BMC Geriatrics

RESEARCH Open Access

A serial mediation model of physical exercise and loneliness: the role of frailty and depression

Song Gu[1*] and Shiling Liu[1]

Abstract

Background Frailty, depression, and loneliness are significant risk factors that hinder successful aging. Physical exercise has been widely recognized as an effective intervention to improve both the physical and mental health of older adults. Guided by the integral conceptual model of frailty, this study aimed to explore the relationships among physical exercise, frailty, depression, and loneliness, providing theoretical support for designing targeted exercise interventions to alleviate loneliness in older adults.

Methods This study employed a structural equation model (SEM) and bootstrap method to examine a serial mediation model, investigating the roles of frailty and depression in the relationship between physical exercise and loneliness. A descriptive and cross-sectional design was adopted, and data were collected from 505 older adults aged 60 and above in China between February and July 2023. The data were collected using the Physical Activity Rating Scale (PARS-3), the UCLA Loneliness Scale (ULS-8), the Tilburg Frailty Indicator (TFI) and the Patient Health Questionnaire-9 (PHQ-9).

Results The findings revealed a significant direct negative relationship between physical exercise and loneliness (Effect = -0.063, 95% CI: -0.085 to -0.040). Furthermore, frailty and depression were found to mediate this relationship both independently and serially. The independent mediation effect of frailty was – 0.072 (95% CI: -0.090 to -0.055), while the independent mediation effect of depression was – 0.010 (95% CI: -0.019 to -0.003). The serial mediation effect of frailty and depression was – 0.007 (95% CI: -0.011 to -0.002). Collectively, the total indirect effect of the three mediation pathways accounted for 58.55% of the observed relationship.

Conclusions This study demonstrated a negative correlation between physical exercise and loneliness among older adults, with frailty and depression serving as significant mediators in this relationship. The findings suggest that physical exercise may alleviate loneliness in older adults by enhancing physiological function and fostering psychosocial empowermen.

Keywords Older adults, Physical exercise, Loneliness, Frailty, Depression, Mediating role

*Correspondence:
Song Gu
lhgusong@zjnu.edu.cn
[1]College of Physical Education and Health Sciences, Zhejiang Normal University, Jinhua, China

Background

Loneliness in older adults, defined as a distressing emotional state stemming from perceived social isolation and lack of meaningful connections [1]. Loneliness is increasingly recognized as a critical public health issue. Substantial evidence links chronic loneliness to multifaceted health risks, including reduced quality of life, higher prevalence of mental disorders (e.g., depression), physical comorbidities (e.g., hypertension), and elevated mortality/suicide rates [2–4]. Clinical studies suggest that declining adaptive capacity and compromised bodily resilience in older adults can exacerbate feelings of isolation, creating a bidirectional cycle between loneliness and deteriorating health [5].

Scholarly definitions of loneliness vary. Weiss conceptualized it as emotional distress from unmet desires for social connection [1], whereas Sermat and Peplau emphasized discrepancies between expected and actual relationship quality [6, 7]. Despite conceptual divergence, loneliness universally reflects (1) dissatisfaction with interpersonal relationships, (2) subjective self-perception rather than objective isolation, and (3) an inherently unpleasant emotional state.

Weiss conceptualizes loneliness as two distinct dimensions: social loneliness and emotional loneliness. These dimensions may coexist or manifest independently [1]. Specifically, social loneliness is closely tied to social isolation, which results from a lack of connection and integration into society [8]. Empirical studies indicate that functional limitations in activities of daily living (ADL) among older adults exacerbate social isolation by restricting participation in social activities and reducing interpersonal interactions, thereby amplifying perceptions of loneliness [9-11].

Frailty, recognized as a multidimensional syndrome of diminished physiological reserves and resilience, heightens vulnerability to stressors and disease susceptibility in older adults [12]. Emerging evidence delineates its bidirectional relationship with activities of daily living (ADL): frailty exacerbates functional decline through mechanisms such as impaired physiological function, chronic disease burden, cognitive-psychological deterioration, and a self-reinforcing frailty-ADL vicious cycle [13, 14]. Notably, frailty exhibits early-stage reversibility, where timely interventions (e.g., resilience-building programs) can mitigate disability progression and improve health outcomes [15]. The World Health Organization prioritizes frailty management as a cornerstone of healthy aging, asserting that it - more than chronological age - serves as a critical biomarker of functional capacity and quality of life.

While existing research has predominantly examined frailty through a biomedical lens, emerging evidence underscores its psychosocial dimensions. Longitudinal data reveal that frail older adults exhibit 1.5-fold higher loneliness prevalence than their non-frail counterparts, with loneliness independently predicting a 40% increased frailty risk [12]. The integral frailty model conceptualizes physical, social, and psychological domains (Fig. 1), with synergistic interactions exacerbating disability and mental health risks. Importantly, multimodal interventions (e.g., exercise, nutritional support, cognitive-behavioral strategies) demonstrate frailty reversibility, advocating integrated care frameworks [17–19].

