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Bidirectional association between ADL disability and depressive symptoms among older adults: longitudinal evidence from CHARLS

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This study investigates the bidirectional relationship between Activities of Daily Living (ADL) disability and depressive symptoms (DS) among middle-aged and older adults in China, utilizing data from the China Health and Retirement Longitudinal Study (CHARLS) from 2015 to 2018. A total of 8994 participants were analyzed to assess the impact of ADL on the risk of depressive symptoms, while 9673 participants were included to examine the influence of depressive symptoms on the risk of ADL disability. Cox proportional hazards regression models were employed to evaluate these relationships, adjusting for sociodemographic, lifestyle, and health-related covariates. Results revealed that ADL disability significantly increased the risk of depressive symptoms (HR = 1.090, 95% CI 1.058–1.123), and depressive symptoms were associated with a higher risk of ADL disability (HR = 1.033, 95% CI 1.025–1.042). Subgroup analyses demonstrated that factors such as education level, social activity, and disability significantly modified the relationship between ADL and depressive symptoms, while age, marital status, and pain influenced the association between depressive symptoms and ADL. Sensitivity analyses confirmed the robustness of these findings. This study highlights the complex interplay between ADL and depressive symptoms, emphasizing the need for targeted interventions to mitigate the risk of depression and improve functional independence in aging populations.

Keywords Activities of daily living, Depressive symptoms, Cohort study

Abbreviations

CHARLS	Chinese Health and Retirement Longitudinal Study
DS	Depressive symptoms
ADL	Activities of daily living
CDS	Categories of depressive symptoms
CADL	Categories of ADL
HRs	Hazard ratios
Cis	Confidence intervals

With the global aging population rapidly increasing, effective strategies for promoting healthy aging have garnered significant attention. Healthy aging is broadly defined as the maintenance of physical functionality, cognitive health, and mental well-being[1]. Among the various challenges to healthy aging, depression stands out as a critical public health issue worldwide. Globally, depression affects approximately 3.8% of the population, including 5.0% of adults and 5.7% of individuals aged 60 and older, with an estimated 280 million people suffering from this condition[2]. In China, depression has become a major public health concern over the past

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decade[3]. According to the World Health Organization (WHO), China now bears the second-largest burden of depression globally, with over 54.8 million cases reported. The COVID-19 pandemic has further exacerbated this issue, with large-scale online surveys indicating that more than 27.9% of the general population in China experiences depressive symptoms[4,5]. Depression is a prevalent mental health issue that significantly impacts the elderly population worldwide. Major depressive disorder stands out as one of the primary causes of suicide among the elderly, with its prevalence ranging from 5.37–56%[6]. In China, the prevalence of depressive symptoms among middle-aged and older adults is notably high[7]. Beyond its psychological implications, depression exerts profound effects on physical health, social functioning, and economic well-being. It is closely associated with an increased risk of chronic diseases, reduced productivity, and diminished quality of life[8–10]. Among the elderly, various factors such as educational level, marital status, smoking, alcohol consumption, social engagement, and the presence of chronic diseases and disabilities can influence the onset of depression[11–15].

Activities of Daily Living (ADL) refer to the ability to perform essential everyday tasks and can be broadly categorized into Basic Activities of Daily Living (BADL) and Instrumental Activities of Daily Living (IADL). BADL is one of the most commonly used standards for assessing functional independence and includes fundamental self-care activities such as bathing, dressing, eating, and moving around indoors. IADL, on the other hand, reflects an individual's capacity to manage their environment and encompasses tasks like using the telephone, shopping, cooking, and housekeeping[16]. Maintaining ADL capabilities is crucial for preserving independence and enhancing the quality of life in older adults. Functional disability poses a significant public health challenge, with over one billion people worldwide experiencing one or more forms of disability[17]. Ensuring that older adults maintain their ADL abilities not only supports their autonomy but also mitigates the broader societal impacts associated with loss of function. Recent studies in China have demonstrated that the prevalence of ADL disability among older adults is 41.0%[18]. A survey conducted among older adults in China indicated that the incidence of ADL disability increases with age[19].

