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Impact of physical activity on the depression and self-care ability among Chinese older adults during the COVID-19 pandemic: propensity score matching analysis

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Abstract

Introduction The present study aimed to explore the effect of different levels of physical activity on depression, instrumental activities of daily living (IADLs), and activities of daily living (ADLs) among older adults over the age of 60.

Methods Data on older adults' health were obtained from the China Longitudinal Aging Social Survey (CLASS) conducted in 2021. A questionnaire was used to survey older adults aged 60 years and older in 28 regions of China. The International Physical Activity Questionnaire (IPAQ) was used to evaluate physical activity, and participants were categorized into groups based on their physical activity levels: vigorous (5.38%), moderate (16.33%), light (74.58%), and no physical activity (control group). The CES-D9 scale was used to assess the level of depression, and both the activities of daily living (ADLs) scale and the instrumental activities of daily living (IADLs) scale were used to evaluate self-care ability. Propensity score matching was used to determine the intensity of physical activity that affected depression, instrumental daily activity ability (IADLs), and activities of daily living (ADLs) among the participants.

Results The participation rates of vigorous, moderate, and light physical activities among the older adult Chinese participants were 5.38%, 16.33%, and 74.58%, respectively. Propensity score matching (PSM) showed moderate and light physical activity decreased depression by -0.367 and −0.409 units, respectively. Moderate and light physical activity increased instrumental activities of daily living (IADLs) by 0.165 and 0.607 units, respectively. Light physical activity increased the level of activities of daily living (ADLs) by 0.265 units.

Conclusion Moderate and light physical activity in older adults alleviates depression and improves instrumental activities of daily living (IADLs), and light physical activity improves the level of activities of daily living (ADLs).

Keywords Older adults, Chinese participants, Physical activity, Mental health, Self-care ability, Propensity matching score

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Background

The onset of the COVID-19 pandemic has brought unprecedented challenges, particularly affecting older adults. The report titled "World Population Prospects: The 2019 Revision" indicates that by 2050, 1 in 6 people globally will be aged 65 years or older (16%) [1]. China's older adult population is projected to increase to 30 – 40% by 2050, making it one of the countries with the highest number of older adults and one of the fastest-aging populations in the world. In response, governments have been exploring the concept of "healthy and active aging" to address population aging. The World Health Organization has proposed successful aging based on healthy and active aging principles. Prior research suggests that physical activity (PA) promotes successful aging in older adults, effectively reducing the risk of chronic diseases [2] and risk of functional loss [3], improving self-rated health [4] and enhancing cognition [5]. PA is also known to have significant antidepressant effects [6], which delay dementia [7], prevent cognitive deterioration [8], and positively ameliorate depressive symptoms (DS) in older adults [3]. DS and cognition are essential factors affecting the ability to perform daily activities in older adult participants [9]. Increases in instrumental activities of daily living (IADLs) and activities of daily living (ADLs) serve as key indicators of the functional ability of older adults [10]. Improvements in instrumental activities of daily living (IADLs) and activities of daily living (ADLs) reflect better functional health status. Physical activity (PA) itself is linked to reduced disability risk and improved functional capacity in older adults. Moreover, LPA can alleviate DS and promote mental health in older adults [11]. Several studies report that LPA can effectively improve the ability to perform ADLs, enhance cognition, and reduce DS in older adults [12, 13]. Prior findings indicate that LPA at different intensities modulates physical health in older adults [14]. Parra-Rizo, M.A. et al. [15] and Stevens et al. [16] report that moderate and light physical activity (LPA) plays a protective role in physical and mental health in older adults. However, the positive effects of vigorous physical activity (VPA) were not supported by valid evidence [17].

With over 40 million disabled and semi-disabled older people [18], the health of older adults in China has garnered scholarly attention. Findings showed that 2.34% of Chinese older adults over 60 have impaired self-care [19]. Zhang Ziwei [20] reported that the detection rate of depressive symptoms among older adults Chinese over 60 is 45.9%. Recent studies found that improving self-care ability significantly alleviates DS [21]. Moreover, recent reports suggest that enhancing PA participation among Chinese older adults is crucial in improving self-care ability and reducing DS [22–24].

The COVID-19 pandemic has significantly impacted the lifestyle and health behaviors of older adults, presenting unique challenges and necessitating adaptations in care strategies. Studies have observed a drastic reduction in social, recreational, and professional activities among older individuals due to the fear of COVID-19 infection, leading to increased feelings of loneliness, social isolation, and depression [25]. This social isolation and disruption in routine activities have been linked to a deterioration in mental and physical health among older adults [26]. Additionally, the pandemic has highlighted the importance of addressing mental health concerns, particularly among vulnerable groups like older adults, due to increased risks such as depressive symptoms and suicide [27, 28].

Given the negative consequences of social isolation and reduced physical activity during the pandemic, low levels of physical activity and increased sedentary behavior have been associated with declines in mental health and functional capacity among older adults. Functional capacity refers to an individual's physical and cognitive abilities to perform tasks necessary for daily life, including both activities of daily living (ADLs) and instrumental activities of daily living (IADLs) [24, 25]. Reduced functional capacity can lead to difficulties in performing basic self-care tasks and more complex activities required for independent living, ultimately affecting the quality of life [26, 27]. Studies have shown that decreased physical activity contributes to worsening depressive symptoms and diminished functional capacity, highlighting the importance of maintaining an active lifestyle for mental health and daily functioning in older adults [28, 29].

