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A serial mediation model of physical exercise and loneliness: the role of perceived social support and resilience

Song Gu^{1*}, Xin Zhang¹ and Yanguang Peng²

Abstract

Background Loneliness is a risk factor for numerous negative life outcomes and diseases among older adults. Physical exercise can reduce social isolation among older adults and improve their health status. This study focused on the relationships among physical exercise, perceived social support, resilience and loneliness to provide theoretical support for physical exercise interventions to address loneliness in older adults.

Methods This study used a structural equation model and bootstrap method to test a serial mediation model of physical exercise and loneliness and the role of perceived social support and resilience. In this descriptive and cross-sectional study, a questionnaire survey was conducted on 516 older adults from 5 January 2024 to 20 January 2024. The data were collected using the physical activity rating scale (PARS-3), UCLA loneliness Scale-8 (ULS-8), perceived social support scale (PSSS) and Connor-Davidson Resilience Scale (CD-RISC).

Results The results showed that physical exercise among older adults had a direct negative relationship with loneliness (Effect = -0.049, 95% CI: -0.072 to -0.027). In addition, perceived social support and resilience mediated the relationship between physical exercise and loneliness both independent and serially, with the independent mediation effect of perceived social support being -0.041 (95% CI: -0.056 to -0.028), the independent mediation effect of resilience being -0.018 (95% CI: -0.026 to -0.011), and the serial mediation effect of perceived social support and resilience being -0.009 (95% CI: -0.015 to -0.005). The total indirect effect of the three mediation paths was 58.47%.

Conclusions (1) In this study, physical exercise and loneliness in older adults were negatively correlated. Perceived social support and resilience play mediating roles in the relationship between physical exercise and loneliness. (2) This study suggests that participation in group events or team sports is valuable for alleviating loneliness caused by a lack of social interaction.

Keywords Physical exercise, Perceived social support, Resilience, Older adults, Mediating role

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Background

Loneliness has become a common problem that affects the health of older adults and is a risk factor for numerous negative life outcomes and diseases [1]. Elucidating the influencing factors of loneliness and intervention methods among older adults has practical significance for promoting healthy ageing. Research shows that social support and resilience are protective factors for the mental health of older adults [2, 3] and that moderate-intensity aerobic exercise can effectively alleviate various psychological disorders. Our literature review revealed that physical exercise, perceived social support and resilience are significantly positively correlated, whereas loneliness, perceived social support and resilience are significantly negatively correlated [4–7]. Therefore, exploring the relationships among physical exercise, social support, resilience and loneliness may help researchers gain an in-depth understanding of the influencing factors of loneliness among older adults and possible interventions.

Loneliness is a subjective negative experience of individuals when they feel isolated from others. It includes two components: social loneliness and emotional loneliness. Social loneliness arises from an individual's lack of quality social networks, while emotional loneliness is due to the loss or lack of intimate emotional attachment. The loneliness of older adults is influenced by various factors, including age, illness, family situation, social factors, parent–child support and interpersonal communication. Among these, social support is considered one of the most effective methods for alleviating the loneliness of older adults. Some scholars have noted that physical exercise is a type of social activity and a means of interpersonal communication [8]. In daily life, physical exercise is an important strategy for older adults to participate in social activities and contributes to a lifestyle that may change their social environment. Changes in the environment can affect older adults' attitudes and beliefs, thereby improving their self-awareness and expanding their social support network. Research has shown that short-term aerobic exercise can alleviate negative emotional states and induce positive emotional states, whereas long-term aerobic exercise can significantly improve older adults' physical function and mental health [9, 10]. Thus, physical exercise can alleviate not only the loneliness of older adults through social support but also the negative influence of loneliness through positive emotions. These two paths can therefore alleviate social and emotional loneliness.

The mainstream view of social support is that perceived subjective social support is more meaningful than objective social support. Although the social support perceived by individuals is not necessarily an objective fact, it is a psychological reality that influences human behaviour and development [11]. Perceived social support is

individuals' subjective perception of the level of social support they receive. Research has shown that physical exercise has a significant positive influence on older adults' level of perceived social support, especially in the form of collective sports [9]. Physical exercise can influence individuals' adaptability to the environment through social support [12, 13]. Loneliness can be understood as a negative consequence of maladjustment to the environment. Therefore, this study proposes Hypothesis 1 (H1): Perceived social support mediates the relationship between physical exercise and loneliness in older adults.