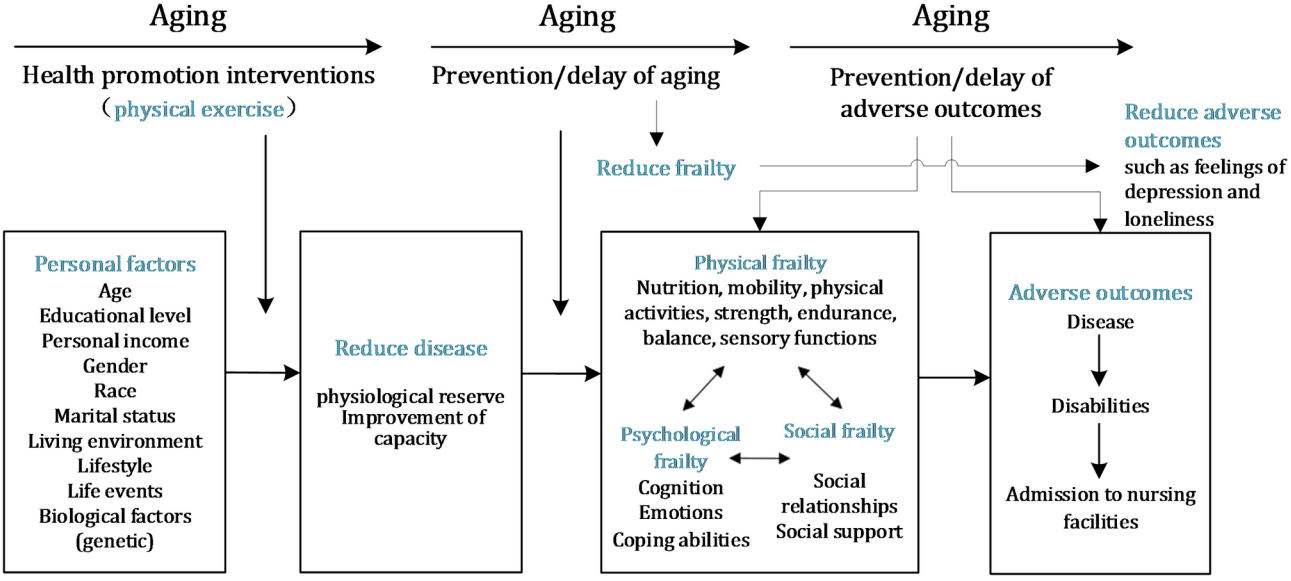

Fig. 1 Physical exercise and loneliness in the integral conceptual model of frailty

Table 1 Descriptive information

Variables	Group	*N*	%
Age (years)	60–69	445	88.1
	70–79	56	11.1
	≥ 80	4	0.8
Sex	male	287	56.8
	female	218	43.2
Residence	urban	487	96.4
	rural	18	3.6
Marital Status	married	491	97.2
	divorced	3	0.6
	single	1	0.2
	widowed	10	2.0
Living Arrangement	with children	341	67.5
	only with spouse	151	29.9
	living alone	11	2.2
	other	2	0.4
Personal Annual Income	0–10,000 yuan	13	2.6
	10,000–30,000 yuan	40	7.9
	30,000–50,000 yuan	171	33.9
	50,000–80,000 yuan	221	43.8
	80,000-120,000 yuan	46	9.1
	120,000-200,000 yuan	10	2.0
	200,000 yuan and above	4	0.8

Among these interventions, physical exercise is considered the preferred strategy for preventing and treating frailty in older adults. Research has shown that a combination of resistance training, balance exercises, and other forms of physical activity can significantly improve lower limb strength and balance in frail older adults [20]. Concurrently, aerobic modalities mitigate psychological frailty by alleviating negative emotions and enhancing self-efficacy [21]. Social engagement inherent in group-based exercise programs further attenuates social frailty through strengthened interpersonal connectivity, synergistically addressing physical, psychological, and social frailty domains [22, 23].

Prior studies have examined frailty in relation to physical exercise and loneliness separately, yet no study has systemically examined their triadic interactions. Guided by the Integral Conceptual Model of Frailty, we posit that: 1) High physical frailty may engender negative self-schemas and social isolation risks through excessive preoccupation with physical vulnerability; 2) Social frailty manifests as diminished social networks and inadequate support systems; 3) Psychological frailty is marked by heightened susceptibility to negative affective states. These intersecting risk domains, whether operating independently or synergistically, potentiate adverse psychosocial outcomes such as depression and loneliness.

As a multidimensional health intervention, physical exercise augments physiological reserve capacity while attenuating physical and psychological frailty through enhanced systemic resilience. Concurrently, its social engagement component reduces social frailty by mitigating isolation mechanisms inherent in limited interpersonal connectivity [24, 25]. We therefore posit H1: Frailty mediates the association between physical exercise and loneliness in older adults.

Depression and loneliness often co-occur in older adults, with correlation coefficients ranging from 0.4 to 0.6 [26, 27]. Evidence suggests bidirectional associations: depression mediates loneliness through social withdrawal and negative self-appraisals that impair social engagement, while loneliness exacerbates depressive symptoms via chronic stress responses, dysregulated cortisol secretion, and hippocampal dysfunction [28, 29]. Depression and loneliness in older adults are not isolated phenomena but rather a complex interplay involving physiological, psychological, and social factors.

Empirical evidence confirms physical exercise's antidepressant efficacy via multimodal mechanisms [30, 31]. Physiological pathways involve neuroendocrine adaptations (dopaminergic/serotonergic regulation), anti-inflammatory modulation (IL-6/TNF-α reduction), and neuroplastic enhancement (hippocampal neurogenesis) [32, 33]. Psychosocial processes include negative affect regulation and social reinforcement through self-efficacy cultivation [34]. Given depression's established role as both exercise-modifiable risk factor and loneliness precursor in aging populations, we posit H2: Depression

mediates the association between physical exercise and loneliness in older adults.

Frailty serves as a critical prodromal marker for late-life depression, which frequently manifests as somatic symptomatology (e.g., fatigue, psychomotor retardation) rather than overt emotional distress - a phenotype termed "masked depression" [35]. This clinical overlap with frailty arises from shared pathophysiological substrates, particularly chronic neuroinflammation marked by elevated IL-6, CRP, and TNF-α [36, 37]. Vascular depression variants further exemplify this nexus through motoric slowing and muscular weakness that presage frailty development [38, 39].

From a biological perspective, chronic inflammation may impair hippocampal neurogenesis and prefrontal cortex function through the "brain-immune axis," while simultaneously accelerating muscle loss, thereby creating a vicious cycle of "inflammation-frailty-depression" [40]. Loneliness, as an extension of this cycle, may be further exacerbated by frailty and depression, leading to a negative feedback loop of "self-isolation and heightened loneliness."

This study proposes physical exercise may serve as a potential therapeutic strategy to disrupt the frailty-depression-loneliness triad. The possible mechanisms could include anti-inflammatory effects, physiological improvements, enhanced neuroplasticity, and psychosocial empowerment. These multidimensional changes might ultimately contribute to alleviating loneliness among older adults. Given the cross-sectional nature of this study, Hypothesis 3 is proposed as a speculative framework: Frailty and depression play a serial mediating role in the relationship between physical exercise and loneliness in older adults.

Methods

Recruitment and participants

This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Zhejiang Normal University (ZSRT20240125).

A purposive criteria-based sampling approach was employed to enhance the representativeness of the sample relative to the target population. Five cities in Zhejiang Province were selected for investigation based on population size, level of economic development, and regional spatial distribution. Specifically, Hangzhou was chosen as the most populous city in the province, Ningbo as the city with the highest per capita GDP, and Jinhua, Quzhou, and Wenzhou as cities representing distinct geographic regions within Zhejiang.