Although the relationship between PA and DS and self-care ability in older adults has been extensively explored, there is a dearth of studies evaluating this relationship among older adult Chinese participants, particularly during the COVID-19 pandemic. Moreover, the effects of different intensities of PA on DS and self-care ability has not been fully elucidated [30]. Therefore, this study aims to fill this gap by using propensity score matching (PSM) analysis to evaluate how different intensities of physical activity are associated with depressive symptoms and self-care ability among Chinese older adults. PSM is a robust statistical method that allows for precise comparison of outcomes between matched groups, with such comparisons termed 'treatment effects' in statistical literature [31, 32]. The hypothesis for the study is that PA in older adults positively affects DS and self-care ability.

Methods

Study design and sample selection

This study employed a cross-sectional design using data from the China Longitudinal Aging Social Survey (CLASS) conducted in 2021. The CLASS survey is

designed to collect social, economic, family, and health information from Chinese older adults aged 60 years and above. It aims to explore the challenges older adults face in the aging period and to evaluate their personal growth history, family history, occupational history, health, and physical activity. The survey meets the requirements of multiple cohort studies from a life course perspective. It employs a longitudinal design that follows participants over time, collecting data regularly to observe changes and developments in their health status. This approach allows for the examination of the long-term effects of physical activity on depression and self-care ability among older adults [33, 34]. We utilized propensity score matching (PSM) to analyze the effects of different intensities of physical activity on these outcomes, which helped to reduce potential selection bias and confounding factors inherent in observational studies. In this study, three methods were used for sample matching, including nearest neighbor matching with caliper, radius matching, and kernel matching, to ensure the robustness of the estimation results. The estimation was considered robust when the results obtained from different matching methods were consistent. The data were retrieved in January 2022, with an initial sample size of 11,398 participants. After data cleaning, which involved the elimination of participants with incomplete or irrelevant data, a total of 8,483 valid samples were used for the analysis. The stratified multi-stage probability sampling method selected county-level areas as the primary sampling units (PSUs) and villages/residential councils as the secondary sampling units (SSUs). The final sample included participants from 476 villages/residential committees in 30 provinces/autonomous regions or directly administered cities in China.

Study participants

The participants recruited in the study were Chinese citizens aged 60 and above (without an upper age limit) living in the study area. The interviewers read the the questionnaire items and recorded responses from the participants. The survey comprised 476 villages/residents' committees in 30 provinces/autonomous regions or directly administered cities. The Capital University of Physical Education and Sport Ethics Committee approved the study protocol (approval number: ChiCTR-IOR-ChiCTR2200063177).

Table 1 summarizes the descriptive statistics of the study's dependent, independent, and control variables. The dependent variables (DV) include the depression score (DS), instrumental activities of daily living (IADLs), and activities of daily living (ADLs). These are presented as continuous variables, with mean ± standard deviation reported. Independent variables, such as physical activity levels—vigorous (VPA), moderate (MPA), and light (LPA)—are presented as categorical variables using percentages. Control variables (CV), such as gender, marital status, and education level, are also categorical. Continuous control variables include family numbers (FN, representing the count of family members), sedentary time per week (SEDT, in minutes), daily sleep time (SLPT, in minutes), and age (in years), and these are reported using mean ± standard deviation. Satisfaction variables, including self-rated life satisfaction (SWL), self-rated health (SRH), and peers' relative health (PRH), are presented

Table 1 Descriptive statistics Covar association and attributes

VN		VS	PF		VN	VS	PF
DV	DS	Continuous	15.84 ± 3.02	**MV**	FN	Continuous	1.77 ± 1.26
	IADLs		22.17 ± 2.01		SLPT		462.31 ± 79.76
	ADLs		17.77 ± 1.04		SEDT		1390.69 ± 714.73
IV	VPA	0 = No	94.62%		SWL	1 = Very dissatisfied	1.43%
		1 = Yes	5.38%			2 = Not satisfied	5.72%
	MPA	0 = No	83.67%			3 = Commonly	24.57%
		1 = Yes	16.33%			4 = Satisfied	50.84%
	LPA	0 = No	25.42%			5 = Verysatisfied	17.44%
		1 = Yes	74.58%		SRH	1 = very unhealthy	2.34%
CV	Gender	1 = Man	50.08%			2 = Relatively Unhealthy	12.37%
		2 = Woman	49.92%			3 = Commonly	35.68%
	Age	Continuous	72.11 ± 6.22			4 = Relatively Healthy	41.29%
	Marital Status	1 = Married	76.15%			5 = very healthy	8.33%
		2 = Unmarried	23.85%		PRH	1 = Much worse	1.91%
	Education level	1 = Elementary	62.81%			2 = Worse	11.99%
		2 = Middle school	25.25%			3 = Commonly	54.74%
		3 = High school	9.31%			4 = be nicer	26.56%
		4 = University	2.63%			5 = Much Better	4.79%

Note: The headings in the table Variable name, Variable classification, Presentation Format, Dependent variable, Independent Variable, Controlled Variable, and Match variables correspond to the abbreviations VN, VS, PF, DV, IV, CV, MV

as categorical distributions, with responses distributed across levels of satisfaction. Continuous control variables, such as FN, SEDT, and SLPT, are also used as match variables (MV) in the propensity score matching analysis.

