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ORIGINAL RESEARCH

Joint Trajectories of Physical Activity and Depressive Symptoms in Postmenopausal Women in China: A Group-Based Dual Trajectory Analysis of the Five-Year Longitudinal Study

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Objective: The trajectories of the associations of physical activity (PA) with depressive symptoms in postmenopausal women are still unclear. This study aimed to identify the joint trajectories of PA and depressive symptoms over a 5-year period among Chinese postmenopausal women and to comprehensively examine their associations and predictors.

Methods: The study included 1303 postmenopausal women who participated in the China Health and Retirement Longitudinal Survey (CHARLS) between 2015, 2018 and 2020. Depressive symptoms were measured by CESD-10. PA was assessed by the IPAQ-SF. Group-based dual trajectory modeling (GBDTM) was applied to examine the joint trajectories of PA and depressive symptoms in postmenopausal women. Quantile regression assessed their associations within trajectory groups, and a multinomial logistic model identified group predictors.

Results: Three distinct dual trajectories of PA and depressive symptoms were identified in postmenopausal women: moderate stable-low increase (32.0%), high curve-moderate increase (46.1%), and low stable-high increase (21.9%), all showing a worsening trend in depressive symptoms. Consistent moderate PA was accompanied by low slightly increased depressive symptoms. Low PA was positively associated with high depressive symptoms in the 10th and 30th quantiles. High PA initially suppressed depressive symptoms, but its inhibitory effect diminished as symptoms worsened. Predictors of latent trajectory groups included rural residence, uneducated, insufficient sleep, and comorbidities.

Conclusion: Screening for depressive symptoms in postmenopausal women is necessary, especially in those with long-term low PA. PA interventions should be tailored according to the severity and trajectory of depressive symptoms.

Keywords: depressive symptoms, physical activity, postmenopausal women, dual trajectories, longitudinal study

Introduction

Depression is a major cause of global burden and a leading cause of disability worldwide.[1] Epidemiological and clinical evidence have demonstrated that women have a higher prevalence of depression than men,[2,3] with the differences potentially related to hormonal changes in the endocrines that control the reproductive system.[4] Women in postmenopausal stage are particularly susceptible, as the decline in estrogen levels during this period can significantly affect mood regulation.[5] Depressive symptoms are common in postmenopausal women, with the global pooled depression prevalence in them being 28.0%.[6] Depression is associated with decreased quality of life,[7] and increased risk of cardiovascular disease[8] and even suicide.[9] Especially in China, living in the rural area, chronic disease, and abnormal sleep duration

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were associated with an increased incidence of depressive symptoms.[10] Therefore, identifying the potentially modifiable correlates and intervening to prevent depressive symptoms in postmenopausal women is crucial.

Physical activity (PA) is a modifiable health behavior with the potential to alleviate depressive symptoms in postmenopausal women.[11] Although recent studies have gradually focused on the association between PA and depressive symptoms, their relationship remains complex and not well explored. Several studies have indicated that high levels of PA are associated with lower depressive symptoms.[12,13] However, these findings are not always consistent. A dose-response relationship between PA and depressive symptoms has been reported,[14] suggesting that both excessive and insufficient PA may increase the risk of depression. Other studies have found that only insufficient PA was associated with depressive symptoms.[15,16]

In addition, changes in PA may also result from alterations in depressive symptoms over time. Depression may hinder PA,[17] as a key feature of the condition, anhedonia, often reduces the desire to engage in PA.[18] The bidirectional relationship between PA and depressive symptoms has been documented in recent studies.[19,20] For example, higher genetic susceptibility to depression was associated with lower PA levels, and vice versa.[20] However, both PA levels and depressive symptoms are not always stable in the long term, and their relationship may vary as they change over time. Longitudinal studies are needed to track changes in PA and depressive symptoms over time for each individual, allowing for a more comprehensive analysis of their dynamic relationship.