Currently, numerous cross-sectional studies have investigated the relationship between ADL and DS, with most studies finding a significant positive correlation between ADL and DS among older adults. Multiple studies have identified ADL disability as a risk factor for depression among older adults in rural China[19–22]. ADL disability can affect the quality of life of older adults with multiple chronic conditions, either directly or indirectly, through depression[23]. Therefore, preventing or reducing ADL disabilities may have a positive impact on the healthcare of older adults with depressive symptoms[24]. These cross-sectional studies provide evidence of the association between ADL disability and depressive symptoms in older adults.

However, some studies have found that ADL does not significantly influence depressive symptoms among older adults living alone[25]. Additionally, there is a paucity of longitudinal studies investigating the relationship between ADL and depression. One study using a cross-lagged model to explore the longitudinal association between ADL and DS found that an increase in ADL disability was associated with higher levels of depression, and more severe DS were linked to greater ADL disability. However, the impact of ADL disability on depression was less pronounced than the effect of depression on ADL function[15]. While current research predominantly focuses on the cross-sectional associations between ADL and depression, more longitudinal studies are needed to understand how these relationships evolve over time. Therefore, the longitudinal association between ADL and depressive symptoms in middle-aged and older adults warrants further investigation.

This study aims to investigate the longitudinal association between ADL disability and DS, as well as their mutual influences. Although previous research has explored the relationship between these two factors, most studies have primarily focused on unidirectional pathways, particularly the impact of ADL disability on depressive symptoms. In contrast, this study employs a Cox proportional hazards model to systematically evaluate the bidirectional interactions between depression and ADL disability and their effects on individual health risks. We analyze data from a nationally representative survey of middle-aged and older adults, collected prior to the COVID-19 pandemic. Additionally, we assess the longitudinal association between ADL disability and changes in depressive symptoms over a three-year follow-up period. Our findings contribute to a deeper understanding of how these two critical factors interact over time and their implications for health outcomes in older populations.

Methods

Study design and participants

The dataset used in this study was derived from the Chinese Longitudinal Healthy Longevity Survey (CHARLS), conducted by the Chinese Center for Disease Control and Prevention and guided by Peking University and the Duke University Center for Health Aging and Development. The overall sample was recruited from 23 provinces, covering approximately 85% of China's total population, with about half of the cities/counties in each province selected as primary sampling units[26]. Participants in the CHARLS were recruited through a targeted random sampling process, while the China Health and Retirement Longitudinal Study (CHARLS) employed a four-stage stratified cluster probability sampling design to survey a representative sample of middle-aged and older adults in China. The survey content for CHARLS participants included personal physical and mental health, lifestyle, family structure, interpersonal relationships, and healthcare. The CHARLS database is considered high-quality due to its reliable validity/reliability test results, minimal missing data, and high response rates. For more information on the CHARLS, please visit: http://www.icpsr.umich.edu/icpsrweb/NACDA/studies/36179.

All participants provided informed consent prior to their inclusion in the study. The study protocol was reviewed and approved by the Ethical Review Committee of Peking University (approval number: IRB00001052–11,015). All procedures involving human participants adhered to the ethical standards established by the institutional and/or national research committee, and were conducted in accordance with the 1964 Helsinki Declaration and its subsequent amendments or comparable ethical standards.

To reflect the latest classification of BADL/IADL among Chinese older adults, our analysis included participants from the 2015 wave of the CHARLS survey, excluding those with missing data. The proportional hazards assumption was tested using Schoenfeld residuals, and no significant violations were observed. Time-to-event data were handled by defining the follow-up period from 2015 to 2018, with censoring applied to participants lost to follow-up. This study represents an analysis of CHARLS data from 2015 to 2018, with participants entirely selected from the 2015 cohort of CHARLS. The three-year interval was chosen to balance the need for sufficient time to observe changes in ADL disability and depressive symptoms while minimizing the risk of loss to follow-up. This interval is consistent with previous studies that have used similar timeframes to examine longitudinal associations[27].