Physical activity

For the propensity score matching (PSM) analysis, participants were divided into treatment and control groups based on their physical activity levels as assessed by the International Physical Activity Questionnaire Short Form (IPAQ-SF). The treatment group included participants who engaged in one of three intensity levels of physical activity, namely vigorous, moderate, and light, according to the International Physical Activity Questionnaire Short Form (IPAQ-SF). Vigorous physical activity was defined as activities that cause a significant increase in breathing or heart rate, such as running or heavy lifting. Moderate physical activity included activities that cause a moderate increase in breathing or heart rate, like brisk walking or gardening. Light physical activity refers to activities that cause a slight increase in breathing, such as casual walking or light household chores. The control group comprised participants reporting no engagement in any physical activity during the same period. To ensure comparability between groups, participants were matched based on demographic characteristics (age, gender, marital status, education level) and baseline health indicators (sedentary time and sleep duration). The IPAQ-SF, whose reliability and validity have been demonstrated in the Chinese population [35–37], has shown high reliability with intraclass correlation coefficients (ICC) for test-retest reliability ranging from 0.812 to 0.999 and validity correlations between 0.608 and 1.000 for vigorous activity and 0.916 for walking activities [38, 39]. This tool was used to evaluate the physical activity (PA) of older adult participants over the past seven days. Out of the 8,483 valid samples, 456 participants (5.38%) engaged in vigorous physical activity (VPA), 1,385 participants (16.33%) engaged in moderate physical activity (MPA), and 6,327 participants (74.58%) engaged in light physical activity (LPA). These proportions demonstrate appropriate sample sizes across physical activity intensity levels for conducting PSM analysis, which enables systematic comparison of outcomes between matched groups.

Depression score

DS was determined using the DS Scale (CES-D9) to evaluate the DS levels of participants [40–42]. The scale has three items that represent positive mood (in a good mood, having a good time, and having lots of fun), two items that indicate negative mood (lonely and sad), two items that indicate emotional marginalization (not being useful anymore and having nothing to do), and two items that represent somatic symptoms (not wanting to eat and not sleeping well). Participants who reported any of the DS items in the past week were required to indicate the frequency of the mood on a scale of 0 (none), 1 (sometimes), or 2 (often). The total score indicated the level of DS, with DS ranging from 0 to 18, whereby higher scores indicated higher DS levels. Previous studies have demonstrated good psychometric properties of the CES-D9 scale among Chinese older adult populations, with internal consistency reliability (Cronbach's α) ranging from 0.729 to 0.88 [39, 43–46]. Additionally, the scale exhibits a sensitivity of 0.85 and a specificity of 0.83 [46, 47]. In this study, the Cronbach's α coefficient of the scale was 0.853, indicating good internal consistency.

Self-care ability of daily living

In this study, Activities of Daily Living (ADLs) and Instrumental Activities of Daily Living (IADLs) scales were utilized to evaluate self-care ability, which indicates older adults' physical health and function [33].

Activities of Daily Living (ADLs) are basic self-care tasks necessary for fundamental functioning, reflecting the essential self-care ability of older adults. The ADLs scale comprises six items, including eating, dressing, transferring, toileting, bathing, and managing incontinence [48, 49]. Each item is rated on a three-point ordinal scale: "do not need others' help" (score 1), "need some help" (score 2), and "cannot do anything at all" (score 3). The total ADL score is calculated by summing the item scores, with higher scores indicating greater dependency.

Instrumental Activities of Daily Living (IADLs) assess the ability of older adults to live independently within the community, involving more complex activities than ADLs. The IADLs scale comprises nine items, using the telephone, shopping, cooking, managing finances, taking public transportation, doing housework, lifting weights, walking up and down stairs, and preventing falls [49, 50]. Each item is rated on a three-point ordinal scale: "no help required" (score 1), "some help required" (score 2), and "not able at all" (score 3). The total IADL score is calculated by summing the item scores, with higher scores indicating greater dependency.

Both the ADL and IADL scales have been validated and shown to be reliable for use among Chinese older adult populations [51, 52]. In this study, the Cronbach's α coefficient for the ADL scale was 0.892, and for the IADL scale was 0.891, indicating high internal consistency.

Control variables and matching variables

In the present study, four demographic variables, namely gender, age, marriage status, and education level, were selected as control variables. Average daily sedentary time, average daily sleep time, self-rated life satisfaction, self-rated health satisfaction, and peers' comparative

health satisfaction were used as matching variables in the propensity score matching (Fig. 1).

Statistical analyses

Six items in ADL scores and nine items in IADL scores are categorical variables. However, ADLs and IADLs total scores were treated as approximate continuous variables for statistical analysis, which is a common practice in similar studies [36]. The three categories of PA at different intensities and DS, ADLs, and IADLs were subjected to t-tests to evaluate the differences between the treatment and control groups. The logit model was used to determine the probability of occurrence of participation in different PA among older adults. PSM was used to calculate the average treatment effect on the treated. The endogeneity problem resulting from the individual selectivity bias of older adult participants was eliminated to ensure the robustness of the model results using a propensity value matching analysis model (PSM), which classified the sample into treatment and control groups.

PSM is based on the principle of transforming a multivariate variable X into a one-dimensional propensity score through a functional relationship (Propensity score) $ps\left(\mathrm{X}_i\right)$. Matching is then performed based on the propensity score. The propensity score is an observable characteristic for $\mathrm{X}_i = x$ probability of an individual receiving a disposition.

$$\begin{aligned} &\boldsymbol{E}\left(\mathbf{X}_{\boldsymbol{i}} | \mathbf{D}_{\boldsymbol{i}}=1, \boldsymbol{ps}\left(\mathbf{X}_{\boldsymbol{i}}\right)\right) \\ &=\boldsymbol{E}\left(\mathbf{X}_{\boldsymbol{i}} | \mathbf{D}_{\boldsymbol{i}}=0, \boldsymbol{ps}\left(\mathbf{X}_{\boldsymbol{i}}\right)\right) \end{aligned} \tag{1}$$

