tests by altering the model specifications. As shown in Table 5, we employ the Ologit, the ordered probit model (Oprobit), and ordinary least squares (OLS) to estimate the impact of physical exercise on the older adults SWB. The coefficient associated with physical exercise was found to be significantly positive at the 1% significance level across all three model specifications. In the baseline Ologit model, the estimated coefficient is 0.359. When employing an ordered probit (Oprobit) model, which assumes alternative distributions for the error terms of the latent variable, the coefficient is estimated at 0.210. In contrast, the ordinary least squares (OLS) model, which treats ordered categorical variables as continuous, yields a coefficient of 0.155. Additionally, the control variables also demonstrate sound robustness, social hierarchy and socioeconomic status both exerted a significant positive influence in both ordered choice models and the OLS model, indicating that higher social standing and economic conditions consistently enhance the older adults SWB. The responsibility for elderly care obligations and residence in the western regions are also significantly positive across all models, with their effects remaining robust. The remaining variables, such as gender, household registration, and marital status, are not significant in any of the models, consistent with the findings of the baseline model. Although the magnitude of coefficients cannot be directly compared across models due to differing scales, the high consistency in statistical significance and sign direction provides compelling evidence that the positive impact of physical exercise on the older adults SWB is not an incidental outcome dependent on model specifications, but rather a robust core finding.

Table 4
Results of Ordered Logit Regression Analysis

	Model 1	Model 2	Model 3	Model 4	Model 5
Physical exercise	0.359 (0.097)***	0.286 (0.097)**	0.286 (0.098)**	0.327 (0.097)***	0.242 (0.099)*
Gender	0.020 (0.098)	-0.022 (0.099)	-0.065 (0.099)	0.028 (0.098)	-0.066 (0.099)
Household registration	0.164 (0.110)	0.124 (0.111)	0.073 (0.112)	0.162 (0.110)	0.069 (0.112)
Marriage	-0.026 (0.206)	0.006 (0.201)	-0.068 (0.209)	-0.052 (0.204)	-0.067 (0.206)
Educational attainment (Uneducated = 1)					
Elementary School	0.002 (0.131)	-0.001 (0.131)	0.008 (0.131)	0.003 (0.131)	0.008 (0.131)
Middle School	0.089 (0.134)	0.040 (0.134)	0.041 (0.134)	0.08 (0.133)	0.02 (0.133)
Higher Education	-0.050 (0.221)	-0.071 (0.216)	-0.121 (0.219)	-0.057 (0.216)	-0.127 (0.215)
Region (Eastern region = 1)					
Central region	0.112 (0.118)	0.090 (0.119)	0.137 (0.119)	0.109 (0.118)	0.122 (0.119)
Western region	0.314 (0.116)**	0.332 (0.116)**	0.392 (0.118)***	0.307 (0.116)**	0.384 (0.118)**
Elder care obligations	0.320 (0.095)***	0.325 (0.095)***	0.315 (0.095)***	0.321 (0.095)***	0.319 (0.095)***
Social hierarchy	0.162 (0.029)***	0.148 (0.029)***	0.153 (0.029)***	0.158 (0.029)***	0.145 (0.029)***
Socioeconomic status	0.384 (0.062)***	0.361 (0.062)***	0.331 (0.062)***	0.368 (0.062)***	0.318 (0.063)***
Housing	0.133 (0.104)	0.118 (0.104)	0.086 (0.105)	0.138 (0.104)	0.089 (0.105)
Physical health		0.249 (0.046)***			0.111 (0.049)*
Mental health			0.370 (0.047)***		0.316 (0.051)***
Social interaction				0.164	0.113