However, most previous studies used the variable-centered approach to examine the longitudinal relationship between PA and depressive symptoms and failed to consider individual differences.[21,22] Although a few studies have addressed person-centered approaches, they have primarily focused on the effects of single-variable trajectories and have not considered the joint trajectories of PA and depressive symptoms over time. For example, one study used group-based trajectory modeling (GBTM) to examine how different PA trajectories over time were associated with depressive symptoms in adolescents.[23] Single-variable trajectories of PA or depressive symptoms were insufficient to capture the potential synergistic effect of PA and depressive symptoms.[24] Therefore, further investigation is needed to explore how the trajectories of PA and depressive symptoms evolve and how their relationship develops over time.

Group-based dual trajectory modeling (GBDTM), an extension of GBTM, is a joint model for determining the interrelationships between the trajectories of two simultaneously evolving outcomes.[25,26] As a person-centered latent variable approach, GBDTM identifies distinct subgroups of individuals who follow similar joint developmental trajectories, thereby revealing heterogeneity within the population. Unlike traditional variable-centered methods, a key advantage of GBDTM lies in the co-evolution of two related outcomes over time, offering deeper insight into their combined effects on health.[27] Moreover, GBDTM allows researchers to uncover latent patterns of co-occurrence and identify vulnerable subgroups that may benefit from early and tailored interventions.

However, the GBDTM approach has yet to be applied to examine the concurrent trajectories of PA and depressive symptoms over time, especially in postmenopausal women. Understanding the potential patterns of PA and depressive symptoms has significant practical public health implications for preventing depression in postmenopausal women. But the trajectories of the associations of PA with depressive symptoms in them are still unclear. To fill these gaps, we used the data from the China Health and Retirement and Longitudinal Study (CHARLS) in 2015, 2018, and 2020 to (1) explore the joint trajectories of PA and depressive symptoms over time in postmenopausal women, (2) comprehensively examine the relationships between PA and depressive symptoms in latent trajectory groups, and (3) identify the predictors of the latent trajectory groups.

Methods

Study Participants

The data from China Health and Retirement Longitudinal Study (CHARLS). The first wave was conducted in 2011 (wave 1), with four additional waves occurring in 2013 (wave 2), 2015 (wave 3), 2018 (wave 4) and 2020 (wave 5). A multistage, stratified, probability proportional to size sampling design was used to randomly select samples from 28 provinces, 150 counties and 450 communities in China were randomly selected.[28] The CHARLS study was approved by

the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015) and informed consent was obtained from all participants.

In this study, we used data from CHARLS 2015 as the baseline. We included postmenopausal women aged 45–60 years as our participants. Postmenopausal women were identified by asking the question in the CHARLS 2015 survey. The questions "Have you started menopause?" and "When did you begin the menopause?" were used to screen for postmenopausal women. Female participants who answered "yes" and had been menopausal for more than 1 year were considered eligible for the study.[29] Based on these criteria, 3305 participants were included. Next, female participants who did not complete the depressive symptoms scale and physical activity questionnaire were excluded, resulting in 1623 eligible participants in CHARLS 2015. For the analysis, we performed a 1:1 match to include only those who had completed the follow-up surveys in 2018 and 2020. A total of 1374 participants completed the surveys at all three waves. After excluding 71 participants with incomplete depressive symptoms scale, 1303 postmenopausal women were included in the final analysis. A flow chart of the participants in this study can be found in Supplementary Figure 1.

Measures

Depressive Symptoms

The 10-item Center for Epidemiology Studies Depression Scale (CESD-10) was used to assess depressive symptoms.[30] This scale demonstrated good validity and reliability in the Chinese population.[31] It assesses the frequency of related depressive symptoms in the previous week. All items were rated on a 4-point Likert scale: rarely or not at all, some days (1–2 days), occasionally (3–4 days), and most of the time (5–7 days). Two items require reverse coding. The total scores vary from 0 to 30, with higher values indicating more severe depressive symptoms. The threshold ≥12 was defined as depression.[32] The Cronbach's α of this study was 0.803 at baseline, 0.816, and 0.804 at follow-up, respectively.