The same propensity scores for individuals in the control group $\mathrm{D}_i = 0$ and the treatment group $\mathrm{D}_i = 1$ implies that the mean values of the observable features of individuals in the two groups are equal. Calculating the Average Treatment Effect on the Treated (ATT) based on PSM given mostly observable features x reduces to calculating the treatment effect given the one-dimensional propensity score $ps(x)$. The ATT measures the average effect of the treatment among those who received it, compared to matched controls who did not receive the treatment.

$$\begin{aligned} &\boldsymbol{ATT} \\ &=\boldsymbol{E}\left(\boldsymbol{Y}_{\boldsymbol{i}}(1) | \boldsymbol{D}_{\boldsymbol{i}}=1, \boldsymbol{ps}\left(\boldsymbol{X}_{\boldsymbol{i}}=\boldsymbol{x}\right)\right) \\ &-\boldsymbol{E}\left(\boldsymbol{Y}_{\boldsymbol{i}}(0) | \boldsymbol{D}_{\boldsymbol{i}}=0, \boldsymbol{ps}\left(\boldsymbol{X}_{\boldsymbol{i}}=\boldsymbol{x}\right)\right) \end{aligned} \tag{2}$$

In the formula: $\mathrm{Y}_i(1)$and $Y_i(0)$ are dependent variables representing DS, IADLs, and ADLs in the two groups of participation and non-participation in different PA among the older adult participants, respectively. D_i represents the critical independent variable indicating participation or non-participation in PA, $\mathrm{D}_i = 1$ was used for participation and $\mathrm{D}_i = 0$ for non-participation. X_i represents a set of characteristic variables determined by whether the participants participate in PA or not; $\mathrm{Y}_i(1)$

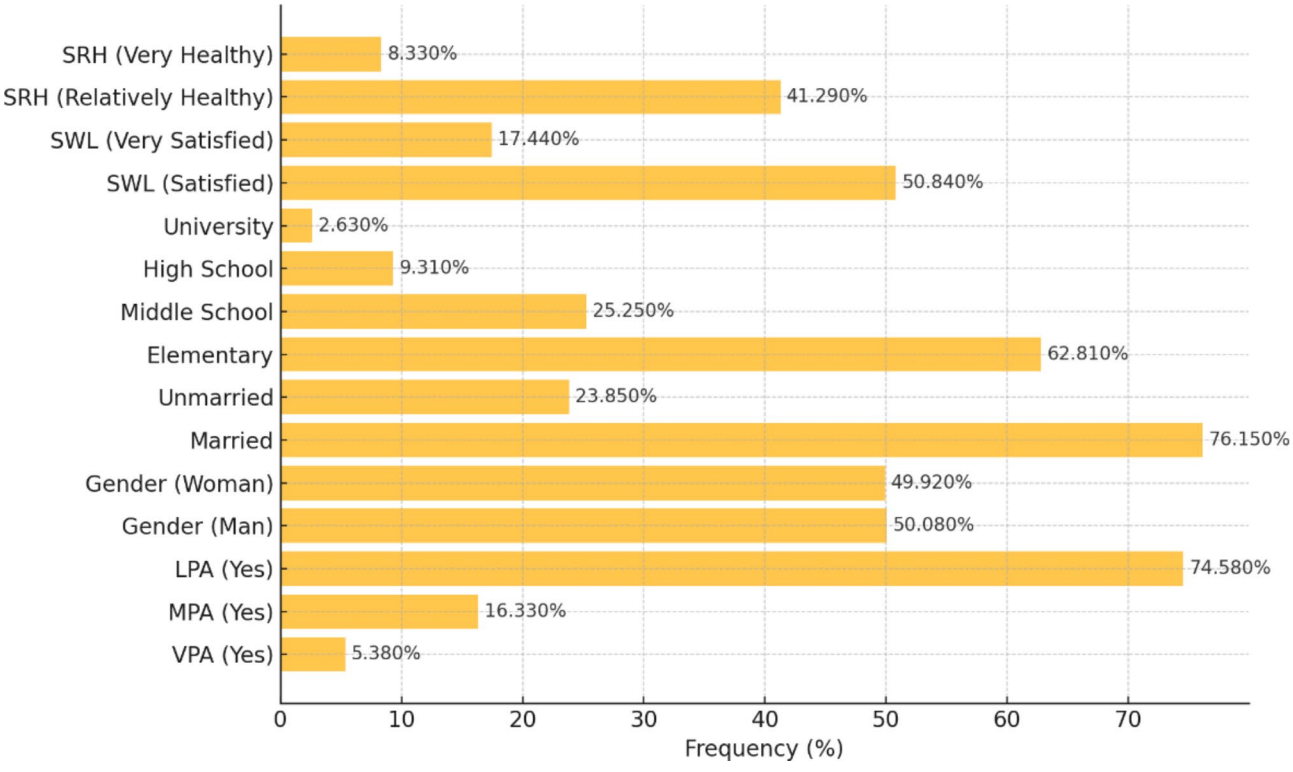

Fig. 1 Frequency distribution of study variables

Table 2 Effect of different intensities of physical activity on DS, IADLs, ADLs

		VPA	MPA	LPA
DS	DSG1	8027	7098	2156
	DSG2	456	1385	6327
	T-Value	5.550	9.650	4.800
IADLS	DSG1	8027	7098	2156
	DSG2	456	1385	6327
	T-Value	-4.900	-8.550	-7.200
ADLS	DSG1	8027	7098	2156
	DSG2	456	1385	6327
	T-value	-4.800	-3.600	-4.650

Note: DSG: different sample groups, DSG1 is the group without PA, DSG2 is the group with PA. T-value is the value of a t-test

and $Y_i(0)$ represent the three dependent variables of older adult participants in the treatment and control groups, respectively.