	Model 1	Model 2	Model 3	Model 4	Model 5
				(0.055)**	(0.055)*
cut1	-1.932 (0.321)***	-1.406 (0.335)***	-0.969 (0.348)**	-1.511 (0.354)***	-0.587 (0.377)
cut2	-0.400 (0.286)	0.136 (0.300)	0.587 (0.314)	0.023 (0.323)	0.972 (0.348)**
cut3	0.925 (0.277)***	1.475 (0.292)***	1.949 (0.309)***	1.353 (0.317)***	2.339 (0.346)***
cut4	3.566 (0.289)***	4.151 (0.308)***	4.676 (0.327)***	4.006 (0.333)***	5.079 (0.366)***
Standard errors in parentheses. * $p < 0.5$, ** $p < 0.01$, *** $p < 0.001$					

Endogeneity Test Analysis

To mitigate potential endogeneity bias, this study employs an instrumental variables approach for estimation. Drawing upon existing research, we select "exercise habits" as the instrumental variable for physical exercise. The validity of instrumental variables requires satisfying two conditions: correlation and exogeneity. Firstly, as shown in the regression results for 'First Stage' in Table 6, the instrumental variable 'exercise habits' exerts a highly significant positive effect on the endogenous variable 'physical exercise' (coefficient = 0.143, $p < 0.01$). Moreover, the F-statistic for the first stage regression was 77.775, significantly exceeding the empirical benchmark of 10. This indicates no weak instrumental variable issues, confirming that 'exercise habits' constitute a valid instrumental variable. The study simultaneously presents the estimation results for the 'naive Ologit model' without considering endogeneity and the 'IV-Oprobit model' that accounts for endogeneity. After controlling for endogeneity, the positive effect of physical exercise on the older adults SWB remains significant. The estimated coefficient for the IV-Oprobit model is 0.522 ($p < 0.05$), higher than the coefficient of 0.359 ($p < 0.01$) from the naive Ologit model. This indicates that disregarding endogeneity may lead to an underestimation of the true extent to which physical exercise enhances the older adults SWB. The endogeneity test based on the instrumental variables method confirms that, after effectively controlling for potential endogeneity bias, the positive impact of physical exercise on the older adults SWB remains robust. Moreover, its true effect may be greater than that indicated by the benchmark regression. This finding further strengthens the reliability of the core conclusion of this study: physical exercise exerts a causal effect on enhancing the older adults SWB.

Table 5
Results of Robustness Analysis

	Ologit	Oprobit	OLS
Physical exercise	0.359 (0.097)***	0.210 (0.055)***	0.155 (0.041)***
Gender	0.02 (0.098)	0.033 (0.056)	0.042 (0.042)
Household registration	0.164 (0.110)	0.083 (0.063)	0.066 (0.047)
Marriage	-0.026 (0.206)	0.007 (0.121)	-0.01 (0.094)
Educational attainment (Uneducated = 1)			
Elementary School	0.002 (0.131)	0.022 (0.074)	0.038 (0.058)
Middle School	0.089 (0.134)	0.085 (0.076)	0.096 (0.058)
Higher Education	-0.05 (0.221)	-0.004 (0.130)	0.034 (0.094)
Region (Eastern region = 1)			
Central region	0.112 (0.118)	0.055 (0.067)	0.049 (0.052)
Western region	0.314 (0.116)**	0.173 (0.066)**	0.137 (0.050)**
Elder care obligations	0.320 (0.095)***	0.186 (0.054)***	0.141 (0.041)***
Social hierarchy	0.162 (0.029)***	0.095 (0.016)***	0.077 (0.012)***
Socioeconomic status	0.384 (0.062)***	0.208 (0.036)***	0.149 (0.027)***
Housing	0.133 (0.104)	0.083 (0.059)	0.078 (0.045)
cons			2.881 (0.129)***
cut1	-1.932 (0.321)***	-0.934 (0.168)***	
cut2	-0.400 (0.286)	-0.211 (0.162)	
cut3	0.925 (0.277)***	0.516 (0.161)**	
cut4	3.566 (0.289)***	2.097 (0.166)***	
N	1848	1848	1848
R^2			0.12
F			17.039
Standard errors in parentheses. * $p < 0.5$, ** $p < 0.01$, *** $p < 0.001$			