Physical Activity

The physical activity (PA) levels were assessed using the Short-form International Physical Activity Questionnaire (IPAQ-SF),[33] which measured the frequency and duration of physical activity over the past seven days. It has been commonly applied in Chinese population-based studies.[34,35] It consisted of seven questions that encompassed three categories of physical activity: vigorous physical activity (VPA), moderate physical activity (MPA), and low physical activity (LPA). The weekly PA duration score was calculated by multiplying the number of days by the daily duration score for each type of physical activity. These duration scores are based on metabolic equivalent (MET) multipliers.[36] According to the related study,[37] the median was taken for each time period and "≥4h" was recorded as 240 min. To quantify total PA, each category of activity was weighted using its corresponding metabolic equivalent (MET): 8.0 METs for VPA, 4.0 METs for MPA, and 3.3 METs for LPA.[36] The total PA = 8.0* VPA weekly duration score + 4* MPA weekly duration score + 3.3 * LPA weekly duration score. The higher the score, the more levels of physical activity.

Covariates

Covariates included age, residence (urban, rural), education (yes, no), marital status (married, others), sleep duration (insufficient, sufficient, excessive), and the number of chronic diseases (0 as no morbidity, 1 as single morbidity, and ≥2 as multimorbidity). Sleep duration includes nighttime sleep duration and nap duration. Participants were asked to self-report their average number of hours of sleep per night and naps per day over the past month. According to related research,[38] we divided sleep duration into three groups: <7 h, 7–8 h, and ≥9 h.

Data Analysis

The sample data were presented as percentages for categorical variables, and means, standard deviations (±), or medians (interquartile ranges) for continuous variables. Differences between baseline characteristics and different trajectory groups were determined using ANOVA, chi-square tests or the Kruskal–Wallis test.

GBDTM was applied to examine the associations of PA with depressive symptoms over time and identify the latent groups of participants following similar trajectories based on PA and depressive symptoms. GBDTM assumes that population is composed of a finite number of latent subgroups, each following a distinct trajectory over time for two

related outcomes.[25] The optimal number and shape of trajectories were assessed based on Bayesian Information Criterion (BIC),[39] Akaike Information Criterion (AIC),[40] Consistent AIC (CAIC), Sample size-adjusted Bayesian information criterion (ssBIC),[41] Hannan-Quinn information criterion (HQIC), and the average posterior probability (Ave PP).[42] Smaller BIC, AIC, CAIC, ssBIC, and HQIC values suggest a better fit for the model. Ave PP $\geq$ 0.9 indicates the high reliability of the models, while Ave PP $\geq$ 0.7 suggests relatively reliable models.[43]

In addition, we fitted quantile regression models on the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th quantiles of the CESD-10 score distribution to comprehensively investigate the relationship between PA and depressive symptoms in latent dual-trajectory groups. In these regression models, we converted PA and depressive symptoms to standardized Z-scores for analysis. Furthermore, a multinomial logistics model was performed to evaluate the variables influencing the latent trajectory groups. Data analysis was performed using R (version 4.4.1) and IBM SPSS Statistics (version 26.0). A two-tailed probability value of <0.05 was considered statistically significant.

Results

The Characteristic of the Sample in the Baseline

A total of 1303 postmenopausal women were included for analysis. The average age of them was (54.66±3.84). Participants were from rural (n = 833, 63.9%) more than urban (n = 470, 36.1%). About half of the participants were educated (n = 642, 49.3%). About 93.3% of the postmenopausal women were married. About 44.4% of postmenopausal women with less than 7 h sleep duration. About two-thirds of them suffer from chronic diseases. Significant differences were observed in most different trajectories, which are summarized in Table 1.

Table 1 Baseline Characteristics of Study Population According to the Trajectories of PA and Depressive Symptoms