PA at different intensities was evaluated for DS, IADLs, and ADLs. The probability of PA participation among older adults was predicted using logit models, and the treatment groups were matched using PSM to estimate the average treatment effect (ATT).

In this study, three methods were used for sample matching, including nearest neighbor matching with the caliper, radius matching, and kernel matching, to ensure the robustness of the estimation results. The estimation was considered robust if the results from the methods were similar. The principle $\varepsilon \leq 0.25 \leq \hat{o}$_pscore was used for the propensity score matching (PSM). The caliper range for both nearest neighbor matching and radius matching was set to 0.001. The psmatch2 package in Stata16 was used to conduct the statistical analysis.

Equilibrium analysis

The balancing hypothesis was tested to verify the quality of matching and the reliability of the estimation results. This involved testing matching variables for balance to determine if there was a significant reduction in individual differences after matching. The standardized deviation was used as the primary indicator for balance determination, with successful matching indicated by standardized deviations controlled within 5% and no significant differences between groups after matching.

Results

Physical activity and successful aging status of older adults

The DS, IADLs, and ADLs were compared for participants under the three different PAs. The results showed that 5.38% of the participants were involved in VPA, 16.33% participated in MPA, and 74.58% participated in LPA. A t-test analysis was also conducted to explore the differences in DS, IADLs, and ADLs between the three groups. The findings indicated significant differences in DS, IADLs, and ADLs between the subgroups based on the intensity of PA (Table 2). Among the 8,483 participants, 456 engaged in VPA, 1,385 engaged in MPA, and 6,327 engaged in LPA, while 315 participants did not engage in any physical activity. The sample sizes across different PA intensity levels were sufficient to perform the propensity score matching analysis effectively.

Table 3 Logit model estimation of the factors affecting participation in different PA intensities

	VPA	MPA	LPA
Gender	−0.057(0.1)	0.026(0.064)	0.104*(0.053)
Age	−0.029*** (0.009)	−0.092*** (0.006)	−0.037*** (0.004)
Marital Status	−0.218(0.142)	−0.187**(0.088)	−0.189***(0.063)
Education level	0.563***(0.049)	0.751***(0.036)	0.588***(0.044)
SLPT	−0.002**(0.001)	−0.001*(0)	0.002***(0)
SEDT	0***(0)	0***(0)	0***(0)
SWL	0.253***(0.07)	0.073*(0.041)	0.278***(0.033)
SRH	0.159*(0.084)	−0.03(0.05)	−0.199***(0.042)
PRH	−0.002(0.085)	0.049(0.055)	−0.279***(0.046)
FN	0.019(0.041)	0.228***(0.024)	0.005(0.21)
cons	-1.82**(0.816)	2.703(0.544)	2.471***(0.394)
Observations	8483	8483	8483
Pseudo R2	0.068	0.068	0.067

Note: *$P<0.05$, ** $P<0.01$, *** $P<0.001$. Robust standard errors in parentheses. SLPT: Average daily sleeping time, SWL: Self-assessment of wellbeing satisfaction, SEDT: Average daily sedentary time, SRH: Self-assessed health satisfaction, PRH: Health satisfaction compared with peers, FN: Number of family members

Propensity score matching analysis

A logit model was used to calculate the propensity scores for participants involved in PA under different intensities. The results showed that age, education level, average daily sleep time, average daily sedentary time, and self-rated life satisfaction had significant effects on whether to participate in different PA. Age, education level, average daily sleep hours, and self-rated health satisfaction showed statistically significant effects on participation in vigorous PA. The factors that affected participation in moderate PA included age, marital status, education level, average daily sedentary time, Self-assessment of wellbeing satisfaction, and family size. Age, education level, average daily sleep time, average daily sedentary time, self-rated life satisfaction, supervisor self-rated health satisfaction, and peer comparative health satisfaction significantly affected participation in LPA. (Table 3; Fig. 2)

Y observations from the chart include: Education Level shows a positive coefficient across all activity intensities, with the strongest influence on MPA, suggesting that higher education levels are associated with increased participation in moderate to vigorous physical activities.

Marital Status and Age have negative coefficients in all categories, indicating that being older or married might be associated with lower participation rates in physical activities across all intensities.