Heterogeneity Analysis

The effects of physical exercise exhibit marked gender and marital status differences (Table 7). For male participants, physical exercise substantially improves SWB among older adults ($\beta = 0.523$, $p < 0.01$). In contrast, while the effect of physical exercise on SWB for female participants is positive, it does not reach statistical significance ($\beta = 0.186$). This finding indicates that the older men derive a more pronounced increase in SWB from physical exercise. The probable reason lies in the differing types of physical exercise undertaken by men and women, their social attributes, and their positioning within societal roles. The SWB effect of physical exercise is highly significant among unmarried individuals ($\beta = 0.339$, $p < 0.01$), but not significant among married individuals. A possible explanation lies in sample size discrepancies, with the married sub-sample comprising only 69 observations. This may result in imprecise estimation outcomes and insufficient statistical test power. On the other hand, it may be that within the unmarried cohort, whose social networks tend to be relatively narrow, physical exercise assumes a more significant role in providing social and psychological compensation. Conversely, for the married cohort, other factors such as family support may have become the primary sources of the older adults SWB, thereby diminishing the marginal contribution of physical exercise.

Table 6
Endogeneity Test Analysis

	First Stage	Naive OLogit	IV OProbit
Exercise habits	0.143 (0.016)***		
Gender	0.081 (0.023)***	0.020 (0.097)	0.005 (0.060)
Household registration	0.208 (0.026)***	0.164 (0.111)	0.010 (0.084)
Marriage	-0.107 (0.057)*	-0.026 (0.233)	0.043 (0.139)
Educational attainment (Uneducated = 1)			
Elementary School	0.097 (0.003)***	0.002 (0.126)	-0.010 (0.075)
Middle School	0.156 (0.031)***	0.089 (0.131)	0.029 (0.086)
Higher Education	0.211 (0.057)***	-0.050 (0.238)	-0.073 (0.148)
Region (Eastern region = 1)			
Central region	0.048 (0.028)*	0.112 (0.119)	0.038 (0.069)
Western region	-0.064 (0.028)**	0.314 (0.116)***	0.185 (0.067)***
Elder care obligations	0.004 (0.022)	0.320 (0.094)***	0.184 (0.054)***
Social hierarchy	0.009 (0.007)	0.162 (0.028)***	0.090 (0.016)***
Socioeconomic status	0.022 (0.014)	0.384 (0.060)***	0.198 (0.035)***
Housing	0.036 (0.024)	0.133 (0.102)	0.068 (0.059)
Physical exercise		0.359 (0.096)***	0.522 (0.238)**
cons	0.052 (0.073)		
cut1		-1.932 (0.332)***	
cut2		-0.400 (0.299)	
cut3		0.925 (0.296)***	
cut4		3.566 (0.308)***	
F	77.775		
Exercise Habits			0.440 (0.051)***
Gender			0.241 (0.067)***

	First Stage	Naive OLogit	IV OProbit
Household registration			0.565 (0.074)***
Marriage			-0.293 (0.163)*
Educational attainment (Uneducated = 1)			
Elementary School			0.281 (0.086)***
Middle School			0.448 (0.089)***
Higher Education			0.592 (0.167)***
Region (Eastern region = 1)			
Central region			0.136 (0.081)*
Western region			-0.189 (0.080)**
Old-age responsibilities			0.013 (0.065)
Social hierarchy			0.025 (0.019)
Socioeconomic status			0.062 (0.041)
Housing			0.097 (0.069)
cut_1_1			
cons			-0.863 (0.189)***
cut_1_2			
cons			-0.148 (0.179)
cut_1_3			
cons			0.571 (0.176)***
cut_1_4			
cons			2.135 (0.176)***
cut_2_1			
cons			1.304 (0.213)***
atanhrho_12			
cons			-0.201 (0.155)
N	1848	1848	1848
r2	0.162		