Before the surveys commenced, all participating researchers received training to ensure uniformity in the procedures and requirements across the surveys.

Prior to data collection, investigators coordinated with local sub-district offices and community neighborhood committees to recruit older adults who met the inclusion criteria. The inclusion criteria were as follows: (a) aged 60 years or older; (b) no language communication barriers or severe cognitive impairment, ensuring the ability to complete the questionnaire; and (c) provision of informed consent and voluntary participation. Exclusion criteria included: (a) serious mental or physical illnesses; (b) inability to read or understand the questionnaire; and (c) unwillingness to cooperate with the survey.

From February 25 to July 1, 2023, ten researchers were divided into two groups conducted a questionnaire survey among 600 older adults (aged ≥ 60 years) across the five selected cities. After excluding 95 questionnaires due to insincere responses, defined as those with identical answers for all questions, incomplete responses, or unclear answers, a total of 505 questionnaires were retained for final analysis.

Instruments

The questionnaire used in this study was developed in Chinese and consisted of three sections. First, participants were informed that the survey adhered to the principles of voluntariness and anonymity. They were assured that their responses would be accessible only to the research team and would not be used for commercial or non-research purposes. The second section collected demographic information about the older adults, including age, gender, education level, and other relevant background details. The third section included the standardized scales required for this study, as described below:

Physical activity rating scale (PARS-3)

The questionnaire was developed by Komio Hashimoto, translated in Chinese and revised by Liang Deqing et al. [41]. The questionnaire measured the level of physical activity in terms of intensity, time, and frequency. The PARS-3 Chinese version of the scale is evaluated using the 5-point scoring method and the scale consists of three questions. The total physical activity level was calculated by multiplying intensity by (time-1) by frequency, with 100 as the highest score and 0 as the lowest score. According to the theory of physical activity level, scores ≤ 19 are recorded as low exercise level, 20–42 are recorded as moderate exercise level, and ≥ 42 are recorded as high exercise level.

UCLA loneliness scale-8 (ULS-8)

The scale was adapted by Hays and DiMatteo based on the UCLA-20 scale (University of California Los Angeles Loneliness Scale), consisting of 8 items [42]. This study translated and revised it. The translated version has

acceptable reliability (Cronbach's α coefficient of 0.757) and validity (The fit indices: $\chi^2/df = 4.577$, CFI = 0.921, GFI = 0.959, RMSEA = 0.082, SRMR = 0.064) when used in the Chinese context. Among them, 6 items are positively stated as "loneliness" and 2 items are phrased negatively as "non-loneliness." Each item is rated using a Likert 4-point scoring method, with scores of 1–4 indicating never, rarely, sometimes, and always. The non-loneliness items are reverse-scored. The score on this scale ranges from 8 to 32, where higher scores indicate higher levels of loneliness.

Tilburg frailty index (TFI)

TFI was developed by Gobbens et al. [16], translated in Chinese and revised by Si et al. [43]. The scale was developed on the basis of the integral conceptual model of frailty, and measured the frailty status of the older adults from three dimensions: physical, psychological and social frailty, with a total of 15 items. The scale items adopt the two-classification scoring method, and the scoring range is 0 ~ 15 points, and 5 points and above points are frailty. The higher the score, the heavier frailty. The scale demonstrates good reliability with a Cronbach's α coefficient of 0.787.

Patient health questionnaire (PHQ-9)

PHQ-9 based on DSM-IV is used to evaluate depression symptoms, comprising nine items. This questionnaire was translated and revised by Chen and has been widely used in the Chinese context [44]. The scoring criteria for PHQ-9 scale were proposed by Kroenke [45]. Each item is scored from 0 to 3, with 0 indicating not at all, 1 indicating several days, 2 indicating more than half the days, and 3 indicating nearly every day. The total score ranges from 0 to 27, with cutoff points at 5, 10, 15, and 20, categorizing the severity of depression as follows: no depression (0–4), mild (5–9), moderate (10–14), moderately severe (15–19), and severe (20–27). Clinically, a score of ≥ 5 indicates a potential association with significant depressive symptoms, with higher scores indicate more severe depression. The scale shows good reliability with a Cronbach's α coefficient of 0.865.

Data collection

Informed consent was obtained from all participants prior to their involvement in the study. The purpose of the research, along with assurances of confidentiality and anonymity, was clearly explained to ensure participants were fully aware of the procedures and any potential risks. Participants were informed of their right to withdraw from the study at any time without consequence.

The study was conducted as an anonymous survey, and all data collected were used solely for scientific research purposes. To minimize external interference and ensure accurate responses, researchers, accompanied by community staff, visited the homes of older adults to administer the questionnaires. Researchers guided participants throughout the questionnaire completion process, assisting them in understanding the meaning of the items. For participants who had difficulty reading or comprehending the questions, researchers read the items aloud and provided additional explanations as needed to facilitate accurate responses.

On average, participants took approximately 20 min to complete the questionnaire. All questionnaires were collected immediately after completion to ensure data integrity.

Data analysis

Data processing and statistical analysis were conducted using SPSS 26.0 (IBM, Armonk, NY, USA) and AMOS 27.0 (IBM, Armonk, NY, USA). Independent sample t-tests and one-way ANOVA were performed to compare group differences. To address potential common method bias, Harman's single-factor test was applied. Pearson correlation analysis was used to examine relationships between variables. Regression analysis and mediation effects were tested using the bias-corrected percentile bootstrap method.

Mediation effects were tested using AMOS. AMOS is a software designed for SEM. It enables the simultaneous estimation of relationships among multiple variables, including direct, indirect, and total effects. For confirmatory factor analysis, AMOS can intuitively construct factor models and provide rich fitting indices to help us evaluate the fitting degree of the model, which is crucial for our research. The Bootstrap method was employed. The parameter settings as follows: the number of bootstrap samples was set to 5,000 to ensure the stability and accuracy of the estimates, the confidence level was set to 95% for calculating the confidence intervals of the mediation effects. In the output, the primary statistical values of interest included the estimated mediation effect, standard error, t-value, and 95% confidence interval. These values are reported in the Results.

A significance level of $p < 0.05$ was set for all statistical tests.