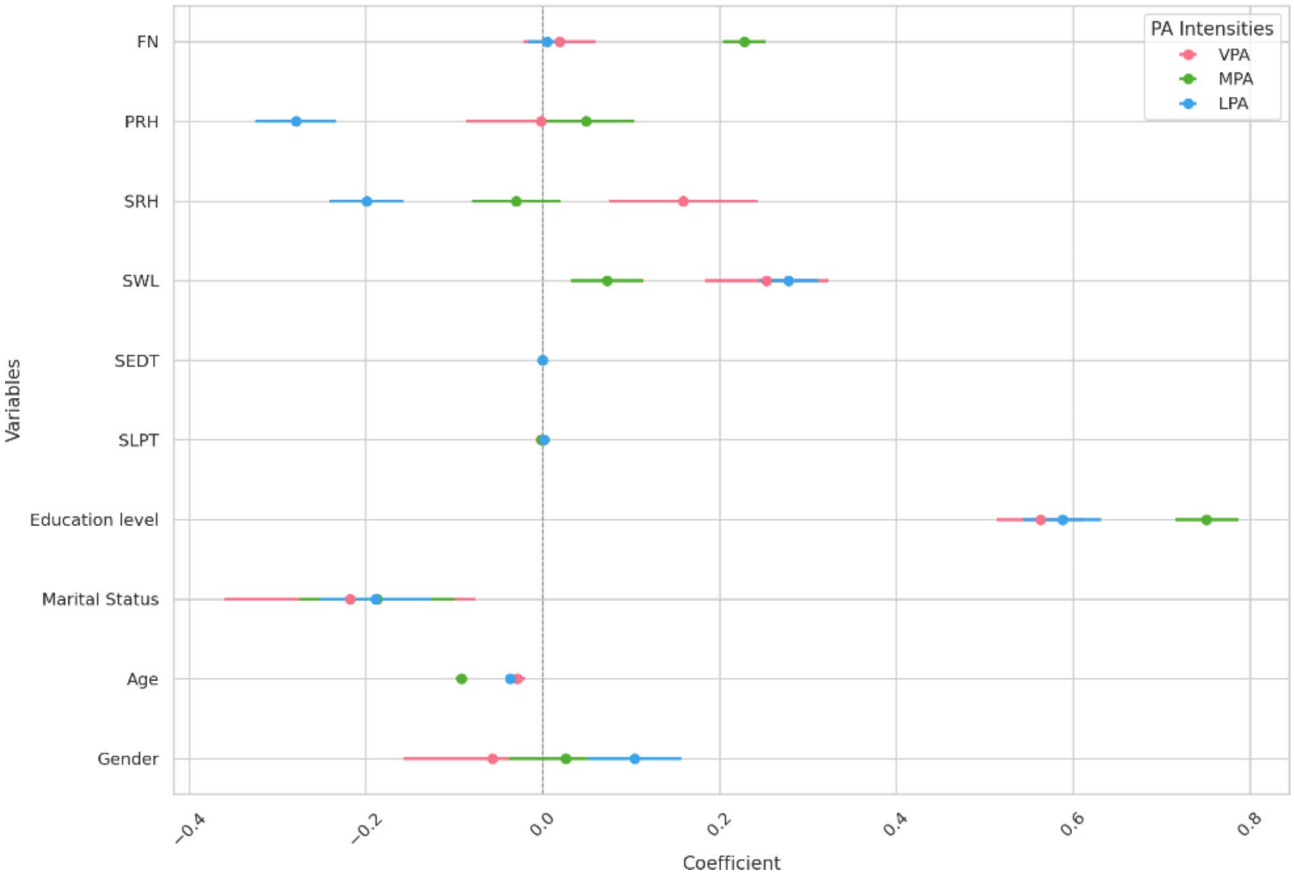

Fig. 2 Logit model estimation of the factors affecting participation in different PA intensities

Self-Rated Health (SRH) and Perceived Relative Health (PRH) exhibit mixed effects. SRH has a positive effect on VPA and LPA participation but a negative effect on MPA, whereas PRH negatively impacts LPA significantly, indicating that personal health perception influences activity levels differently.

Sleep Time (SLPT) and Sedentary Time (SEDT) show minimal to no effect on physical activity participation, suggesting that these factors might not be as influential as others.

The visualization, with its thicker lines for clarity, effectively highlights the varying degrees of influence that different demographic and personal health factors have on physical activity participation. This analysis can inform targeted interventions to promote physical activity across different population segments.

Equilibrium analysis results

The balance test results demonstrated that the standardized mean differences of most matching variables between the treated group and the control group were significantly reduced, with standardized mean differences controlled within 5% (Table 4). The t-test results indicated no significant differences between the two groups after matching, suggesting that the matching was reliable.

Analysis of matching results

The nearest neighbor matching method was reported because the results of the three matching methods (nearest neighbor matching, radius matching, and kernel matching) were similar (Table 5). PSM model analysis showed a significant difference between the VPA treatment group and the control group before matching (difference=-0.871, t=-5.54). The VPA treatment group and the control group did not exhibit a significant difference in average treatment effect on the treated (ATT) (difference=-0.295, t=-1.35) after matching. The MPA-treated and control groups exhibited significant pre-matching differences (difference=-0.914, t=-9.77). The MPA treatment group and the control group showed a significant difference after matching (difference=-0.367, t=-3.14). The LPA group exhibited a significant difference compared with the control group before matching (difference=-0.391, t=-4.79).

The results showed a significant difference in IADLs between the VPA treatment group and the control group

Table 4 Balance test results

		DS			IADLs			ADLs		
		VPA	MPA	LPA	VPA	MPA	LPA	VPA	MPA	LPA
Gender	U	-9.6	-4.1	1.2	-9.6	-4.1	1.2	-9.6	-4.1	-9.6
	M	-0.6	2.5	2.2	-0.4	-4.7	1.2	4.8	0.6	4.8
Age	U	-36.6	-64.0	-29.3	-36.6	-64.0	-29.3	-36.6	-64.0	-36.6
	M	-0.6	-5.2	-4.1	-3.8	-2.7	-3.8	-0.5	-4.0	-0.5
Marital status	U	-24.1	-27.6	-16.8	-24.1	-27.6	-16.8	-24.1	-27.6	-24.1
	M	-1.0	-0.1	0.8	-4.8	-4.7	2.6	-3.3	0.6	-3.3
Education level	U	61.0	75.1	44.3	61.0	75.1	44.3	61.0	75.1	60.0
	M	-1.8	-5.0	-2.5	-4.6	-4.2	-3.6	-4.0	-4.0	-4.0
SLPT	U	-9.3	1.2	16.5	-9.3	1.2	16.5	-9.3	1.2	-9.3
	M	-0.4	1.2	4.8	-2.0	2.0	4.9	-3.5	2.1	-3.5
SEDT	U	-26.0	22.5	19.3	-26.0	22.5	19.3	-26.0	22.5	-26.0
	M	-1.3	4.0	-6.2	1.0	1.6	-5.8	1.6	4.0	1.6
SWL	U	33.5	11.6	14.0	33.5	11.6	14.0	33.5	11.6	33.5
	M	0.2	1.2	1.5	4.2	10.6	0.9	5.9	0.1	5.9
SRH	U	31.8	11.0	-14.1	31.8	11.0	-14.1	31.8	11.0	31.8
	M	3.2	0.1	-2.6	4.5	1.4	-4.2	4.8	-0.3	4.8
PRH	U	26.1	11.9	-18.8	26.1	11.9	-18.8	26.1	11.9	26.1
	M	-0.4	-0.5	0.9	-2.3	2.4	-0.9	-0.6	-0.2	-0.6