	First Stage	Naive OLogit	IV OProbit
ll	-1176.850	-2099.151	-3215.532
Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$			

Mediation effect analysis

Parallel mediating effect analysis

To examine the mediating mechanisms through which physical exercise influences the older adults SWB, we employed a bootstrap-based gSEM for analysis, model fitting indices indicate that all models exhibit good fit (Table 8). The bootstrap test results show that none of the effects at the levels of physical health, mental health and social interaction include 0 within the 95% Bootstrap confidence interval, thus verifying that the effects of each pathway are significant. After controlling for three mediating variables, the direct effect of physical exercise on the older adults SWB remains significant, indicating that physical exercise exerts multiple pathways of influence on enhancing the older adults SWB. Concurrently, the indirect effect is significant across all models, confirming the overall existence of the mediating effect. The results estimated the mediating effect of physical health, mental health and social interaction. Physical exercise has a positive impact on the older adults physicsl health, improves the physicsl health, and then significantly improves the older adults SWB. The indirect effect coefficient is 0.138 (95% CI = [0.073, 0.203], $p < 0.001$), indicating that physical health plays a partial mediating role between physical exercise and the older adults SWB. In addition, physical exercise also improves mental health represents another significant mechanism. The indirect mediating effect coefficient of negative emotions was 0.137 (95% CI = [0.062, 0.212], $p < 0.001$). The study further assesses the mediating role of social interaction. The regression coefficient linking physical exercise to social interaction is found to be 0.061 (95% CI = [0.012, 0.110], $p < 0.05$). The parallel mediations of physical health, mental health, and social interaction continue to play a dominant mediating role, accounting for 32.547%, 32.388%, and 15.762% of all indirect effects, respectively, totaling 80.697%. This shows that individuals get to know more communication objects through physical exercise, which expands the scope of social interaction, and the expansion of social interaction scope significantly increases the older adults SWB.

Table 7
Results of Heterogeneity Analysis

	Subjective well-being		Subjective well-being	
	Female	Male	Unmarried	Married
Physical exercise	0.186 (0.139)	0.523 (0.136)***	0.339 (0.098)***	0.936 (0.690)
Gender			0.019 (0.099)	0.221 (0.677)
Household registration	0.148 (0.159)	0.108 (0.159)	0.174 (0.113)	0.893 (0.844)
Marriage	0.061 (0.335)	-0.115 (0.324)		
Educational attainment (Uneducated = 1)				
Elementary School	0.241 (0.215)	-0.159 (0.159)	0.006 (0.129)	-0.050 (0.721)
Middle School	0.226 (0.208)	0.06 (0.177)	0.084 (0.134)	0.756 (0.829)
Higher Education	-0.046 (0.308)	0.302 (0.424)	-0.024 (0.242)	1.140 (0.538)
Region (Eastern region = 1)				
Central region	0.097 (0.169)	0.132 (0.168)	0.063 (0.120)	3.581 (1.211)***
Western region	0.249 (0.165)	0.370 (0.165)**	0.309 (0.117)***	2.615 (1.129)**
Elder care obligations	0.229 (0.134)*	0.434 (0.134)***	0.324 (0.096)***	0.150 (0.620)
Social hierarchy	0.167 (0.040)***	0.165 (0.039)***	0.159 (0.028)***	0.441 (0.183)**
Socioeconomic status	0.349 (0.086)***	0.426 (0.085)***	0.379 (0.061)***	0.088 (0.412)
Housing	0.339 (0.133)**	-0.195 (0.163)	0.103 (0.103)	0.955 (0.733)
cut1	-1.635 (0.461)***	-2.350 (0.486)***	-1.955 (0.253)***	1.029 (1.794)
cut2	-0.096 (0.422)	-0.809 (0.429)*	-0.438 (0.207)**	3.225 (1.605)**
cut3	1.102 (0.419)***	0.684 (0.421)	0.903 (0.201)***	4.260 (1.618)***
cut4	3.591 (0.437)***	3.504 (0.438)***	3.514 (0.219)***	8.450 (1.928)***
N	890	958	1779	69
r2_p	0.045	0.063	0.049	0.195
Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$				