Pressure and challenges in life are direct causes of loneliness in older adults. Compared with young people, older adults are more likely to experience the influence of life events, such as retirement, an empty nest, the death of family or friends, disability, and illness, leading to emotional isolation and a decrease in their social relationships. In positive psychology, resilience reflects an individual's ability to recover from stress or challenges and adapt to changing environments. According to the theory of resilience framework, individuals' inability to cope with pressure or challenges in their surroundings may lead to negative consequences and maladjustment [14]. Therefore, in theory, older adults face pressures such as retirement, illness, an empty nest and widowhood, which pose challenges to the quality and quantity of their social relationships. When stressors or life challenges are not balanced by protective processes from the external social environment or biopsychospiritual resiliency factors within an individual, imbalances or disruption of homeostasis may occur, resulting in loneliness. According to previous studies, a reduction in resilience can increase the susceptibility of elderly patients with chronic diseases to loneliness [15]. In other words, loneliness in older adults can be alleviated by improving individual resilience. In the theory of resilience framework, this process can be summarised as improving the “person–environment interaction process” through various protective factors, restructuring “internal self–resiliency factors” and enabling individuals to actively cope with stress, which results in the reintegration of homeostasis and alleviates negative outcomes such as loneliness.

According to the resilience framework (Fig. 1), protective factors for resilience in the environment include the dimensions of the family, culture, neighbourhood, school and peers. As an intervention method, physical exercise includes elements required for the development of resilience, such as family sports, sports culture, community sports and collective activities. Thus, it has the potential to enhance individual resilience. A previous study confirmed this viewpoint; older adults who participated in moderate-intensity exercise or higher frequently had higher physical exercise scores in terms of resilience and positive emotions than those who did not participate

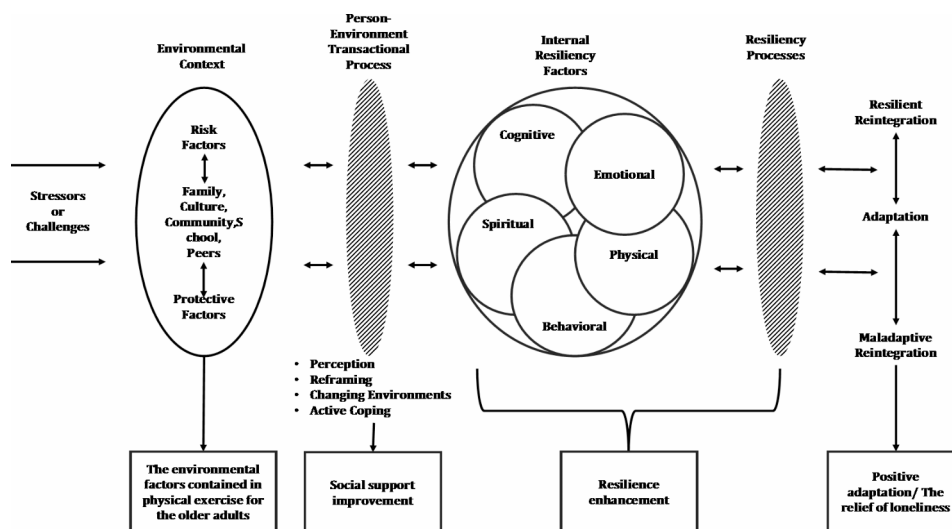


Fig. 1 Physical exercise, social support and loneliness in Resilience Framework Theory

[16]. In this context, most studies suggest that physical exercise can improve individuals' ability to overcome adversity by regulating emotions, enhancing self-confidence and cultivating a positive attitude [17, 18]. Therefore, this study proposes Hypothesis 2 (H2): Resilience mediates the relationship between physical exercise and loneliness in older adults.

Research has shown that social support is not only a protective factor for loneliness but also an important source of resilience for older adults [19, 20]. The emotional support provided by social factors can help older adults establish a positive emotional state and increase their confidence and resilience in coping with difficulties. In addition, the information provided by social support can enhance the coping ability of older adults. They can gain inspiration and cultivate resilience to cope with and actively recover from adversity through communication with and learning from others. Physical exercise provides opportunities for social interaction and allows older adults to establish connections and interact with other participants. A shared interest in sports can serve as a bond in relationships by promoting friendships and social networks, thereby enhancing older adults' sense of support and belonging. These benefits may become a source of resilience for older adults that enables them to actively adapt to interpersonal and emotional pressures, achieve resilient reintegration and alleviate the experience of loneliness. Hence, this study proposes Hypothesis 3 (H3): Perceived social support and resilience 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 (ZSRT2024098).

Purposive criteria-based sampling was conducted to increase the chance that the sample could be representative of the population. The investigators contacted and communicated with the sub-district office or the community neighbourhood committee in advance, and they assisted in the recruitment of older adults who met the inclusion criteria as research sample. Inclusion criteria as follows: (a) aged 60 years and above; (b) those who had no language communication disorder or severe cognitive impairment and were able to complete the questionnaire; and (c) informed consent and voluntary participation. Exclusion criteria were as follows: (a) those with serious mental or physical illness; (b) those who failed to read or understand the questionnaire questions; and (c) those who failed to cooperate with the survey.