Variables[a]	Total (n = 1303)	Group A (n = 417)	Group B (n = 601)	Group C (n = 285)	*p**
Age (years)	54.66±3.84	54.95±3.77	54.44±3.86	54.67±3.85	0.115
Residence, n (%)					< 0.001
Rural	833 (63.9)	192 (46.0)	459 (76.4)	182 (63.9)	
Urban	470 (36.1)	225 (54.0)	142 (23.6)	103 (36.1)	
Education, n (%)					< 0.001
No	537 (41.2)	126 (30.2)	289 (48.1)	122 (42.8)	
Yes	766 (58.8)	291 (69.8)	312 (51.9)	163 (57.2)	
Married status, n (%)					0.139
Married	1216 (93.3)	387 (92.8)	569 (94.7)	260 (91.2)	
Others	87 (6.7)	30 (7.2)	32 (5.3)	25 (8.8)	
Sleep duration, n (%)					< 0.001
<7h	578 (44.4)	144 (34.5)	276 (45.9)	158 (55.4)	
7-8h	469 (35.9)	174 (41.7)	211 (35.1)	84 (29.5)	
>9h	256 (19.5)	99 (23.7)	114 (19.0)	43 (15.1)	
Chronic diseases, n (%)					< 0.001
None	439 (33.6)	181 (43.4)	185 (30.8)	73 (25.6)	
Single	349 (26.8)	103 (24.7)	177 (29.5)	69 (24.2)	
Comorbidity	515 (39.5)	133 (31.2)	239 (39.8)	143 (50.2)	
Depressive symptoms 2015, Median (Q1, Q3)	8.00 (4.00, 13.00)	4.00 (2.00, 6.00)	9.00 (6.00, 15.00)	12.00 (7.00, 17.00)	< 0.001
Depressive symptoms 2018, Median (Q1, Q3)	9.00 (4.00, 14.00)	4.00 (2.00, 7.00)	11.00 (6.00, 16.00)	14.00 (9.00, 18.00)	< 0.001
Depressive symptoms 2020, Median (Q1, Q3)	9.00 (5.00, 15.00)	5.00 (3.00, 7.00)	11.00 (7.00, 16.00)	15.00 (10.00, 19.00)	< 0.001
Physical activity 2015, Median (Q1, Q3)	4800 (1732.5, 10,785)	3337.5 (1732.5, 5544)	10,878 (5358, 16,464)	2100 (462, 4158)	< 0.001
Physical activity 2018, Median (Q1, Q3)	4718 (1732.5, 10,344)	3532.5 (1485, 5598)	10,584 (5544, 16,464)	1732.5 (542, 4158)	< 0.001
Physical activity 2020, Median (Q1, Q3)	4318 (1732, 9198)	3232.5 (1485, 5598)	9138 (4302, 14,340)	2132.5 (900, 4158)	< 0.001

Notes: [a]Data represented variables measured in 2015 and referred to as mean ± SD, n (%) or median (Q1, Q3). **P* value reported for differences between trajectory groups using ANOVA, chi-square tests or Kruskal–Wallis test.

Table 2 Evaluation Indices for the Fitting Performance of GBDTM

Model	Average Posterior Probability (Ave PP)					AIC	BIC	CAIC	ssBIC	HQIC
	Group A	Group B	Group C	Group D	Group E					
traj_1	1					105,436.4	105,480.3	105,487.3	105,458	105,451.9
traj_2	0.924681	0.956831				103,563.9	103,658.0	103,673.0	103,610.3	103,597.3
traj_3	0.893061	0.951016	0.886202			102,892.2	103,030.2	103,052.2	102,960.2	102,941.1
traj_4	0.877199	0.906836	0.860290	0.870948		102,517.7	102,705.8	102,735.8	102,610.5	102,584.4
traj_5	0.814186	0.856066	0.839277	0.832973	0.898021	102,326.5	102,571.1	102,610.1	102,447.1	102,413.3

Dual Trajectories of Physical Activity and Depressive Symptoms

Based on the model selection criteria, the AIC and BIC values were relatively lower for the three-trajectory group model compared to the two-trajectory group model. In addition, the Ave PP values in the three-trajectory group model exceeded those in the four-trajectory group model (Table 2). Therefore, three trajectory groups were identified as the best fit for physical activity and depressive symptoms from the GBDTM. Figure 1 presented the different trends of three groups, including moderate stable-low increase (n = 417, 32.0%), high curve-moderate increase (n = 601, 46.1%), and low stable-high increase (n = 285, 21.9%).