Note: U:Umatched, M:Matched

before matching (difference = 0.471, t = 4.91). However, there was no significant difference in the average treatment effect (ATT) between the treatment group and the control group after matching (difference = 0.057, t = 0.76). Pre-matching results showed a significant difference in ATT between the MPA treatment group and the control group (difference = 0.498, t = 8.54). A significant difference in ATT was observed between the MPA treatment group and the control group after matching (difference = 0.165, t = 3.28). The results showed a significant difference in ATT between the LPA group and the control group before matching (difference = 0.357, t = 7.21) and after matching (difference = 0.607, t = 8.09).

A significant difference in was observed between the VPA treatment group and the control group before matching (difference = 0.308, t = 4.79). However, there was no significant difference in ATT between the VPA treatment group and the control group after matching (difference = 0.013, t = 0.30). The MPA treatment group and control group exhibited significant differences in ATT before matching (difference = 0.141, t = 3.58). However, there was no significant difference in ATT between the MPA treatment group and the control group after matching (difference=-0.003, t=-0.06). A significant difference in ATT was observed between the LPA treatment group and the control group before matching (difference = 0.155, t = 4.65) and after matching (difference = 0.265, t = 5.21).

Unmatched: Not matched; ATT: Average treatment effect on the treated; Control: Control group Treated: Treated group; Difference: Control-Treated.

Discussion

In the present study, we utilized PSM analysis to assess the impact of Physical Activity (PA) intensities on Depressive Symptoms (DS), Instrumental Activities of Daily Living (IADLs), and Activities of Daily Living (ADLs) among older adults. We found that light to moderate physical activity (LPA to MPA) can significantly improve mental health in this demographic. Interestingly, our analysis revealed that VPA did not significantly influence DS in older adults, aligning with the findings of Xie et al. [34].

Additionally, the COVID-19 pandemic has had a profound impact on older adults, exacerbating challenges in both mental and physical health. Studies have shown that the pandemic led to significant changes in health behaviors among older adults, with increased social isolation, reduced PA, and heightened anxiety and DS [25].

VPA reduces cerebral blood flow, thus affecting cognitive ability, as cognitive impairment is one of the major symptoms of DS [53]. LPA and MPA reduce the risk of DS in older adults [34]. Previous studies report that LPA and MPA release protective neurotrophic substances, which promote neuroplasticity and neurovascular development; these physiological effects may alleviate DS in older adults.

A previous study showed that PA improves the self-efficacy of older adults [54]. Findings show that PA plays an important role in reducing negative emotions and lowering the risk of DS in older adults [24]. A study on the relationship between PA intensity and emotional responses resulted in an inverted U-shaped curve [51], indicating

Table 5 Effects of different intensity of PA on the components of DS and self-care ability of Chinese older adults

		VPA			MPA			LPA		
		Treated	Control	Difference	Treated	Control	Difference	Treated	Control	Difference
DS	Unmatched	14.976	15.846	−0.871(0.157) ***	15.027	15.941	−0.914(0.094)***	15.701	16.090	−0.391(0.081)***
	ATT	14.976	15.271	−0.218 (0.157)	15.029	15.394	−0.367(0.117) **	15.709	16.118	−0.409(0.099)***
IADLS	Unmatched	22.667	22.196	0.471(0.096)***	22.638	22.139	0.498(0.059)***	22.312	21.959	0.357(0.050)***
	ATT	22.667	22.609	0.057(0.075)	22.635	22.471	0.165(0.051)***	22.312	21.706	0.607(0.075)***
ADLS	Unmatched	28.833	28.525	0.308(0.064)***	28.659	28.519	0.141(0.039)***	28.581	28.425	0.155(0.033)***
	ATT	28.833	28.821	0.013(0.044)	28.667	28.669	−0.003(0.044)	28.588	28.322	0.265(0.051)***

Note: *: $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. standard errors in parentheses

that higher intensity of PA may result in reduced pleasure [51, 52]. Furthermore, PA positively correlates with sleep quality, which in turn, improves psychological status [55]. From a sociological perspective, engaging in PA enhances personal social networks [56, 57], boosts overall well-being [58], and can alleviate DS in older adults. During the pandemic, the importance of PA for social interaction and meeting interpersonal needs has become even more pronounced, especially as it offers a platform for older adults to engage socially in a restricted environment. Additionally, PA fosters a positive and optimistic mindset, crucial for reducing DS [59].

However, the COVID-19 pandemic has significantly restricted these activities, leading to increased feelings of loneliness, social isolation, and consequently, a rise in mental health issues among older adults [26]. The reduction in PA due to pandemic-related restrictions has further compounded these issues, highlighting the critical need for tailored interventions to support older adults during such crises.