From 5 January 2024 to 20 January 2024, researchers were divided into three groups to conduct a questionnaire survey on 540 older adults (age ≥ 60 years old) in five cities of Zhejiang Province, China. A total of 516 questionnaires were used for the final analysis, excluding 24 questionnaires that had insincere responses. For this study, insincerity was defined as those questionnaires that featured all questions marked with the same response or those which were otherwise incomplete or contained unclear responses in some way.

Selection of study sites

On the basis of the population size, level of economic development, and regional spatial distribution, we

selected five cities in Zhejiang Province for investigation. Hangzhou is the most populous city in Zhejiang Province; Ningbo has the highest per capita GDP among all the cities; Jinhua, Quzhou and Wenzhou are located in different parts of Zhejiang Province.

Instruments

The questionnaire scales involved in this study are all in Chinese and are divided into three parts. First of all, we make it clear that the survey is based on the principle of voluntariness and anonymity; the questionnaire responses are only available to researchers; they should not be used for any form of profit or other purposes. The second part is to collect the basic information about older adults. Thirdly, we set up the scales required for this study. The details are as follows:

Physical activity rating scale (PARS-3)

The scale was compiled by Japanese scholar Koo Hashimoto, which was revised into Chinese by Liang [21]. The PARS-3 Chinese version of the scale is evaluated using the Likert 5-point scoring method and the scale consists of three questions. The formula for calculating the total exercise amount is to multiply the scores of three factors of intensity, time and frequency (the component of physical exercise = intensity score \times (time score - 1) \times frequency score), the higher score obtained, the greater amount of exercise an individual has. The total exercise score ranges from 0 to 100 points. According to the theory of sports activity level, the score ≤ 19 is low level of physical, the score between 20 and 42 is moderate level of physical exercise, and the score ≥ 42 is high level of physical exercise.

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) [22]. The ULS-8 Loneliness Scale has a total of 8 items, including 6 positive items and 2 negative items. Each item adopts a four level frequency rating, with scoring methods of (1) never, (2) rarely, (3) sometimes, (4) often. The higher the total score, the higher the degree of loneliness. This scale was translated and discussed by bilingual researchers to form a translated Chinese version.

Perceived social support scale (PSSS)

Jiang introduced the MSPSS (Multidimensional Scale of Perceived Social Support) scale developed by Zimet et al., which has been translated and revised into the PSSS scale [23]. This scale is used in Chinese widely. Slightly different from the MSPSS scale, the PSSS scale annotated the dimension of "others support" as "leaders, relatives, colleagues, etc.". There are a total of 12 self-evaluation

items, consisting of three dimensions: support from others (leaders, relatives, colleagues, etc.), family support and friend support. The Perceived Social Support Scale assigns values of 1–7 points from "very strongly disagree" to "very strongly agree" using a Likert 7-point scoring system. Each of the 3 dimensions consists of 4 questionnaire items, social support is the sum of 12 items. This scale has good reliability and validity in assessing social support for older adults.

Connor-Davidson Resilience Scale (CD-RISC)

The CD-RISC developed by Connor and Davidson, has been applied and validated clinically which can reflect the overall improvement of adaptation in post-traumatic stress disorder patients during treatment. Yu and Zhang translated and revised it into Chinese [24]. This scale involves three dimensions: tenacity, strength and optimism. The internal consistency of the total scale and each dimension is good, there is a good correlation validity with personality traits, self-esteem and life satisfaction. The CD-RISC contains 25 items as follows: not true at all (0), rarely true (1), sometimes true (2), often true (3) and true nearly all of the time (4). The scale was scored based on the subject's feelings over the past month, with higher scores indicating greater resilience.

Data collection

Informed consent was obtained from all participants. The purpose and confidentiality of the study were explained to participants to ensure that they were aware of possible risks. They could drop out at any time. The study was an anonymous survey, and the data were for scientific research purposes only. The participants were accompanied by the researchers throughout the process of filling in the questionnaire to eliminate irrelevant interference and help older adults understand the meaning of the questionnaire items. For the participants who could not see the questionnaire items clearly or understand the questionnaire items, the questionnaire tester read the items aloud or gave further explanations to help older adults complete their answers. Participants took approximately 20 min to complete the questionnaire, which was collected immediately after completion.