Chain-based mediating effect analysis

To investigate the intrinsic sequential role of physical health, mental health, and social interaction in the relationship between physical exercise and the older adults SWB, this study further constructs and compares 12 potential chain-mediated models (Table 9). Although chain intermediation also achieves significant results, its effects are comparatively weaker than those of parallel intermediation. The results clearly demonstrate that 'PE-PH-MH-SWB' pathway explains the mediating mechanisms, the specific chain-specific mediating effect is 0.143 (95% CI = [0.079, 0.207], $p < 0.001$). This effect size is the largest across all models and exhibited the highest level of statistical significance. This indicates that the promotion of the older adults SWB through physical exercise follows a clear, sequential pathway: from improving physical health to enhancing mental health, ultimately strengthening overall SWB. This pathway accounts for 27.6% of the total effect, highlighting its central role. The specific chain-mediated effect: 'PE-PH-SI-SWB', 'PE-MH-PH-SWB', 'PE-SI-PH-SWB' and 'PE-SI-MH-SWB' have positive coefficients, indirect effect values are 0.012, 0.033, 0.016 and 0.033, respectively. Otherwise, the 'PE-PH-SI-MH-SWB' and 'PE-SI-PH-MH-SWB' pathway also, indicating chain mediation effects are also observed, but physical health, social interaction, and mental health only partially mediate these effects. In other words, physical exercise partially influences the older adults SWB through pathways such as improving health status, expanding social networks, alleviating feelings of frustration, and enhancing SWB. Meanwhile, the direct effect of physical exercise itself on older adults SWB remains active, albeit with a diminished influence.

Table 8
Results of Parallel Mediating Effect Analysis

	Model 6		Model 7		Model 8	
	Physical health	Subjective well-being	Mental health	Subjective well-being	Social interaction	Subjective well-being
Physical exercise	0.553 (0.088)***	0.286 (0.103)**	0.370 (0.091)***	0.286 (0.104)**	0.371 (0.094)***	0.327 (0.102)***
Gender	0.307 (0.094)***	-0.022 (0.100)	0.403 (0.094)***	-0.065 (0.101)	-0.079 (0.095)	0.028 (0.099)
Household registration	0.210 (0.105)*	0.124 (0.115)	0.377 (0.106)***	0.073 (0.116)	-0.039 (0.110)	0.162 (0.114)
Marriage	-0.121 (0.300)	0.006 (0.202)	0.105 (0.270)	-0.068 (0.212)	0.324 (0.236)	-0.052 (0.207)
Educational attainment (Uneducated = 1)						
Elementary School	0.078 (0.123)	-0.0006 (0.130)	0.077 (0.124)	0.008 (0.131)	0.006 (0.127)	0.003 (0.132)
Middle School	0.391 (0.130)**	0.040 (0.133)	0.333 (0.127)**	0.041 (0.133)	0.149 (0.132)	0.080 (0.134)
Higher Education	0.293 (0.210)	-0.071 (0.217)	0.409 (0.256)	-0.121 (0.220)	0.200 (0.221)	-0.057 (0.218)
Region (Eastern region = 1)						
Central region	0.120 (0.110)	0.090 (0.127)	-0.147 (0.116)	0.137 (0.127)	0.070 (0.116)	0.109 (0.127)
Western region	-0.153 (0.112)	0.332 (0.119)**	-0.374 (0.111)***	0.392 (0.121)**	0.155 (0.115)	0.307 (0.119)**
Elder care obligations	-0.007 (0.087)	0.325 (0.099)***	0.059 (0.091)	0.315 (0.099)***	0.023 (0.092)	0.321 (0.099)***
Social hierarchy	0.115 (0.029)***	0.148 (0.029)***	0.068 (0.027)*	0.153 (0.030)***	0.086 (0.030)**	0.158 (0.029)***
Socioeconomic status	0.185 (0.061)**	0.361 (0.062)***	0.278 (0.060)***	0.331 (0.062)***	0.188 (0.065)**	0.368 (0.062)***
Housing	0.105 (0.098)	0.118 (0.105)	0.168 (0.099)	0.086 (0.106)	-0.010 (0.104)	0.138 (0.105)
Physical health		0.249 (0.045)***				
Mental health				0.370 (0.046)***		
Social						0.164