Reliability and validity

Confirmatory Factor Analysis (CFA) was employed to assess the internal validity of each construct. For the ULS-8, the fit indices were as follows: $\chi^2/df = 4.577$, CFI = 0.921, GFI = 0.959, RMSEA = 0.082, SRMR = 0.064. While the chi-square value can be influenced by sample size, value less than 3 are considered ideal, and values less than 5 are relatively acceptable. For the TFI, the fit indices were $\chi^2/df = 1.340$, CFI = 0.970, GFI = 0.968, RMSEA = 0.026, SRMR = 0.038, and the PHQ-9 were

Table 2 Physical exercise status of the older adults

Index	Group	*N*	%
Exercise Level	Low Exercise Level	182	34.5
	Moderate Exercise Level	300	56.8
	High Exercise Level	23	4.40

Table 3 Comparison of loneliness, frailty and depression in different physical exercise levels

Index	Group	Mean	*P*Value
Loneliness	Low Exercise Level	22.59	<0.05
	Moderate Exercise Leve	17.15	
	High Exercise Level	16.52	
Frailty	Low Exercise Level	9.53	<0.05
	Moderate Exercise Level	6.39	
	High Exercise Level	5.60	
Depression	Low Exercise Level	3.93	<0.05
	Moderate Exercise Level	1.68	
	High Exercise Level	1.39	

Table 4 Mean, standard deviations, and correlation

	Mean	Standard Deviation	Physical Exercise	Loneliness	Frailty	Depression
Physical Exercise	24.93	16.69	1			
Loneliness	19.08	5.40	-0.469**	1		
Frailty	7.49	3.72	-0.414**	0.679**	1	
Depression	2.48	2.71	-0.411**	0.474**	0.496**	1

* $p < 0.05$ ** $p < 0.01$

$\chi^2/df = 1.103$, CFI = 0.999, GFI = 0.989, RMSEA = 0.014, SRMR = 0.018. All meet the validity score standards for scales ($\chi^2/df < 3$, CFI > 0.9, GFI > 0.9, RMSEA < 0.08, SRMR < 0.08), indicating a good fit for these scales. In terms of reliability, the Cronbach's α coefficients for the ULS-8, the TFI, and the PHQ-9 were 0.757, 0.787, and 0.865 respectively. Both Cronbach's α coefficients and composite reliability (CR) exceeded the threshold of 0.7, confirming good reliability for the mentioned scales.

Common method bias test

Since all structural data were collected through self-reported surveys, common method bias (CMB) is a potential concern. To mitigate the impact of CMB on the validity of the results, several procedural measures were implemented during the survey process, including balanced item ordering, anonymous questionnaire administration, and standardized measurement protocols. Additionally, Harman's single-factor test was conducted to assess the extent of CMB. The results indicated that the first principal component accounted for 24.47% of the total variance, which is below the recommended threshold of 40%, suggesting that common method bias was not a significant issue in this study.

Results

Descriptive analysis

From February to July 2023, a total of 600 questionnaires were distributed. After excluding questionnaires with excessively short response times and highly consistent answers, 505 valid responses were collected, with a total valid rate of 84.16%.

Overall status and variance analysis of physical exercise in the older adults

Overall status of physical exercise in the older adults refer to Table 2. Differences in loneliness, frailty, and depression scores of older adults people with different exercise levels refer to Table 3. The results suggest that with an increase in exercise levels, loneliness, frailty, and depression scores of older individuals gradually decrease, and there are significant differences in each score.

Correlational analysis

Table 4 shows the average value (M) and standard deviation (SD) of physical exercise, loneliness, frailty, and depression. Spearman's analysis method was used to test the correlation coefficient between physical exercise and loneliness, frailty, and depression. The results demonstrated that all variables were significantly correlated, with correlation coefficients ranging from 0.41 to 0.67, supporting the measurement model and the construction of the mediation effect model.

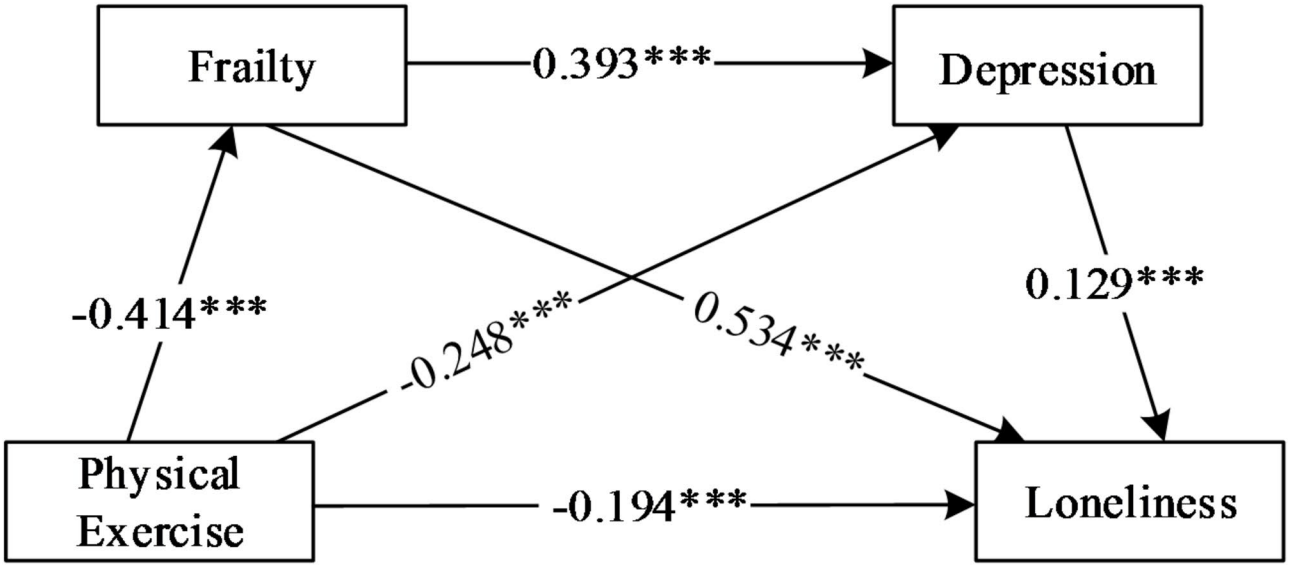

Fig. 2 Frailty and depression play a serial mediating role in the relationship between physical exercise and loneliness