Data analysis

SPSS 26.0 (IBM, Armonk, NY, USA) and PROCESS were used for data processing and statistical analysis. Independent sample t-test and one-way ANOVA were used to compare the differences. Homologous data that might produce common method biases were examined by Harman's single-factor test. Correlation analysis was performed using Pearson correlation. Regression analysis and mediating effect test were performed by deviation-corrected percentile bootstrap method. Model 6

Table 1 Reliability and validity analysis

Variables	Cronbach's α	Items	CMIN/DF	CFI	TLI	GFI	RMSEA
ULS-8	0.80	8	1.096	0.998	0.997	0.990	0.014
PSSS	0.82	12	1.459	0.979	0.972	0.977	0.030
CD-RISC	0.79	25	1.319	0.928	0.92	0.949	0.025

Table 2 Descriptive information

Variables		N	Percentage
Total		516	100
Gender	Male	259	50.2
	Female	257	49.8
Age	60–69	251	48.6
	70–79	204	39.5
	≥ 80	61	11.8
Residence	Urban	387	75
	Rural	129	25
Marital status	Married	415	80.4
	Divorced	18	3.5
	Single	10	1.9
	Widowed	73	14.1
Living arrangement	Living with children	332	64.3
	Other	184	35.7

in PROCESS plug-in of SPSS was used to test the chain mediating effect [25]. Statistical significance was set at $p < 0.05$.

Reliability and validity of the instrument

The reliability and validity of the scale data were analysed using SPSS 26.0 and AMOS 24.0. The Cronbach's α coefficients of the ULS-8 loneliness scale, the PSSS scale and the CD-RISC scale were 0.8, 0.82 and 0.79 respectively, which all were greater than 0.7. These results suggested that the above scales all had good reliability, and the results of confirmatory factor analysis showed that the ULS-8 loneliness Scale, the PSSS scale and the CD-RISC Scale met the scale validity scoring criteria (CMIN/DF < 3, CFI > 0.9, TLI > 0.9, GFI > 0.9, RMSEA < 0.08). Thus, the above scales all had a good fit (Table 1).

Common method bias

Multiple questionnaire items and short testing time can easily lead to CMB issues. To minimise the interference of common method bias on content validity, we applied a balanced item order, anonymous questionnaire measurement and standardised measurement in the questionnaire. Through Harman's single-factor test, we found that the variance explained by the first factor of principal component analysis was 22.2%, which was lower than the critical standard of 40%. CFA showed that the fit index of the multifactorial model (CMIN/DF = 1.176, RMSEA = 0.018, CFI = 0.949, IFI = 0.950 and TLI = 0.946) was significantly better than that of the single-factor model (CMIN/DF = 1.709, RMSEA = 0.037, CFI = 0.793,

IFI = 0.796 and TLI = 0.784). In conclusion, the influence of CMB in the present study was within a reasonable range.

Results

Demographic information

In this study, a majority of the participants (48.6%, $n = 251$) were in the age range of 60–69, 39.5% ($n = 204$) were in the age range of 70–79, and 11.8% ($n = 61$) were over 80 years old. Most of the participants lived in the urban area (75%, $n = 387$), whereas 25% in the rural area ($n = 129$). The demographic information of the participants are reported in Table 2.

The descriptive analysis of physical exercise scores in the questionnaire data using SPSS26.0 revealed that 316 individuals engaged in minimal exercise, accounting for 61.2%; 113 individuals participated in moderate exercise, accounting for 21.9%; and 87 individuals engaged in high levels of exercise, accounting for 16.9%. The most common form of exercise among these participants was walking, followed by group dancing and Tai Chi. Walking is the simplest and most convenient way to exercise, whereas group dancing and Tai Chi are traditional Chinese forms of exercise that are particularly popular and enjoyed by older adults. In terms of exercise duration, the majority of participants reported exercising for 20–30, 30–60 or over 60 min, with each category comprising over 20% of the total. In terms of frequency, '3–5 times a week' and 'about once a day' topped 20%. Chinese older adults excelled in maintaining lengthy exercise sessions and a high frequency of workouts.

Subsequently, differential comparisons were made on the scores of loneliness, perceived social support and resilience scales under different levels of physical exercise. The results showed that differences in loneliness, perceived social support and resilience scores were statistically significant at different levels of physical exercise ($P < 0.01$). Older adults with low levels of exercise had the highest scores for loneliness, but the lowest scores for perceived social support and resilience. Older adults with high levels of physical activity had the lowest scores for loneliness, but the highest scores for perceived social support and resilience. Thus, as the amount of physical exercise increased, the loneliness score of older adults decreased gradually, whereas the scores of perceived social support and resilience increased gradually, and the difference was significant. Detailed results are shown in the Table 3.