	Model 6		Model 7		Model 8	
	Physical health	Subjective well-being	Mental health	Subjective well-being	Social interaction	Subjective well-being
interaction						(0.054)**
Indirect effect	0.138 [0.073, 0.203]***		0.137 [0.062, 0.212]***		0.061 [0.012, 0.110]*	
Direct effect	0.286 [0.084, 0.488]**		0.286 [0.083, 0.490]**		0.327 [0.126, 0.527]***	
Total Effect	0.424 [0.217, 0.631]***		0.423 [0.211, 0.636]***		0.387 [0.184, 0.591]***	
AIC	9611.95		9254.911		9119.339	
BIC	9805.22		9448.176		9312.604	
Relative Model Fit	0.98		0.98		0.98	
Standard errors in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$						

Table 9 Chain-based Mediating Effect Analysis

	Specific chain-mediated effect	Overall effect
PE-PH-MH-SWB	0.143 [0.079, 0.207]***	0.519 [0.295, 0.743]***
PE-PH-SI-SWB	0.012 [0.0007, 0.024]*	0.451 [0.241, 0.662]***
PE-MH-PH-SWB	0.033 [0.0004, 0.0664]*	0.465 [0.245, 0.685]***
PE-MH-SI-SWB	0.008 [-0.0010, 0.0177]	0.446 [0.230, 0.662]***
PE-SI-PH-SWB	0.016 [0.003, 0.030]*	0.454 [0.243, 0.665]***
PE-SI-MH-SWB	0.033 [0.010, 0.057]**	0.459 [0.241, 0.677]***
PE-PH-MH-SI-SWB	0.008 [-0.001, 0.017]	0.544 [0.316, 0.772]
PE-PH-SI-MH-SWB	0.005 [0.0005, 0.0099]*	0.551 [0.322, 0.779]***
PE-MH-PH-SI-SWB	0.003 [-0.001, 0.007]	0.489 [0.265, 0.713]***
PE-MH-SI-PH-SWB	0.0007 [-0.0004, 0.0017]	0.502 [0.276, 0.727]***
PE-SI-PH-MH-SWB	0.017 [0.003, 0.031]*	0.555 [0.326, 0.784]***
PE-SI-MH-PH-SWB	0.008 [-0.0006, 0.0166]	0.502 [0.277, 0.728]***
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$		

Discussion

This study finds that physical exercise significantly improved the older adults SWB. The main findings of this study indicate that the older adults with superior physical health, mental health, and social interaction tend to participate in physical exercise more frequently. Concurrently, these individuals also exhibit higher levels SWB. In curreent analysis, the results showed that after controlling for a series of demographic and socioeconomic factors, physical exercise had a continuous and significant positive predictive effect on the SWB level of the older adults. Meanwhile, this further substantiates the earlier assertion regarding the fundamental role of physical exercise in fostering physical, mental health and social interactions, thereby ultimately improving the older adults SWB [20, 32, 36]. This establishes a coherent logical sequence: older adults who engage more frequently in physical exercise tend to exhibit superior physical and mental health, maintain more active social networks, and report elevated SWB level.