Specifically, group A (moderate stable-low increase) showed that postmenopausal women consistently maintained moderate levels of PA, accompanied by low levels of depressive symptoms that slowly increased over time. Group B (high curve-moderate increase) showed that PA remained high, exhibiting an inverted J-shaped curve with a slight

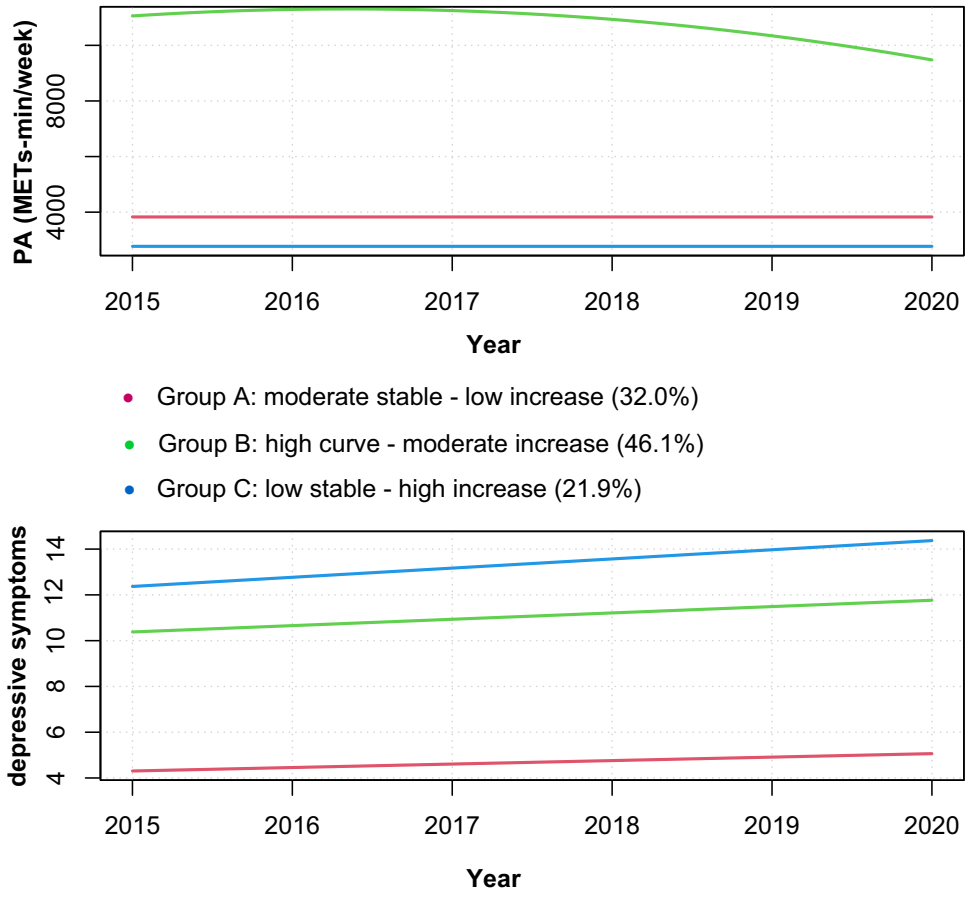

Figure 1 Latent trajectory groups of physical activity and depressive symptoms.
Notes: The variable before the "-" indicates physical activity, while the variable after the "-" indicates depressive symptoms.

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increase followed by a decrease, accompanied by moderate depressive symptoms that increased over time. PA was lowest when depressive symptoms approached the threshold. Group C (low stable-high increase) showed that PA levels maintained low consistently, accompanied by high levels of depressive symptoms that increased over time. Of note, depressive symptoms increased over time in all three trajectory groups (Figure 1).

Associations Between Physical Activity and Depressive Symptoms in Three Trajectory Groups

Table 3 presents the estimates of the associations between PA and depressive symptoms of different quantile distributions in three trajectory groups. The models were adjusted for age, education, residence, married status, sleep duration and chronic diseases. In trajectory group B, high PA was negatively associated with depressive symptoms at low quantiles (10th, 20th, and 30th), with the largest estimate at the 30th quantile. Above the 30th quantile, however, high PA was not significantly associated with depressive symptoms. In trajectory group C, low PA was positively associated with high depressive symptoms in the 10th and 30th quantiles ($p < 0.05$). More details are shown in Supplementary Figure 2.