Table 3 Differential comparison between each scale under different levels of physical exercise

Scale	Level	M ± SD	F	P
ULS-8	1	21.31 ± 5.11	69.78	< 0.01
	2	17.93 ± 5.10		
	3	14.08 ± 5.93		
PSSS	1	46.33 ± 11.08	70.891	< 0.01
	2	52.66 ± 12.40		
	3	64.3 ± 17.29		
CD-RISC	1	59.49 ± 9.87	69.823	< 0.01
	2	66.59 ± 10.01		
	3	73.49 ± 12.13		

1 - Low level of physical exercise
 2 - Moderate level of physical exercise
 3 - High level of physical exercise

Table 4 Differential comparison between each scale under demographic characteristics

Variables	N	ULS-8	PSSS	CD-RISC
Gender				
Male	259	19.38 ± 5.96	50.94 ± 14.70	62.58 ± 12.08
Female	257	19.32 ± 5.89	50.56 ± 13.75	64.24 ± 11.07
t		0.129	0.305	-1.629
P		0.898	0.761	0.104
Age				
60–69	251	19.06 ± 6.01	50.39 ± 14.16	63.82 ± 11.02
70–79	204	19.28 ± 5.82	51.39 ± 14.45	63.55 ± 12.18
≥ 80	61	20.75 ± 5.75	50.07 ± 13.84	61.25 ± 11.96
F		2.041	0.353	1.23
P		0.131	0.703	0.293
Residence				
Urban	387	19.44 ± 5.98	51.11 ± 14.16	63.49 ± 11.50
Rural	129	19.09 ± 5.73	49.65 ± 14.4	63.15 ± 11.95
t		0.584	1.012	0.293
P		0.559	0.312	0.77
Marital status				
Married	415	19.4 ± 5.84	50.89 ± 14.39	63.29 ± 11.93
Divorced	18	17.67 ± 6.04	50.72 ± 12.29	64.61 ± 6.61
Single	10	15.6 ± 6.79	53.7 ± 14.77	70 ± 15.22
Widowed	73	20 ± 6.07	49.55 ± 13.77	62.89 ± 9.99
F		2.142	0.329	1.204
P		0.094	0.804	0.307
Living arrangement				
Living with children	332	19.16 ± 5.87	51.29 ± 14.39	63.92 ± 11.48
Other	184	19.69 ± 6.00	49.78 ± 13.89	62.47 ± 11.81
t		-0.976	1.155	1.362
P		0.33	0.249	0.174

Table 5 Correlation analysis among the four variables: perceived social support, resilience, loneliness and physical exercise

	M	SD	1	2	3	4
Physical exercise	20.20	20.98	—			
Loneliness	19.35	5.92	-0.419**	—		
Perceived social support	50.75	14.22	0.420**	-0.530**	—	
Resilience	63.41	11.61	0.436**	-0.465**	0.477**	—

Note: * $P < 0.05$, ** $P < 0.01$

Independent-sample t-test and one-way ANOVA were performed on the questionnaire data using SPSS 26.0. Whether ULS-8, PSSS or CD-RISC was used, none of the scores were significantly different in the demographic variables. Overall, loneliness increased with age, and widowed older adults had the lowest loneliness score among the sample population. For social support, older adults living in towns and living with their children scored higher than their counterparts. The level of resilience among older adults declined with increasing age gradually. However, older adults who lived with their children had better performance in resilience than those who did not. (Table 4 for details).

Correlational analysis

In this analysis, the exploratory correlation analysis was conducted through the correlation between Pearson variables. According to the analysis results, there are significant correlation between the variables in this analysis and all at the 99% significance level. According to the results of the correlation coefficient, physical exercise is negative with loneliness significantly and positively correlated with perceived social support and resilience significantly. There is a significant positive correlation between perceived social support and resilience; Perceived social support and resilience is negatively correlated with loneliness significantly (Table 5). It can be seen that all variables correlated were significant, which supports the measurement model and mediating effect model construction.

Testing the serial mediation effect

Since cross-sectional designs do not allow for the inference of causal relationships between variables, this study reflects only covariant relationships between physical exercise, perceived social support, resilience and loneliness in the hypothesised directions. The PROCESS plugin of SPSS was used for the mediating effect test and the results are shown in the Table 6. The results of the regression analysis show that physical exercise was significantly positively associated with perceived social support ($B = 0.28, p < 0.001$), which in turn was significantly negatively associated with loneliness ($B = -0.15, p < 0.001$); meanwhile, the direct effect of physical exercise on loneliness was significant ($B = -0.05, p < 0.001$); supporting H1. Moreover, physical exercise was significantly positively associated with resilience ($B = 0.16, p < 0.001$),

Table 6 Results of regression analysis from PROCESS macro testing

Variables		Overall Fitting Coefficient			Regression Coefficient					
Outcome Variables	Predictor Variables	R	R ²	F	B	SE	t	p	LLCI	ULCI
Perceived social support	Physical exercise	0.42	0.18	109.83	0.28	0.03	10.48	<0.001	0.23	0.34
	Resilience	0.54	0.30	107.31	0.16	0.02	7.02	<0.001	0.11	0.20
Loneliness	Perceived social support				0.29	0.03	8.73	<0.001	0.23	0.36
	Physical exercise	0.60	0.36	96.90	-0.05	0.01	-4.31	<0.001	-0.07	-0.03
	Perceived social support				-0.15	0.02	-8.41	<0.001	-0.18	-0.11
	Resilience				-0.11	0.02	-5.27	<0.001	-0.16	-0.07