Cases that participated only in 2015 or 2018 were excluded, resulting in 15,476 subjects who completed both ADL and DS tests. To minimize bias, cases with missing covariate information were excluded, leading to a final analysis sample of 13,724 participants. Although this approach may introduce selection bias, we considered it appropriate given the low proportion of missing data. Future studies may explore alternative methods such as multiple imputation to address missing data. After excluding those with baseline depressive symptoms (DS) (4,630 cases), 8,994 participants remained. Further exclusion of participants with baseline ADL impairments (3,951 cases) resulted in a final sample size of 9,673. Figure 1 shows the flowchart of sample selection for this study (Fig. 1).

Measurement of depressive symptoms

The CHARLS study utilized the CES-D-10 questionnaire to assess the risk of depressive symptoms experienced by respondents in the past week. This questionnaire has been validated for use among Chinese older adults and has demonstrated good reliability, with a Cronbach's α coefficient of 0.78–0.79[28,29]. The CES-D-10 scale consists of 10 questions targeting specific emotions or behaviors, and respondents report the frequency of each item over the past week, ranging from "rarely or none of the time" to "most or all of the time." Each item is scored on a four-point scale, ranging from 0 (rarely or none of the time) to 3 (most or all of the time), with 8 items being negative and 2 items being positive. Items 5 and 8 are reverse-scored. Overall, the scale score ranges from 0 to 30, with higher scores indicating more severe depressive symptoms and a higher likelihood of depression. Previous