To address the robustness of our findings, the stratified analysis of residence and education was conducted. The results found that the correlation trends for all stratifications were approximately the same as in the main analysis (Supplementary Tables 1 and 2).

The Variables of the Latent Trajectory Groups of Physical Activity and Depressive Symptoms

Variables associated with the latent trajectory groups were measured by multinomial logistic regression (Table 4). Compared to group A, postmenopausal women who lived in rural areas, were uneducated, had insufficient sleep duration, and suffered from comorbidity were more likely to belong to the group B and C.

Table 3 Relationships Between Physical Activity and Depressive Symptoms of Different Quantiles in Three Trajectory Groups

Variable: Physical Activity	P10	P20	P30	P40	P50	P60	P70	P80	P90
Group A	−0.030	−0.083	−0.000	−0.595	−0.477	−0.794	−0.950	−1.937	−1.038
Group B	−0.286***	−0.206***	−0.143**	−0.098	−0.062	−0.040	0.000	0.010	0.008
Group C	0.100***	0.087	0.185***	0.134	0.027	0.017	−0.024	0.070	−0.070

Notes: **p<0.01, ***p<0.001; Adjusted for age, education, residence, married status, sleep duration and chronic diseases.

Table 4 Predictor for Latent Trajectories in PA and Depressive Symptoms (OR, 95% CI)

Variables	Group B	Group C
Age	0.939 (0.905, 0.973)**	0.950 (0.910, 0.991)*
Residence, n (%)		
Rural	3.550 (2.667, 4.706)***	2.028 (1.462, 2.813)***
Urban	Ref.	Ref.
Education, n (%)		
No	1.806 (1.358, 2.403)***	1.553 (1.109, 2.175)**
Yes	Ref.	Ref.
Married status, n (%)		
Married	1.214 (0.697, 2.114)	0.793 (0.441, 1.425)
Others	Ref.	Ref.

(*Continued*)

Table 4 (Continued).

Variables	Group B	Group C
Sleep duration, n (%)		
<7h	1.997 (1.394, 2.861)***	2.790 (1.802, 4.319)***
7-8h	1.252 (0.874, 1.793)	1.271 (0.806, 2.005)
>9h	Ref.	Ref.
Chronic diseases, n (%)		
None	0.569 (0.415, 0.780)***	0.383 (0.264, 0.557)***
Single	0.976 (0.694, 1.372)	0.630 (0.424, 0.937)*
Comorbidity	Ref.	Ref.

Notes: Group A as reference; *p<0.05, **p<0.01, ***p<0.001.

Discussion

Previous studies have examined the separate trajectories of PA or depressive symptoms. However, the patterns of co-evolution of PA and depressive symptoms have never been investigated, particularly in postmenopausal women. Based on the GBDTM, three distinct dual-trajectory patterns for PA and depressive symptoms were identified in this study. Quantile regression models were introduced to comprehensively explore the associations between PA and depressive symptoms in the three trajectory groups. The predictors of latent groups were also identified. These findings may inform early screening and intervention strategies in clinical settings and assist health policy decision-makers in identifying priority populations of postmenopausal women, thereby providing direction for the prevention of depressive symptoms.

In this study, depressive symptoms in postmenopausal women worsened over time, aligning with previous findings.[12,44] However, the rate of increase varied across the three distinct trajectory groups. In the "moderate stable-low increase" trajectory group, 32.0% of the sample were classified. Postmenopausal women in this group maintained moderate PA consistently, accompanied by the lowest depressive symptoms, with a slight increase in symptoms over time. This finding was confirmed in the study of older European adults, which showed that moderately strong associations between changes in PA and depressive symptoms over time.[45] The relationship between moderate PA and low depressive symptoms in postmenopausal women is interactive. Previous studies have found that average PA has a protective effect on depressive symptoms,[46,47] while individuals with low depressive symptoms are more likely to engage in more PA.[18] Notably, postmenopausal women in this group maintained PA at around 4000 METs-min/week over time, which supports the findings of a meta-analysis that concluded that optimal PA level to mitigate the progression of chronic diseases is 3000–4000METs-min/week.[48] Total PA should be higher than the currently recommended minimum level of 600 METs-min/week[49] to reduce depressive symptoms in postmenopausal women.