Table 5 The mediation effect analysis of frailty and depression in the influence of physical exercise on loneliness

		Effect	Standard Error	t	*P*Value	LLCI	ULCI
Total effect		-0.152	0.012	-11.899	<0.001	-0.176	-0.126
Direct effect		-0.063	0.011	-5.496	<0.001	-0.085	-0.040
Indirect effect	TOTAL	-0.089	0.008			-0.106	-0.072
	Ind 1	-0.072	0.009			-0.090	-0.055
	Ind 2	-0.010	0.004			-0.019	-0.003
	Ind 3	-0.007	0.002			-0.011	-0.002

Ind 1: physical exercise → frailty → loneliness, Ind 2: physical exercise → depression → loneliness, Ind 3: physical exercise → frailty → depression → loneliness, LLCI: Lower Limit Confidence Interval, ULCI: Upper Limit Confidence Interval

Path analysis of mediation model

Before testing the path model, confirmatory factor analysis was conducted on physical exercise, loneliness, frailty, and depression. According to Kline (1998) [46], the recommended $\chi 2/df$ ratio is less than 3; CFI and TLI values should be greater than 0.90; RMSEA values should be less than 0.08, indicating an acceptable model. The measurement model in this study fits the data well ($\chi 2/df = 1.618$, CFI = 0.933, TLI = 0.928, RMSEA = 0.035, SRMR = 0.047).

In the mediation effects model (Fig. 2; Table 5), all path coefficients are significant ($P < 0.001$), it can be concluded that the mediation effect of frailty and depression between physical exercise and loneliness is significant. Using Bootstrap testing to verify the model, with 5,000 repetitions and calculating a 95% confidence interval. The final model results show that the confidence interval of the mediation effect from physical exercise to frailty -depression to loneliness is [-0.011- -0.002], which does not include 0, confirming a significant mediation effect.

From Table 5, it is evident that the direct effect of physical exercise on loneliness is -0.063, with an indirect effect (mediation effect) of -0.089, accounting for 58.55% of the total effect. Frailty and depression play a partial mediating role in the relationship between physical exercise and loneliness, confirming H3.

Discussion

Based on the integral conceptual model of frailty, the high correlation between depression and loneliness, the shared pathological mechanisms of frailty and depression, and the established effects of physical exercise on frailty, depression, and loneliness, this study examined the roles of frailty and depression in the relationship between physical exercise and loneliness. The findings suggest that physical exercise may alleviate loneliness in older adults by enhancing physiological function and fostering psychosocial empowerment, providing theoretical support for the design of exercise-based interventions targeting loneliness in this population. It is important to note that, as a cross-sectional study, this research can only describe the associations between these factors and cannot infer causality.

Direct effect of physical exercise on loneliness

Scientific evidence indicates that one of the most significant benefits of regular physical activity may be the

improvement of quality of life related to physical fitness, particularly through the maintenance or enhancement of age-related functions in key physiological systems, including the endocrine, respiratory, cardiovascular, and musculoskeletal systems [47]. Long-term and regular physical exercise not only effectively enhances physiological reserves and resilience in older adults, reducing the risk of social isolation due to increased bodily vulnerability or disease, but also modulates the levels of certain neurotransmitters, such as monoamines (e.g., dopamine and serotonin) and endorphins [48]. These neurotransmitters can stimulate brain function at a broader level, fostering more positive self-perceptions and thereby reducing a range of negative emotions and cognitive patterns. This process is similar to the effect of physical exercise on subjective well-being, both of which are achieved through the sense of vitality and pleasure derived from physical activity itself.

In addition, long-term longitudinal studies have shown that older adults who consistently engage in physical exercise have a social network size 40% larger than those who are sedentary [49] In daily life, many older adults view participation in physical activities as a primary means of social engagement, which alters their social environment. This environmental change can influence their attitudes and beliefs toward life, thereby shaping their perceptions of their own circumstances and enhancing their perceived social support. High levels of social support have been shown to effectively reduce feelings of loneliness among older adults [3].

In summary, this study suggests that physical exercise may be associated with a reduction in loneliness among older adults. This association may manifest in two ways: on the one hand, physical exercise may help alleviate emotional loneliness by directly enhancing physiological resilience and providing a sense of vitality and pleasure derived from the activity itself; on the other hand, through indirect psychosocial mechanisms such as expanding social networks and strengthening social support, physical exercise may positively influence the reduction of social loneliness.

The mediating role of frailty between physical exercise and loneliness

According to the integral conceptual model of frailty, the combined effects of physical, psychological, and social frailty are significant contributors to adverse outcomes such as diseases and psychological disorders. These frailty factors can be mitigated through health promotion interventions, including physical exercise, nutrition, cognitive training, psychological support, and socioeconomic assistance. Among these, physical exercise is the preferred strategy for preventing and treating frailty in older adults [12]. Studies have shown that effective exercise interventions can improve the condition of approximately 10–20% of individuals with physical frailty or pre-frailty during follow-up periods [47], which has positive implications for alleviating social isolation caused by limited mobility.

The stress-buffering model suggests that functional decline in older adults is a significant stressor [50]. Resilient older adults may adopt proactive and problem-focused coping strategies, gaining growth from effective coping. Research has confirmed that physical exercise can promote the development of psychological resilience in older adults [51]. The author posits that those who improve their resilience through exercise demonstrate higher self-control, resilience, and positive attitudes when facing adversity, which helps alleviate internal dysregulation, maintain mental health stability, and reduce psychological frailty and associated loneliness.

As individuals age, older adults tend to prioritize maintaining their current health and abilities over improving them. For example, leisure exercise activities involving social interactions are not only enjoyable and low-risk but also fulfill the need for love and belonging. This study found that older adults prefer participating in group-based physical activities, such as walking with family or friends. This finding is understandable because China is a country with a collectivist culture, and group-based physical exercise may provide an ideal social environment for collective-oriented individuals to satisfy their desire for collectives. The integral conceptual model of frailty indicates that a broader social network significantly reduces social frailty levels, and older adults with lower social frailty tend to experience less loneliness. Therefore, group-based physical exercise creates more opportunities for social interaction, offering significant value in reducing loneliness caused by social isolation or social frailty.