ADLs are crucial for the survival and independence of older adults, with physical activity (PA) playing a vital role. While several studies have been conducted to explore the effects of PA on ADLs [60], only a few studies have been conducted on IADLs [8, 61]. This implies that the types of PA that improve IADLs and ADLs have not been fully explored. Our results indicate that VPA does not affect IADLs among older adults, while LPA and MPA improve IADLs in this group.

Previous studies report that LPA enhances IADLs and ADLs [5, 62, 63]. LPA has a positive impact on IADLs and ADLs, which is consistent with previous findings that LPA in gymnastics activity delays the loss of instrumental activity skills [64]. Additionally, the COVID-19 pandemic has significantly influenced older adults' health behavior, underscoring the need for community-based physical activity interventions.

In the current study, the results showed that VPA did not affect instrumental activities of daily living (IADLs) and activities of daily living (ADLs), which is consistent with previous findings [63]. This indicates that VPA did not affect ADLs among older adults. Additionally, MPA does not affect the daily living activities of older adults, whereas LPA improves the ADLs of older adults. Excessive PA intensity may negatively affects the ability of older adults to live independently and potentially results in disability. However, the COVID-19 pandemic has significantly reduced physical activity levels among older adults, potentially exacerbating these challenges [5, 65]. Several studies report that MPA negatively affects ADLs in older Chinese adults, possibly owing to poor physical health, which includes chronic conditions such as cardiovascular disease, reduced mobility due to joint problems,

or age-related frailty that limits their ability to perform daily activities effectively [48, 66].

IADLs have a positive effect on cognitive deficits and DS in older adults [67, 68]. The present findings indicate that moderate and light physical activity (MPA and LPA) enhances IADLs. In addition, the results show that PA alleviates DS in older adults. The results show that PA improved DS, IADLs, and ADLs in older adults. A previous study reported that PA improves sleep quality, which is linked to DS and ADLs [21]. However, the COVID-19 pandemic has led to changes in health behaviors, including a marked decline in physical activity levels among older adults, potentially impacting their DS and cognitive functioning. Studies should be conducted to explore the mechanisms of the effects of different types of PA on DS, ADLs, and IADLs. It is important to note that our study was conducted during the COVID-19 pandemic, which may have influenced our results in several ways. The pandemic has led to significant changes in health behaviors among older adults, including reduced physical activity levels and increased social isolation [69]. These factors may have exacerbated depressive symptoms and impacted self-care abilities differently compared to non-pandemic periods. For instance, while our study found that light to moderate physical activity improved mental health and self-care ability, the magnitude of this effect may be larger than in non-pandemic times due to the overall reduced activity levels and increased psychological stress during lockdown periods [70]. Additionally, the pandemic may have altered the types of physical activities available to older adults, potentially shifting from group exercises to more solitary or home-based activities [71]. Notably, PSM is an effective method for evaluating the impacts of PA on DS, ADLs, and IADLs among older adults.

Limitations of the study

This study has some limitations. First, the data used in this study were cross-sectional survey data, and data on PA, DS, and self-care ability were obtained through self-reporting rather than through objective experiments, which may introduce response bias and affect the reliability of the data. Second, the cross-sectional design of the study limits our ability to establish causal relationships between PA and the outcomes of DS and self-care ability. Third, although propensity score matching (PSM) was used to evaluate the associations between PA and DS and self-care ability, PSM can only adjust for observed confounders and cannot account for unobserved variables, meaning that residual confounding may still be present. Therefore, the associations observed may not accurately reflect the actual causal effects of PA on DS and self-care ability.

Conclusions

This study suggests that moderate and light physical activity (MPA and LPA) are associated with lower levels of depressive symptoms and better instrumental activities of daily living (IADLs) among older adults. In addition, LPA is associated with improved activities of daily living (ADLs). The findings indicate that maintaining appropriate levels of PA may be beneficial for mental and physical health. Encouraging older adults to maintain appropriate PA levels might help improve their mental well-being and self-care ability. However, the COVID-19 pandemic has altered health behaviors in older adults, leading to decreased physical activity and potentially impacting the benefits observed in this study.

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Author contributions

Z.Z. was responsible for the procurement of finding, conceptualization and design of the study.Z.Z. Has full access to all data in the study and was responsible for the completeness of the data and the accuracy of the data analysis. XL, BZ, QYand QW conceived and designed this research. XL analyzed the data. XL, ZZ, and BZ drafted the manuscript. ZG Collate and check data and tables. WL collates documents and adjusted the formatting. All authors read and approved the final version of the manuscript.

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Data availability

Data supporting the findings of the study can be found on the http://class.ruc.edu.cn/index.htm website, which can be accessed by logging in to the application.

Declarations

Ethics statement

This study utilizes data from the China Longitudinal Aging Social Survey (CLASS), which is conducted and maintained by the Renmin University of China. The physical activity questionnaire component of the survey was designed by the Capital University of Physical Education and Sports. Both institutions obtained ethical approval for the data collection and management processes from their respective ethics committees. The CLASS survey was carried out by the principles of the Declaration of Helsinki and the relevant ethical guidelines for research involving human participants. All participants in the survey provided written informed consent before participating, and their privacy was safeguarded throughout the data collection process. All data used in this study were anonymized and aggregated to ensure that no personally identifiable information can be traced back to the participants. The authors of this study have complied with the ethical guidelines and requirements set forth by their own institution and the data providers. Any potential conflicts of interest have been disclosed and managed according to the appropriate protocols. For further information about the ethical considerations of this study or the data collection process, please contact the corresponding author.

Competing interests

The authors declare no competing interests.

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