In the "low stable - high increase" trajectory group, 21.9% of postmenopausal women were classified. In this group, postmenopausal women with long-term low PA accompanied by the most severe depressive symptoms, and the rate of increase is the most evident. This pattern aligns with a previous study, which showed that low PA increased the risk of depressive disorder, while major depressive disorder raised the risk of physical inactivity.[19] We also found that low PA was positively associated with high depressive symptoms at the 10th and 30th quantiles in this group, which is consistent with the previous study.[50] This suggests that long-term low PA may worsen the condition of postmenopausal women experiencing severe depressive symptoms. Prospective cohort studies have found that low PA is associated with elevated CRP, IL-6, and fibrinogen.[51,52] Long-term low PA exacerbates the inflammatory response in postmenopausal women's bodies, which in turn worsens depressive symptoms. Thus, screening for depressive symptoms in postmenopausal women is necessary, especially in those with long-term low PA. In addition, one study found that individuals with moderate to severe depressive symptoms reported feeling considerably happier when they participated in higher levels of PA than usual.[53] Moderate levels of PA may contribute to the reduction of depressive symptoms in postmenopausal women. However, the adverse effects of excessive PA on postmenopausal women with depression need to be considered. Too much is too little. Excessive PA may worsen depressive symptoms through the secretion of cytokines and cortisol.[54]

The "high curve - moderate increase" trajectory group encompassed the largest proportion of postmenopausal women (46.1%), exhibiting a high PA with an inverted J-shaped curve, accompanied by moderate depressive symptoms that increased over time. This trajectory suggests that there was a dose-response relationship in the association between high PA and moderate depressive symptoms, supporting the findings of previous studies.[55,56] In addition, the quantile regression model found that high PA was negatively associated with depressive symptoms at low quantiles. It appears that when in the early stages of depressive symptoms, high PA may help to suppress these symptoms. Biological changes induced by PA may explain this finding. PA improves brain-derived neurotrophic factor (BDNF) secretion levels,[57] modulates cortical glutamate levels, and increases neurogenesis and synaptogenesis in the hippocampus,[51] all of which could produce an antidepressant effect. However, when depressive symptoms increased close to the threshold, the inhibitory effect of high PA on depressive symptoms was not significant. Therefore, PA should be prescribed at the early signs of depressive symptoms to disrupt the progression of depression and improve the mental health of postmenopausal women at the earliest possible moment.[58]

Due to the heterogeneity of PA and depressive symptom trajectories among postmenopausal women, intervention strategies should consider differences in PA intensity and type across subgroups. Moderate PA may be an effective way to improve depressive symptoms in postmenopausal women. For example, Tai Chi, a traditional Chinese healthcare exercise classified as moderate physical activity (MPA), has been demonstrated to be an effective PA for improving depression.[59]

In addition, our study also contributes to the existing literature by further investigating the predictors of latent trajectory groups. Postmenopausal women living in rural areas were more likely to be classified in the "high curve - moderate increase" and "low stable - high increase" trajectory groups. Urban-rural inequalities in socioeconomic status, living environment, occupations, and personal lifestyle among postmenopausal women could explain these findings.[60] On one hand, rural postmenopausal women have lower levels of education and work in more physically demanding occupations than those in urban, that is, social determinants that impair mental health.[61] Our study confirmed that being uneducated was also a risk factor for the latent trajectory groups. On the other hand, postmenopausal women living in rural areas were associated with an increased risk of depressive symptoms, which has already been proved in previous studies.[62,63] In addition, postmenopausal women with insufficient sleep duration were the predictor of latent trajectory groups. Recent evidence has found that insufficient sleep was associated with an increased risk of developing depression in postmenopausal women.[64]