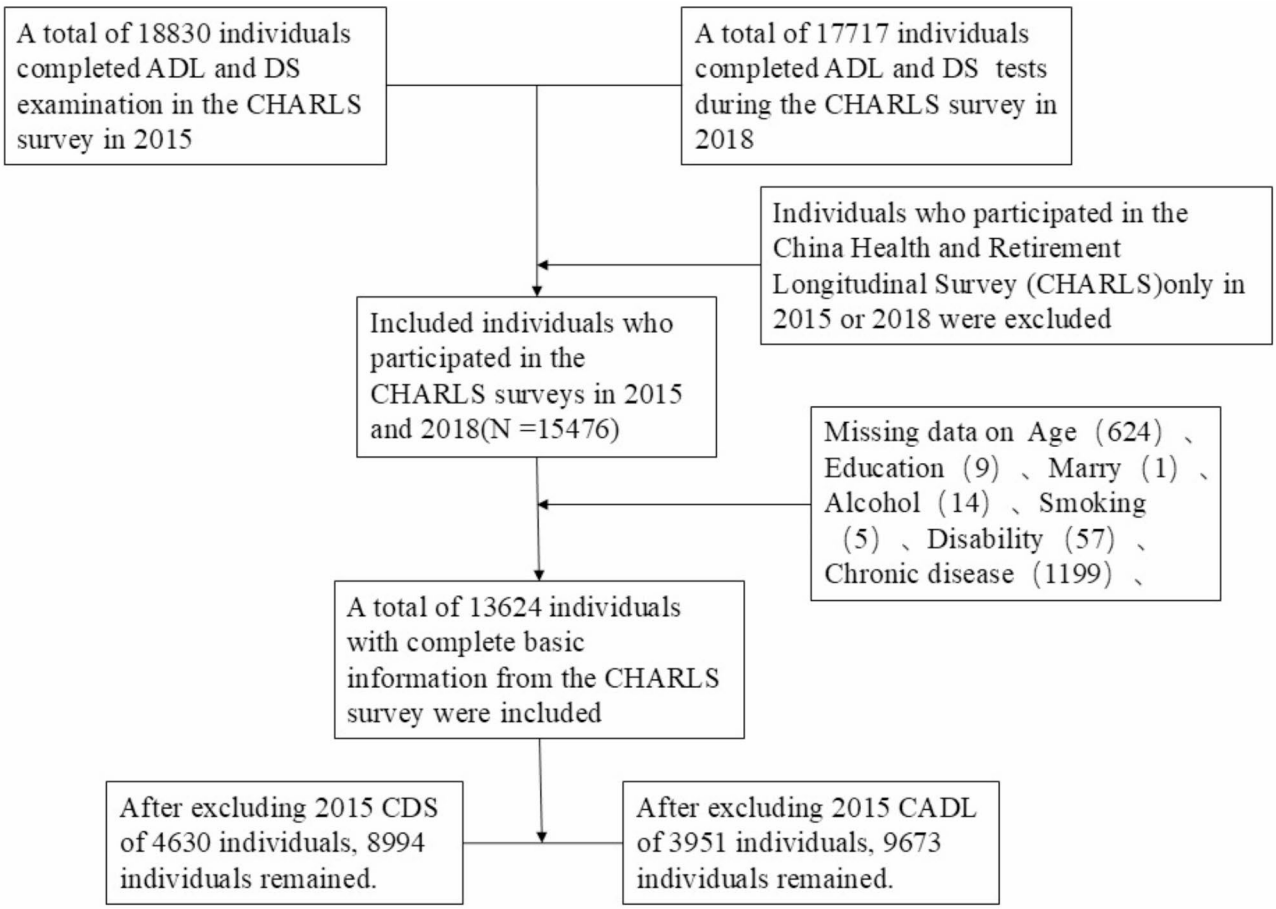

Fig. 1. Flowchart of the study sample of Chinese middle aged and older adults: CHARLS, 2015–2018. Flow Chart of Participant Selection: Chinese Longitudinal Healthy Longevity Survey (CHARLS); DS, Depressive Symptoms; ADL, Activities of Daily Living; CDS, Categories of Depressive Symptoms; CADL, Categories of ADL.

research on the CES-D-10 scale has suggested a cutoff score of 10 for identifying depressive symptoms in older adults. Therefore, a cutoff score of 10 was set to distinguish participants with and without depressive symptoms (≥ 10: high-risk CDS coded as 1; <10: low-risk CDS coded as 0)[24,30,31].

Assessment of ADL disability

Activities of Daily Living (ADL) disability were measured based on Basic Activities of Daily Living (BADL) and Instrumental Activities of Daily Living (IADL). The assessment of ADL includes two components: BADL and IADL. BADL is evaluated using six items: bathing, dressing, indoor mobility, toileting, eating, and using the toilet. IADL is assessed using five items: doing housework, cooking, shopping, managing money, and taking medication. Evidence suggests that BADL and IADL can serve as independent indicators for effectively predicting functional disability in older adults[18,32]. Responses to each item are coded as follows: "Can do it independently" is coded as 0. "Has some difficulty or worse" is coded as 1. The ADL score is the sum of the BADL and IADL scores, ranging from 0 to 11. Higher scores indicate more severe ADL disability. A cutoff score of 1 was set to distinguish participants with and without ADL disability (ADL ≥ 1: CADL impairment coded as 1; ADL = 0: no CADL impairment coded as 0)[33].

Covariates

Covariates included sociodemographic factors (age, gender, marital status[11], educational level, and place of residence), lifestyle and health behaviors (smoking, alcohol consumption and social Activity[12])[13], physical health status (disability, chronic diseases and pain[14])[15].

Age: Categorized into two levels: 45–65 years and 65 years and older.

Gender: Coded as maleand female.

Marry: Categorized into two groups: married or cohabiting and other, including separated, divorced, unmarried, widowed, or married but living apart.

Educational Level: Categorized into four groups: below primary school, primary school, secondary school, High school and above.

Residence: Categorized as urban and rural).

Social Activity: Categorized as no and yes.

Smoking Status: Categorized as smoker and non-smoker.

Alcohol Consumption: Categorized as drinker (1) and non-drinker (0).

Disability: Categorized as disabled (1) and not disabled (0).