The mediating role of depression between physical exercise and loneliness

As individuals age, changes in brain biochemistry and structure often occur, accompanied by shifts in personality traits such as social withdrawal, passivity, dependency, and stubbornness. These changes reduce older adults' resilience to stress, thereby increasing the risk of depression and other psychological issues. Additionally, environmental stressors and challenges (e.g., retirement, empty nest syndrome, loss of loved ones, disability, and illness) significantly impact mental health, leading to reduced social connections and emotional isolation [51].

Depression not only impairs an individual's ability to maintain relationships but also negatively affects interpersonal interactions, increasing the risk of loneliness. Research indicates that depression and loneliness are related yet distinct constructs: loneliness may

unpredictably predict subsequent depression, while depression has a stable prospective effect on loneliness [52]. Therefore, simultaneously assessing depression and loneliness is crucial for breaking the vicious cycle between the two.

This study found that depression mediates the relationship between physical exercise and loneliness in older adults. The neurobiological hypothesis suggests that physical exercise can enhance positive emotions and reduce depressive symptoms by modulating the HPA axis's response to stress, promoting the secretion of endorphins and monoamine neurotransmitters, and increasing the release of neurotrophic factors [50]. Even when the level of social support in physical activities is low, these physiological mechanisms may still provide some emotional improvements, as exercise meets the physiological needs embedded in human evolutionary mechanisms, thereby enhancing resilience to negative emotions such as loneliness.

Furthermore, the distraction hypothesis posits that physical exercise can alleviate depression and anxiety by diverting attention from negative emotions or promoting positive behaviors [53]. At the same time, social interactions during exercise provide opportunities for relaxation and social support, further reducing depression and loneliness. In summary, physical exercise mitigates depression in older adults through biological, psychological, and sociological pathways. Given the close link between depression and loneliness, the experience of loneliness may also decrease as a result.

The serial mediating role of frailty and depression between physical exercise and loneliness

Research indicates that a vicious cycle exists between frailty and depression in older adults. Frailty increases the risk of depression by impairing brain function through chronic inflammation, oxidative stress, and neuroendocrine dysregulation (e.g., HPA axis dysfunction) [54]. Conversely, depression exacerbates frailty as individuals often adopt unhealthy behaviors (e.g., reduced physical activity, poor nutrition), accelerating muscle loss and functional decline [55]. This bidirectional relationship places individuals experiencing both frailty and depression at higher health risks. The author posits that loneliness reflects the social isolation resulting from limited mobility or intensified negative emotional experiences. Therefore, comprehensive interventions are needed to address this complex interplay.

Studies have demonstrated the significant efficacy of comprehensive interventions in alleviating frailty, depression, and loneliness. For example, cognitive behavioral therapy (CBT) combined with exercise interventions can increase the remission rate of depression by 40% in frail older adults [56]. Additionally, multicomponent interventions integrating exercise, nutrition, and psychosocial support can improve frailty by 20% and reduce depressive symptoms by 35% [48]. These findings underscore the importance of multidimensional interventions in breaking the "frailty-depression" vicious cycle.

Based on the evidence, the author suggests that exercise interventions for loneliness in older adults should adopt a stratified approach tailored to frailty levels, depressive symptoms, and available social resources to enhance adherence and effectiveness. Specific strategies include:

For Social Frailty: Community or group-based exercise programs (e.g., Tai Chi, square dancing) may enhance social interactions and alleviate depressive symptoms, social isolation and loneliness.

For High and Physical Frailty: Resistance training (e.g., elastic band exercises, dumbbell training) may improve muscle function, physical resilience, and ADL.

For Psychological Frailty: Personalized exercise plans based on physical condition and personal interests, starting with low-intensity activities (e.g., walking, yoga) and gradually increasing intensity and duration, may enhance psychological resilience and foster positive experiences.

Future studies should further explore the underlying mechanisms, focusing on shared molecular pathways (e.g., inflammatory pathways, neuroplasticity) and longitudinal relationships among frailty, depression, and loneliness. This will facilitate the development of personalized exercise interventions to optimize outcomes.

Conclusions

This study demonstrated a negative correlation between physical exercise and loneliness among older adults, with frailty and depression serving as significant mediators in this relationship. The findings suggest that physical exercise may alleviate loneliness in older adults by enhancing physiological function and fostering psychosocial empowermen.

Limitations and prospects

This study has several limitations that should be acknowledged:

Limited Generalizability to Disabled Older Adults: The findings of this study can not reflect the situation of disabled older individuals, as they were not specifically included in the analysis.

Regional and Spatial Bias: The respondents were primarily from Zhejiang, China, which may introduce regional and spatial biases. Future studies could expand the sample to include diverse geographical areas to enhance the generalizability of the conclusions.

Multidimensional Nature of Frailty: While frailty is a multidimensional construct, this study was unable to precisely predict the effects of each dimension (e.g., physical,

psychological, social) on loneliness. Further research is needed to explore these relationships in greater detail.

Sample Heterogeneity: The study did not account for potential influences of sample differences, such as gender, family structure, urban–rural disparities, or educational and cultural backgrounds. Future studies could stratify samples based on these factors to provide more nuanced insights.

Post-Pandemic Context: The potential impact of changes in living habits and health awareness among older adults following the COVID-19 pandemic could not be estimated in this study. Future research should consider these evolving dynamics to better understand their influence on the results.

Abbreviations

ADL	Activities of daily living
CMB	Common method bias
CBT	Cognitive behavioral therapy
PARS-3	Physical activity rating scale
PHQ-9	Patient health questionnaire-9
SEM	Structural equation modeling
TFI	Tilburg frailty indicator
ULS-8	UCLA loneliness scale
LLCI	Lower limit confidence interval
ULCI	Upper limit confidence interval

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05988-5.

Supplementary Material 1

Author contributions

Conceived and designed the research: Song Gu. Wrote the paper: Song Gu & Shiling Liu. Analyzed the data: Shiling Liu. Revised the paper: Song Gu & Shiling Liu. The authors read and approved the final manuscript.

Funding

This study was supported by grants from Department of Social Sciences, Ministry of Education of China. Research project name: Construction and practical research on community sports intervention for loneliness among old adults people in urban areas of China. Initials of the authors who received each award: SG. Grant ID: 24YJC890014. The full name of each funder: Humanities and Social Sciences Research Project of the Chinese Ministry of Education: https://www.sinoss.net/.

Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Zhejiang Normal University (ZSRTZSRT20240125). All methods were carried out in accordance with relevant guidelines and regulations. Informed consent has been obtained from the participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Received: 26 May 2024 / Accepted: 25 April 2025
Published online: 17 May 2025

References

1. Weiss RS. The study of loneliness. Loneliness: the experience of emotional and social isolation. Cambridge, MA: MIT Press; 1973. pp. 1–15.
2. Fay BA. This modern epidemic: loneliness as an emotion cluster and a neglected subject in the history of emotions. Emot Rev. 2018;175407391876887. https://doi.org/10.1177/1754073918768876
3. Kang HW, Park M, Wallace JP. The impact of perceived social support, loneliness, and physical activity on quality of life in South Korean older adults. J Sport Health Sci. 2016;7(2):115–22. https://doi.org/10.1016/j.jshs.2016.05.003
4. Zhu Y, Liu J, Qu B, et al. Quality of life, loneliness and Health-Related characteristics among older people in Liaoning Province, China: A Cross-Sectional study. BMJ Open. 2018;8(11). https://doi.org/10.1136/bmjopen-2018-021822
5. Ganesalingam G. Higher Risk of Physical Frailty in Older Person Is Associated with Increased Levels of Loneliness Rather Than Social Isolation. Evidence-Based Nursing, 2019, 22(4): ebnurs-2018-103047. https://doi.org/10.1136/ebnurs-2018-103047
6. Sermat V. Sources of loneliness. Essence. 1978;2(4):271–6.
7. Peplau LA, Perlman D. Perspectives on loneliness. New York: Wiley; 1982.
8. Gale CR, Westbury L, Cooper C. Social isolation and loneliness in relation to frailty progression. Age Ageing. 2019. https://doi.org/10.1093/ageing/afx188
9. Koning JD, Richards S, Stathi A, Loneliness. Social isolation, and objectively measured physical activity in Rural-Living older adults. Hum Kinetics, 2020(3). https://doi.org/10.1123/JAPA.2019-0027
10. Davies K, Maharani A, Chandola T et al. Loneliness, social isolation and frailty among older adults in England: results from the english longitudinal study of ageing. Age and ageing. 2021(Supplement_1): supplement_1. https://doi.org/10.1093/ageing/afab029.03
11. Mehrabi F, Beland F. Effects of social isolation, loneliness and frailty on health outcomes and their possible mediators and moderators in Community-Dwelling older adults: A scoping review. Arch Gerontol Geriatr. 2020;90:104119. https://doi.org/10.1016/j.archger.2020.104119
12. Gale C, Westbury L, Cooper C. Social isolation and loneliness as risk factors for the progression of frailty: the english longitudinal study of ageing. Age Ageing. 2018;47(3):392–7. https://doi.org/10.1093/ageing/afx188
13. Franke T, Gould JS, Nettlefold L, et al. It makes me feel not so alone: features of the choose to move physical activity intervention that reduce loneliness in older adults. Res Square. 2020. https://doi.org/10.21203/rs.3.rs-65551/v3
14. Clegg A, Young J, Iliffe S, et al. Frailty in elderly people. Lancet. 2013;381(9868):752–62. https://doi.org/10.1016/S0140-6736(12)62167-9
15. Derck J, Jordan E, et al. Quality of life in liver transplant candidates: frailty is a better Indicator than severity of liver disease. Transplantation Official Journal of the Transplantation Society; 2015.
16. Gobbens RJ, Luijkx KG, Wijnen-Sponselee MT, et al. Towards an integral conceptual model of frailty. J Nutr Health Aging. 2010;14(3):175–81. https://doi.org/10.1007/s12603-009-0142-6
17. Dent E, Morley JE, Cruz-Jentoft AJ, et al. Physical frailty: ICFSR international clinical practice guidelines for identification and management. J Nutr Health Aging. 2019;23(7650). https://doi.org/10.1007/s12603-019-1273-z
18. Lammes E, Rydwik E, Akner G. Effects of nutritional intervention and physical training on energy intake, resting metabolic rate and body composition in frail elderly: A randomised, controlled pilot study. J Nutr Health Aging. 2012;16(2):162. https://doi.org/10.1007/s12603-011-0157-7
19. Ting C, Qifan L, Yuexian S et al. Effects of exercise combined with nutrition support on the elderly with frailty or Pre-Frailty: A Meta-Analysis. Chin Nurs Manage, 2019.
20. Trombetti A, Hars M, Pahor M, et al. Effect of physical activity on frailty. Ann Intern Med. 2018;169(4):267. https://doi.org/10.7326/L18-0243
21. Yoo J, Ruppar T, Wilbur JE, et al. Effects of Home-Based exercise on frailty in patients with End-Stage renal disease: systematic review. Biol Res Nurs. 2021;4109980042110330. https://doi.org/10.1177/10998004211033031
22. Nynke DJ, Paw MJCA, DGL C, et al. Nutrient-Dense foods and exercise in frail elderly: effects on B vitamins, homocysteine, methylmalonic acid, and neuropsychological functioning. Am J Clin Nutr. 2001;73(2):338–46. https://doi.org/10.1039/b713899g