Postmenopausal women with comorbidities were the risk factor of latent trajectory groups. Previous studies have shown that individuals with comorbidities tend to have low PA.[65] Among postmenopausal women with comorbidities, those who consistently maintained low PA may experience diminished self-efficacy and perceive less social support from family and friends,[66] ultimately leading to the development of aggregated depressive symptoms. Self-efficacy and social support are mechanisms through which PA exerts antidepressant effects.[51] Given these findings, more public health initiatives should be implemented to promote adequate participation in PA to prevent depression in postmenopausal women, especially for those with comorbidities. Policymakers should pay greater attention to vulnerable subgroups, such as those living in rural areas, uneducated, insufficient sleep, and comorbidities, by tailoring PA interventions to their specific needs and barriers. Such targeted strategies may enhance the effectiveness of mental health promotion efforts and reduce the burden of depression in vulnerable subgroups.

Strengthens and Limitations

Our study has several strengths. Firstly, this is the first study to analyze the trajectories of concurrent changes in PA and depressive symptoms in Chinese postmenopausal women from a person-centered perspective. Using the GBDTM, we analyzed the heterogeneity of the co-evolution of PA and depressive symptoms. This allowed us to identify sensitive populations with important public health implications and provide directions for the prevention of depression in postmenopausal women. Secondly, quantile regression models were employed to fully estimate the correlation between PA and depressive symptoms across three trajectory groups. These results can capture the comprehensive association of PA with the entire distribution of depression to better understand the role of PA interventions in alleviating depressive symptoms in postmenopausal women. Thirdly, we identified the predictors of the latent trajectory groups that may

contribute to developing an integrated prevention program to prevent worsening depressive symptoms in postmenopausal women. These findings provide an important foundation for developing tailored PA interventions and mental health screening strategies in community and primary care settings, particularly for postmenopausal women with stable low PA.

Several limitations should be noted. First, the measurements of depressive symptoms and PA were based on self-reported questionnaires, and recall bias may affect the results. Future research should use objective-measure assessments to examine the joint trajectories of PA and depressive symptoms over time. Second, participants who did not complete the depressive symptoms scale or PA questionnaire were excluded, which may have introduced selection bias and limited the generalizability of the findings. Third, we did not include premenopausal and perimenopausal women in this study. Comparisons of the trajectories of both PA and depressive symptoms in premenopausal, perimenopausal, and postmenopausal women need to be explored in the future studies. Fourth, we did not distinguish between different forms of PA. Future research should more comprehensively examine different types of PA and assess their specific effects on depressive symptoms in postmenopausal women. Fifth, although this study used longitudinal data to explore the trajectories of PA and depressive symptoms, the complexity of the bidirectional relationship demands caution in inferring causality, so the future studies with experimental or interventional designs would be highly beneficial to strengthen the evidence of causality. Sixth, although the study made efforts to control for various covariates, it is still possible that there are confounding variables, such as occupation, and social participation, that we have not accounted for. However, the subgroup analysis suggests that our findings are relatively robust. Finally, the characteristics of marital status, sleep duration, and chronic diseases in postmenopausal women may change over time. Our study only considered the baseline characteristics, which may have biased the results.

Conclusion

This study generated the first evidence on the joint trajectories of PA and depressive symptoms in postmenopausal women. Three dual trajectory groups were identified. In these groups, depressive symptoms in postmenopausal women worsened over time, especially in those with low stable PA. Postmenopausal women with low stable PA aggravated depressive symptoms. In addition, while high curve PA may help to suppress depressive symptoms at an early stage, its protective effect weakened as symptoms worsened. PA intervention projects should be tailored to the different depressive conditions of postmenopausal women, especially focusing on those who live in rural areas, are uneducated, have insufficient sleep, and have comorbidity. Tailored PA may be more beneficial in maximizing the alleviation of depressive symptoms in postmenopausal women.

Data Sharing Statement

The dataset generated for this study is available in online repositories, and access is provided through the following link: http://charls.pku.edu.cn.

Ethics Approval and Consent to Participate

The CHARLS was approved by the Ethics Review Committee of Peking University (IRB00001052-11015), and all participants signed the informed consent at the time of participation. This study was also approved by the Ethics Review Committee of Shanxi Medical University (2025014). This research has been performed in accordance with the Declaration of Helsinki.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically

reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

We declare that we have no conflict of interests.

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