Chronic Diseases: Respondents were classified as having a chronic disease if they provided a positive response or were currently taking medication for conditions such as hypertension (antihypertensive drugs), diabetes (antidiabetic drugs, insulin injections), or hyperlipidemia (lipid-lowering drugs).

Pain:

Data analysis

In this study, statistical analyses were performed using R software (version 4.4.2). Continuous variables that followed a normal distribution were expressed as mean ± standard deviation (SD) and compared between groups using Student's t-test. Categories of Depressive Symptoms (CDS) and Categories of ADL (CADL) were used to classify participants based on predefined cutoff scores. Categorical data were presented as frequencies and proportions (n (%)) and compared using the chi-square (χ^2) test. Cox regression analysis was employed to examine the relationship between ADL and the risk of developing DS, as well as between DS and the risk of ADL disability. Additionally, four Cox regression models were constructed to evaluate the data. Model 1 was unadjusted. In Model 2, adjustments were made for sex and age, while Model 3 further included adjustments for marital status, education, residence, smoking, alcohol consumption, and social activities. Model 4 additionally adjusted for disability, chronic diseases, and pain. Sensitivity analysis was conducted based on Model 4 by excluding subjects with baseline independent variable values in the extreme 15% to test the robustness of the results. Finally, subgroup analyses and interaction analyses were performed according to different covariates. A p-value < 0.05 was considered statistically significant.

Results

Sociodemographic characteristics of participants

In the analysis of the impact of ADL on the risk of DS, a total of 8,994 participants were included. During the longitudinal follow-up from 2015 to 2018, 2,292 participants developed probable DS, yielding a cumulative incidence rate of 25%. Table 1 compares the baseline characteristics between participants with probable DS and the normal control group. Participants with probable DS exhibited significantly higher ADL disability scores compared to the control group. They were more likely to be female and had a higher proportion of individuals with lower educational attainment (primary school or below). Additionally, this group was more likely to reside in rural areas. Lifestyle factors, such as abstinence from alcohol, non-smoking, and limited engagement in social activities, were associated with a higher incidence of DS. Furthermore, individuals with physical disabilities, chronic diseases, and pain reported higher rates of DS. These findings indicate that, beyond age and marital status, other covariates may significantly influence the onset of DS.

In the analysis of the impact of DS on the risk of ADL disability, a total of 9,673 participants were included. During the longitudinal follow-up from 2015 to 2018, 2,292 participants developed probable ADL disability, yielding a cumulative incidence rate of 19%. Table 2 compares the baseline characteristics between participants with probable ADL disability and the normal control group. Participants with probable ADL disability exhibited significantly higher DS scores compared to the control group. They were more likely to be over 65 years old, female, divorced, and had a higher proportion of individuals with lower educational attainment (primary school

Characteristic	2108CDS		Total 8994 (100%)	*p*
	No *N* = 6702 (75%)	Yes *N* = 2292 (25%)		
Age years (Mean ± SD)	60.365 ± 8.885	60.230 ± 8.901		0.531
2015ADL	0.281 ± 0.876	0.610 ± 1.397		0.000
2015CADL				0.000
No	5649 (77%)	1664 (23%)	7313 (81%)	
Yes	1053 (63%)	628 (37%)	1681 (19%)	
Age				0.596
45–65(0)	4633 (74%)	1598 (26%)	6231 (69%)	
> 65(1)	2069 (75%)	694 (25%)	2763 (31%)	
Gender				0.000
Female	2928 (70%)	1262 (30%)	4190 (47%)	
Male	3774 (79%)	1030 (21%)	4804 (53%)	
Education				0.000
Below primary school	2261 (68%)	1060 (32%)	3321 (37%)	
Primary school	1645 (75%)	562 (25%)	2207 (25%)	
Secondary school	1695 (79%)	445 (21%)	2140 (24%)	
High school and above	1101 (83%)	225 (17%)	1326 (15%)	
Marry				0.064
Other conditions	666 (72%)	259 (28%)	925 (10%)	
Married/cohabiting	6036 (75%)	2033 (25%)	8069 (90%)	
Residence				0.000
City	2933 (79%)	773 (21%)	3706 (41%)	
Countryside	3769 (71%)	1519 (29%)	5288 (59%)	
Alcohol drinker				0.000
No	3986 (72%)	1524 (28%)	5510 (61%)	
Yes	2716 (78%)	768 (22%)	3484 (39%)	
Smoking status				0.025
No	4638 (74%)	1643 (26%)	6281 (70%)	
Yes	2064 (76%)	649 (24%)	2713 (30%)	
Social				0.000
No	2758 (72%)	1050 (28%)	3808 (42%)	
Yes	3944 (76%)	1242 (24%)	5186 (58%)	
Disability				0.000
No	5119 (76%)	1576 (24%)	6695 (74%)	
Yes	1583 (69%)	716 (31%)	2299 (26%)	
Chronic disease				0.000
No	1605 (80%)	392 (20%)	1997 (22%)	
Yes	5097 (73%)	1900 (27%)	6997 (78%)	
Pain				0.000
No	5774 (78%)	1655 (22%)	7429 (83%)	
Yes	928 (59%)	637 (41%)	1565 (17%)	