23. Mckelvie M, Donnelly M, O'Reilly D, et al. Psychological frailty and social frailty in older adults: A scoping review. BMJ Publishing Group Ltd; 2021. https://doi.org/10.1136/JECH-2021-SSMABSTRACTS.123
24. Jaroslava Z. Impact of Physical and Social Frailty on the Utilization of Nursing Care Services in Very Old Adults. Innovation in Aging, 2021(Supplement_1): Supplement_1. https://doi.org/10.1093/geroni/igab046.2193
25. Zhao M, Gao J, Li M, et al. Relationship between loneliness and frailty among older adults in nursing homes: the mediating role of activity engagement. J Am Med Dir Assoc. 2019. https://doi.org/10.1016/j.jamda.2018.11.007
26. Donovan NJ, Wu Q, Rentz DM, et al. Loneliness, depression and cognitive function in older U.S. Adults. Int J Geriatr Psychiatry. 2017. https://doi.org/10.1002/gps.4495
27. Domènech-Abella J, Lara E, Rubio-Valera M, et al. Loneliness and depression in the elderly: the role of social network. Soc Psychiatry Psychiatr Epidemiol. 2017;52(4):381–90. https://doi.org/10.1007/s00127-017-1339-3
28. Pei G, Yan Y, et al. Rumination and loneliness independently predict Six-Month later depression symptoms among Chinese elderly in nursing homes. PLoS ONE. 2015. https://doi.org/10.1371/journal.pone.0137176
29. Raut NB, Singh S, Subramanyam AA, et al. Study of loneliness, depression and coping mechanisms in elderly. J Geriatric Mental Health. 2014;1(1):20. https://doi.org/10.4103/2348-9995.141920
30. Yang F, Wu B, Wang F. The effect of physical exercise on the degree of depression in the elderly in China. China Sports Sci Technol. 2023;59(1):38–43. https://doi.org/10.16470/j.csst.2021103
31. Erickson KI, Miller DL, Roecklein KA, Other. 2012, 18(1). https://doi.org/10.1177/1073858410397054
32. Thompson SM, Kallarackal AJ, Kvarta MD, et al. An excitatory synapse hypothesis of depression. Trends Neurosci. 2015;38(5):279–94. https://doi.org/10.1016/j.tins.2015.03.003
33. Duman RS, Nanxin L. A neurotrophic hypothesis of depression: role of synaptogenesis in the actions of NMDA receptor antagonists. Philos Trans R Soc Lond. 2012;367(1601):2475–84. https://doi.org/10.1098/rstb.2011.0357
34. Mazzola P, Commentary. Depression and social isolation are associated with loneliness among seniors with Mild-to-Moderate Dementia—Findings from the IDEAL cohort study. Evid Based Nurs. 2020. https://doi.org/10.1136/ebnurs-2020-103387
35. Gobbens RJJ, Van Assen MALM, Luijkx KG, et al. The Tilburg frailty indicator: psychometric properties. J Am Med Dir Assoc. 2010;11(5):344–55. https://doi.org/10.1016/j.jamda.2009.11.003
36. Lohman M, Briana B, et al. Depression and frailty in late life: evidence for a common vulnerability. Am J Geriatric Psychiatry. 2014. https://doi.org/10.1016/j.jagp.2013.12.062
37. Katz IR. Depression and frailty: the need for multidisciplinary research. Am J Geriatric Psychiatry. 2004. https://doi.org/10.1097/00019442-200401000-00001
38. Paulson D, Lichtenberg PA. Vascular depression: an early warning sign of frailty. Aging Mental Health. 2012;17(1). https://doi.org/10.1080/13607863.2012.692767
39. Hurst C, Sayer AA. Improving muscle strength and physical function in older people living with sarcopenia and physical frailty: not all exercise is created equal. J Royal Coll Physicians Edinb. 2022;52(2):166–71. https://doi.org/10.1177/14782715221104859
40. Meng X, Li J, Hua S, et al. Research progress on the correlation between frailty and depression in the elderly. PLA J Nurs. 2018;35(16):46–9. https://doi.org/10.3969/j.issn.1008-9993.2018.16.009
41. Liang D. Stress level of college students and its relationship with physical exercise. Chin J Mental Health. 1994;8(1):2. DOI:CNKI:SUN:ZXWS.0.1994-01-001.
42. Hays R, Dimatteo MR. A Short-Form measure of loneliness. J Pers Assess. 1987;51(1):69–81. https://doi.org/10.1207/s15327752jpa5101_6
43. Si HX, Jin YR, Qiao XX, et al. Reliability and validity of the Chinese version of the Tilburg frailty Indicator in elderly people in nursing homes. Chin J Gerontol. 2018;38(16):4. DOI:CNKI:SUN:ZLXZ.0.2018-16-084.
44. Chen R, Wang Y, Yu JY, et al. Reliability and validity of the PHQ-9 in hospitalized patients in general hospitals. Sichuan Mental Health. 2017;30(2):5. https://doi.org/10.11886/j.issn.1007-3256.2017.02.013
45. Kroenke, Kurt RL, Spitzer, Williams JBW. The PHQ-9: validity of a brief depression severity measure. J Gen Intern Med. 2001;16(9):606–13. https://doi.org/10.1046/j.1525-1497.2001.016009606.x
46. Kline B. Software review: software programs for structural equation modeling: Amos, EQS, and LISREL. J Psychoeducational Assess. 1998;16(4):343–64. https://doi.org/10.1177/073428299801600407
47. Theou O, et al. Exercise interventions for the management of frailty: A systematic review of randomized controlled trials. J Aging Res. 2011;2011:1–9.
48. Vancampfort D, et al. Sedentary behavior and physical activity levels in people with schizophrenia, bipolar disorder and major depressive disorder: A global systematic review and Meta-Analysis. World Psychiatry. 2017;16(3):308–15.
49. Jeon GS, Jang SN, Park S, Social Support. Social network, and frailty in Korean elderly. J Korean Geriatr Soc. 2012;16(2):84. https://doi.org/10.4235/jkgs.2012.16.2.84
50. Nolen-Hoeksema S. Responses to depression and their effects on the duration of depressive episodes. J Abnorm Psychol. 1991;100(4):569–82. https://doi.org/10.1037/0021-843x.100.4.569
51. Netz Y, et al. The effect of a single aerobic training session on cognitive flexibility and emotional resilience in older adults. Psychol Aging. 2005;20(4):647–57.
52. Ren L, Mo B, Liu J et al. A Cross-Lagged regression analysis of loneliness and depression: A Two-Year trace. Eur J Dev Psychol, 2020;(2):1–15. https://doi.org/10.1080/17405629.2020.1865146
53. Izquierdo M, Morley JE, Lucia A. Exercise in people over 85: advanced age is no barrier to the benefits of tailored exercise. BMJ (Online). 2020;1(1):368. https://doi.org/10.1136/bmj.m402
54. Miller AH, Raison CL. The role of inflammation in depression: from evolutionary imperative to modern treatment target. Nat Rev Immunol. 2016;16(1):22–34.
55. Brosse AL, et al. Exercise and the treatment of clinical depression in adults: recent findings and future directions. Sports Med. 2002;32(12):741–60.
56. Ng TP, et al. Nutritional, physical, cognitive, and combination interventions and frailty reversal among older adults: A randomized controlled trial. Am J Med. 2015;128(11):1225–36.

Publisher's note