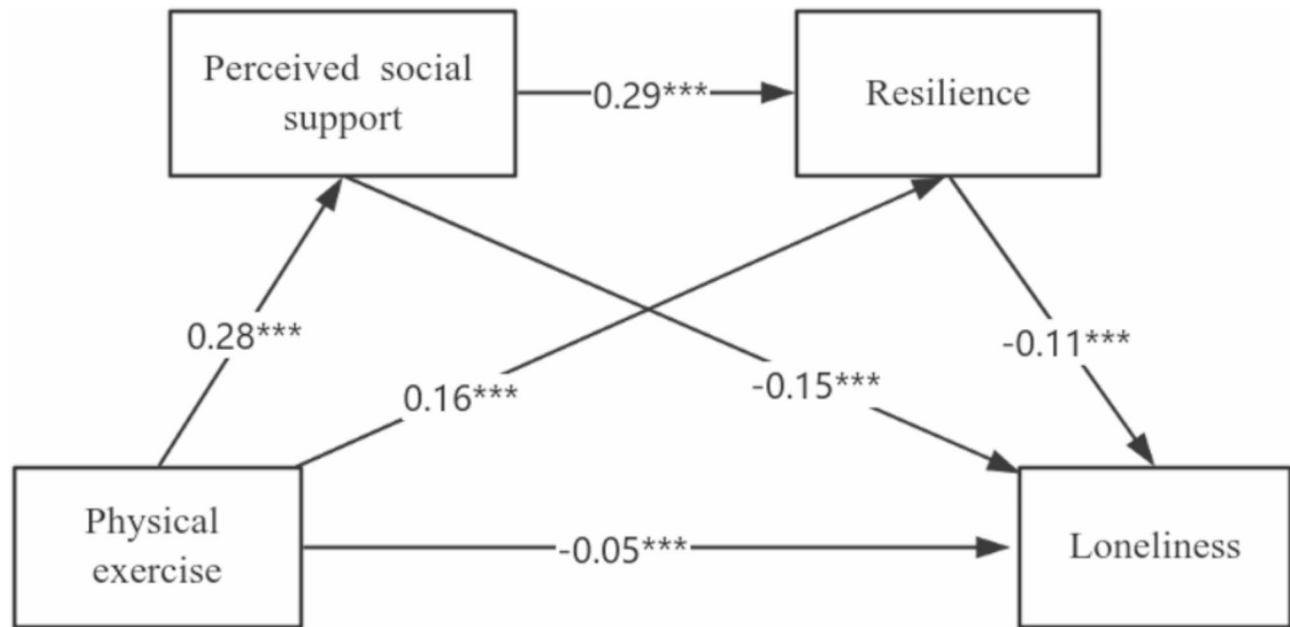


Fig. 2 The serial mediation effect. Note: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 7 Effects estimate of the hypothesized model (non-standardized coefficients)

	Effect value	SE	95% CI	%
Total effect	-0.118	0.011	-0.140 ~ -0.096	-
Direct effect	-0.049	0.011	-0.072 ~ -0.027	-
Total indirect effect	-0.069	0.009	-0.086 ~ -0.052	58.47%
Ind1	-0.041	0.007	-0.056 ~ -0.028	34.47%
Ind2	-0.018	0.004	-0.026 ~ -0.011	15.25%
Ind3	-0.009	0.002	-0.015 ~ -0.005	7.63%

Ind1 Physical exercise → Perceived social support → Loneliness
 Ind2 Physical exercise → Resilience → Loneliness
 Ind3 Physical exercise → Perceived social support → Resilience → Loneliness

which in turn was significantly negatively associated with loneliness ($B = -0.11$, $p < 0.001$), supporting H2. Finally, perceived social support was significantly positively associated with resilience ($B = 0.29$, $p < 0.001$), forming a serial mediation pathway that supported H3. The detailed path model was shown in Fig. 2.

Bootstrap test uses the range of confidence intervals to evaluate whether the mediating effect is significant. The bootstrap test results (Table 7) showed that perceived

social support and resilience partially mediated the relationship between physical exercise and loneliness, with a total indirect effect of -0.069, accounting for 58.47% of the total effect. Specifically, the mediating effect was composed of indirect effects generated by three pathways: (1) physical exercise → perceived social support → loneliness (effect = -0.041, 95% CI: -0.056 to -0.028), accounting for 34.47% of the total effect; (2) physical exercise → resilience → loneliness (effect = -0.018, 95% CI: -0.026 to -0.011), accounting for 15.25% of the total effect; and (3) physical exercise → perceived social support → resilience → loneliness (effect = -0.009, 95% CI: -0.015 to -0.005), accounting for 7.63% of the total effect.