When considering demographic factors, the impact of physical exercise on life satisfaction in older adults may be contingent upon various moderating factors, including demographic characteristics [19]. In terms of household registration, the participation rates of physical exercise and SWB among the older adults with non-agricultural household registration are significantly higher than those with agricultural household registration, this reflects the structural differences between urban and rural areas in terms of resource accessibility, health concepts and leisure facilities. Furthermore, an increase in educational attainment is positively associated with an upward trend in both the participation rate in physical exercise and SWB, which indicated that education may contribute by improving health literacy, augmenting income levels, and

expanding social capital. The participation rate of physical exercise in th old men is significantly higher than that in old women, suggesting that gender equality should be paid attention to when promoting physical exercise. Whether it is the objective socioeconomic status or the subjective social class, their improvement is accompanied by a significant increase in the participation rates of physical exercise and SWB. This confirms the "social causality theory", that is, resources and status have a fundamental impact on healthy behaviors and subjective feelings. In addition, the SWB of who has houses was significantly lower, but the physical exercise participation rate was higher. One possible explanation is that the older adults who own properties may bear more economic pressure or family responsibilities (such as buying a house for their children), thereby affecting their sense of happiness, but they may also be more capable or motivated to make healthy investments as a result. When it refers to chinese cultural connotations, the older adults who internalize their responsibility for elderly care obligations have significantly higher SWB, this is in line with the traditional Chinese concepts of "enjoying grandchildren" and "family responsibility is value", and taking on family roles may bring a sense of meaning and achievement. These models offer a detailed framework for conducting in-depth investigations into the specific mediating mechanisms through which physical exercise influences SWB. Furthermore, they underscore that, within the context of Chinese cultural and socioeconomic conditions, enhancing the older adults SWB necessitates a holistic approach that combines individual behavioral interventions, social psychological support, and structural reforms.

To examine the impact of physical exercise on the older adults SWB and its potential pathways, this study constructs five ordered Logit regression models. After controlling for demographic and socioeconomic variables, the model 1 reveals that physical exercise has a significant positive impact on the older adults SWB. This effect remains robust even after incorporating different mediating variables. It is consisted with a cross-sectional survey, physical exercise directly affected the older adults SWB [22]. Engagement in regular physical activity has been reported to exert a positive influence on SWB [14]. To test the robustness of the results of the benchmark model, this study respectively adopted the ordered Probit model and the ordinary least square method for estimation. Whether using the ologit, ordered Probit or OLS model, physical exercise has a significant positive impact on the older adults SWB and the directions of the coefficients are consistent. This confirms that the positive association between physical exercise and happiness holds true under different model Settings under the robust control variables. The high consistency of the significance patterns and directions among the three groups of results strongly supports the reliability of the benchmark ologit regression results. Meanwhile, to address potential endogeneity issues, the instrumental variable method for two-stage was estimated. After controlling for endogeneity, the positive causal effect of physical exercise on the older adults SWB was stronger and more significant than the benchmark result, and the evidence that physical exercise has a positive causal effect on the older adults SWB has been strengthened, indicating that the benchmark regression results are likely to be conservative estimates.

Otherwise, models 2 to 4 respectively examines the situations of physical health, mental health and social interaction as a single mediating path. The results show that all variables significantly positively predicted happiness, and the physical exercise coefficients decreased after their inclusion, suggesting that there might be a partial mediating effect. The cut values of each model increase with the rise of the category, which conforms to the basic assumptions of ordered models. The results of the comprehensive model support the research hypothesis that physical exercise not only directly affects the older audlts SWB, but