Discussion

Physical exercise and loneliness

This study revealed a direct negative relationship between physical exercise and loneliness in older adults. This finding corroborates previous studies [26]. Interviews with the research subjects revealed that older adults who participate frequently in physical exercise perform well in terms of mental outlook, language expression,

interpersonal communication, and enthusiasm for life and are less susceptible to negative emotions.

After retirement, older adults often face problems such as narrower social networks, poor communication channels, and weakened physical functions, which are important causes of negative emotions such as loneliness, depression, and anxiety. Physical exercise provides some resources for older adults to combat loneliness. Physiologically, exercise can enhance the flexibility of bones, muscles, and joints; enhance the functional levels of the cardiovascular, respiratory, neurological, and motor systems; contribute to the development of resistance; and enable older adults to maintain good physical function and participate in social activities, thereby alleviating the loneliness caused by social isolation [18, 27]. Psychologically, physical exercise is an effective method to regulate emotions. Older adults can relieve their loneliness and boredom and increase their confidence and optimism through physical exercise [28]. Additionally, physical exercise can provide opportunities and space for social interaction and can improve interpersonal relationships. These positive experiences and social interactions can help to alleviate the emotional and social loneliness of older adults.

The mediating role of perceived social support

This study found that perceived social support mediated the relationship between physical exercise and loneliness, supporting H1. Previous studies have shown that social support can reduce an individual's experience of loneliness [29], and that the amount of physical exercise is positively correlated with perceived social support scores. Physical exercise can influence social support networks among older adults in the following ways: (1) physical exercise can improve and reconstruct weak connections in older adults' social networks [30]; (2) physical exercise can increase the density of social network relationships, network interaction frequency, emotional intimacy, trust, and reciprocity among older adults [31]; and (3) physical exercise can improve older adults' social support [32]. The stronger a social support network is, the more social resources an individual can obtain.

Previous studies generally suggest that loneliness is caused mainly by individuals' lack of social network engagement [33]. The results of this study imply that physical exercise builds a bridge for older adults to communicate with others. Through physical exercise, older adults can obtain social and emotional resources that meet their need for social communication and reduce their experience of loneliness. In addition, previous immunological studies [34] have suggested that high levels of social engagement and living with others are associated with low levels of C-reactive protein (CRP), fibrinogen and white blood cell (WBC), whereas low

levels of loneliness are associated with high levels of insulin like growth factor-1 (IGF-1), which has anti-inflammatory properties. Physical exercise has been shown to be a key driver of chronic inflammation. Even among the oldest older adults, physical exercise may improve physiological mechanisms, such as mitochondrial dysfunction, cardiovascular disease, myokine release, autophagy, oxidative damage and insulin-like growth factor signalling, thereby improving physical and psychological levels to reduce the burden of noncommunicable diseases and premature overall mortality [35, 36].

Notably, physical exercise has a greater effect on loneliness through perceived social support than through other pathways. The author of this article believes that this is related to older adults' participation in group sports activities. Walking is the most popular sport among older adults in China, and they usually participate in this sport with their family or friends. The second most popular sport is group dancing, which is a low-barrier group activity. By participating in collective dance sessions, older adults not only enjoy a sense of unity and enthusiasm but also establish valuable social connections. The third most popular sport is Tai Chi. As a traditional Chinese sport, Tai Chi not only builds strength and flexibility but also fosters mental well-being. Studies have verified that Tai Chi can help individuals unwind and relieve negative emotions stemming from stress and maladaptation [37]. Furthermore, Tai Chi often involves a teacher–student relationship and provides a platform for people to bond over a shared interest, enhancing social connections. In summary, older adults who participate in physical exercise with others or groups for a long period of time receive higher levels of social support than those who do not. This finding is understandable because China is a country with a collectivist culture, and group sports may provide an ideal social environment for collective-oriented individuals to satisfy their desire for collectives [38]. Thus, participating in group sports may increase the frequency of communication among older adults, which is highly valuable for alleviating the loneliness caused by social insufficiency.

The mediating role of resilience

In support of H2, we found that resilience mediates the relationship between physical exercise and loneliness. According to the resilience framework proposed by Kumpfer, resilience stems from a combination of internal factors and processes. The internal factors include (1) spiritual or motivational characteristics; (2) cognitive competencies; (3) behavioural/social competencies; (4) emotional stability and emotional management; and (5) physical wellbeing and physical competencies. Previous studies have shown that physical exercise can modulate attention orientation, improve cognitive function,

enhance emotional regulation and promote physical health, which are closely related to the formation of resilience internal factors in older adults [39–42]. In addition, Kumpfer noted that family, cultural, community, school and peer resources are protective factors for resilience, and these protective factors are often found in older adults' physical exercise environment. For example, in China, communities are the main place for physical exercise among older adults [43], and adults usually participate in group forms of physical exercise. Their companions usually include family members, neighbours, or co-enthusiasts. These similar environmental factors suggest the potential role of physical exercise in the development of resilience in older adults.

Research has shown that resilience plays a protective role in negative mood and cognitive dissonance regardless of the level of adversity [44]. Loneliness is also a subjective negative experience or irrational cognitive outcome. As a positive personality trait and psychological ability, resilience can help older adults maintain a healthy mental state under environmental stress and setbacks, cope with various changes in life and enhance their perseverance and self-control [45]. These positive qualities are helpful in alleviating loneliness in older adults. Both the present study and existing findings support this view [46]. In other words, older adults who improve their resilience through physical exercise exhibit enhanced self-control, perseverance and positive attitudes when facing adversity, all of which are beneficial for alleviating the negative effects of loneliness. According to the resilience framework, the ideal environment is an essential condition to promote the development of resilience. Thus, when organising and conducting physical exercise interventions for older adults, we should focus not only on the intensity and type of physical exercise but also on older adults' connections with their families, friends and communities to develop resilience from an ecological perspective.

The serial mediating role of perceived social support and resilience

The key finding of this study is that the association between physical exercise and loneliness is partially mediated by perceived social support and resilience through a sequential pathway, supporting H3. This result supports existing research and demonstrate the value of physical exercise for improving loneliness among older adults [47, 48]. On the one hand, there is a positive correlation between physical exercise and perceived social support, and high levels of social support can alleviate loneliness in older adults [49]. These findings suggest that physical exercise is an important means for older adults to participate in social interactions and prevent social loneliness. However, physical exercise and resilience are

positively correlated, and resilience is valuable for reducing negative states [50]. This may be due to some resilience traits of individual internal factors. In summary, we believe that the effect of physical exercise on loneliness in older adults involves a combination of external factors (social support) and internal factors (resilience). These factors are linked. A similar chain-mediated effect has been found in which social support can indirectly alleviate some negative emotions through resilience [51, 52]. The results of the present study partially support this view.

After individuals enter the elderly stage, they gradually detach from labour production, the social circles they have established in the past gradually decrease, and family and community become their main activity spaces. Physical exercise has become an important means of maintaining connections between older adults and society. It encourages older adults to move from solitude to public spaces such as parks, squares and activity centres. This movement provides opportunities for older adults to engage in increased interpersonal communication and interaction with their families during physical exercise or to meet like-minded fitness partners. Older adults can release interpersonal and emotional stress while engaging in physical exercise and social support, thereby alleviating loneliness. Improving mental health is a long-term process. We encourage older adults to persist in participating in physical exercise and social interactions, which will allow them to continuously benefit from physical exercise.

Limitations and future study

(1) This study cannot infer the situation of disabled older adults in this model. (2) This study is cross-sectional in nature, and it cannot infer causal relationships between variables. In the future, a tracking design could be used to validate the viewpoints of this study. (3) The respondents are concentrated in Zhejiang, China, and the research conclusions may have regional spatial deviation. Future studies could further expand the scope of the sample to improve the study conclusions. (4) Perceived social support and resilience contain multiple secondary variables, but this study cannot predict the precise effect of their dimensions on loneliness objectively. (5) This study does not consider the influence of internal sample differences on the research results. In future research, samples could be further distinguished, such as considering gender, family structure, urban–rural differences, and even educational or cultural background. (6) After the epidemic, the living habits and health cognition of older adults may change, and the potential influence on the results cannot be estimated in this study.

Conclusions

(1) In this study, physical exercise and loneliness in older adults were negatively correlated. Perceived social support and resilience play mediating roles in the relationship between physical exercise and loneliness. (2) This study suggests that participation in group events or team sports is valuable for alleviating loneliness caused by a lack of social interaction.

Abbreviations

SEM	Structural Equation Modeling
PARS-3	Physical Activity Rating Scale
ULS-8	University of California Los Angeles Loneliness Scale-8
PSSS	Perceived Social Support Scale
MSPSS	Multidimensional Scale of Perceived Social Support
CD-RISC	Connor-Davidson Resilience Scale

Acknowledgements

We express our great gratitude to all the authors of the scales and all the participants in the present study.

Author contributions

Conceived and designed the research: SG. Wrote the paper: SG & XZ. Analyzed the data: XZ. Revised the paper: SG & YP. 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 generated and/or analyzed during the present study are not publicly available to preserve the anonymity of the participants but are available from the corresponding author at 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 (ZSRTZSRT2024098). 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: 2 April 2024 / Accepted: 25 September 2024

Published online: 05 October 2024

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