also indirectly plays a role by improving physical and mental health and promoting social interaction. To separately examine the independent mediating roles of physical health, mental health and social interaction between physical exercise and SWB. Parallel mediation analysis verifies the research hypothesis that physical exercise not only directly enhances the older adults SWB, but also has significant indirect promoting effects respectively through enhancing physical health, improving mental health and promoting social interaction. Among them, the mediating contribution of the physical and mental health path is greater than that of the social interaction path. To examine the complex mechanism by which physical exercise affects SWB through multiple continuous pathways such as "PE→PH→MH→SI→SWB", this study analyzed 12 possible chain mediating pathways. There is a strong link between mental health and physical health, but little is known about the pathways from one to the other [48]. The study indicated that physical exercise has a positive impact on improving the physical and mental health of older adults, particularly in enhancing physical health, psychological health, and social interactions [42]. In current analysis, the chain mediating effect of "PE→PH→MH→SWB"was 0.143, which is the largest and most significant, which indicates that the most significant mechanism by which physical exercise affects SWB. First, it improves physical health, then enhances mental health, and ultimately boosts the older adults SWB. Chain mediation analysis reveals that physical exercise enhances the happiness of the elderly not through a single isolated path, but through a dynamic network with "body → mind" as the core transmission axis and "social interaction" as the key node. Among them, physical health is a crucial initial step, and the benefits it generates are mainly conveyed through promoting mental health. Therefore, when designing health intervention programs, it should be based on enhancing physical functions, while simultaneously paying attention to the synergy of psychological and social support to achieve the maximum increase in the older adults SWB.

Conclusions and prospects

First, physical exercise has a stable and positive significant effect on the older adults SWB. Specifically, physical exercise can not only directly affect the older adults SWB, but also indirectly affect the older adults SWB through intermediary factors such as physical health, mental health and and social interaction. Secondly, the mediating path of physical exercise to improve the older adults SWB is diversified, which not only plays a role through parallel mediation, but also relies on multiple chain mediation to have an impact. Among them, the three parallel mediating paths of health promotion effect, emotion regulation effect and social interaction effect play a leading role. The chain-like mediating effect shows that the older adults can enhance their physical health through physical exercise, alleviate psychological burdens, and ultimately improve their SWB through good social interactions. In this study, the measurement of physical exercise adopts the binary division of participation frequency, and does not consider the intensity of physical exercise. Future research needs to further improve the definition of core variables.In the future, more in-depth research needs to be carried out in combination with exercise pattern classification and multi-dimensional measurement tools to further reveal the comprehensive action path of physical exercise.

Limitations

While the findings of this study holds both theoretical and practical importance, certain limitations should be acknowledged. Firstly, the scope of the CGSS questionnaire data limited the ability to conduct a more

detailed causal analysis of the relationship between physical exercise and SWB, especially concerning specific aspects such as physical exercise frequency and type. Secondly, limitations inherent in the survey content impede the examination of the mediating mechanisms by which physical exercise exerts its effects. Third, the CGSS does not disaggregate the health of older adults into distinct components for comprehensive evaluation, representing an additional limitation. Futhermore, longitudinal studies require more data, but due to the lack of data availability.

Declarations

Ethics approval and consent to participate

The 2023 CGSS adhered to the ethical principles outlined in the Declaration of Helsinki and obtained approval from the ethics committees of Nanjing University of Chinese Medicine and Nanjing Normal University, including protocols for securing participant consent. Additionally, the study protocol received authorization from the National Social Science Foundation of China (approval number 05ASH003). As the dataset utilized is publicly accessible and fully anonymized, further Institutional Review Board (IRB) approval was deemed unnecessary for this secondary analysis. The provincial-level data employed in this research consist of aggregated regional statistics, for which individual informed consent is not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Author Contribution

L.S. designed the formal analysis and led the original drafting of the manuscript, as well as the review and editing process. L.S. were responsible for data curation, providing resources, and validating the findings. S.S. conceptualized the study, developed the methodology, and oversaw the project administration and supervision. P.F. also contributed resources and reviewed and edited the manuscript. All authors read and approved the final manuscript. All authors read and approved the final submitted manuscript.

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Data Availability

This study conducted an analysis of publicly accessible datasets. The data utilized are available at http://cgss.ruc.edu.cn/ and were employed in accordance with the terms and conditions established by the database.

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