Table 1. Baseline characteristics of participants by risk of DS.

or below). Additionally, this group was more likely to reside in rural areas. Lifestyle factors, such as abstinence from alcohol, non-smoking, and engagement in social activities, were associated with a higher incidence of ADL disability. Furthermore, individuals with physical disabilities, chronic diseases, and pain reported higher rates of ADL disability. These findings indicate that all aforementioned covariates may significantly influence the onset of ADL disability.

Cox proportional hazards regression models

We employed Cox proportional hazards regression models to examine the impact of ADL disability on the risk of DS. In the unadjusted model, the ADL disability score in 2015 was a significant predictor of DS, with each one-unit increase in the ADL disability score associated with a 16.3% increase in the risk of developing DS (HR = 1.163, 95% CI: 1.132–1.194). After sequential adjustments for age, gender, education, marital status, place of residence, alcohol consumption, smoking, social engagement, disability, chronic diseases, and pain, ADL disability remained significantly associated with an elevated risk of DS (HR = 1.090, 95% CI: 1.058–1.123). Similarly, the unadjusted model demonstrated that the DS score in 2015 was a significant predictor of ADL

Characteristic	2108CADL		Total 9673 (100%)	*p*
	No *N* = 7843 (81%)	Yes *N* = 1830 (19%)		
Age years (Mean ± SD)	58.769 ± 8.319	62.541 ± 8.977		0.000
2015DS	6.028 ± 5.114	8.654 ± 6.252		0.000
2015CDS				0.000
No	6187 (85%)	1126 (15%)	7313 (76%)	
- Yes	1656 (70%)	704 (30%)	2360 (24%)	
Age				0.000
45–65(0)	5946 (84%)	1097 (16%)	7043 (73%)	
> 65(1)	1897 (72%)	733 (28%)	2630 (27%)	
Gender				0.000
Female	3566 (77%)	1073 (23%)	4639 (48%)	
Male	4277 (85%)	757 (15%)	5034 (52%)	
Education				0.000
Below primary school	2534 (73%)	956 (27%)	3490 (36%)	
Primary school	1980 (82%)	430 (18%)	2410 (25%)	
Secondary school	2079 (87%)	302 (13%)	2381 (25%)	
High school and above	1250 (90%)	142 (10%)	1392 (14%)	
Marry				0.000
Other conditions	713 (71%)	293 (29%)	1006 (10%)	
Married/cohabiting	7130 (82%)	1537 (18%)	8667 (90%)	
Residence				0.000
City	3274 (84%)	606 (16%)	3880 (40%)	
Countryside	4569 (79%)	1224 (21%)	5793 (60%)	
Alcohol drinker				0.000
No	4658 (79%)	1272 (21%)	5930 (61%)	
Yes	3185 (85%)	558 (15%)	3743 (39%)	
Smoking status				0.000
No	5371 (80%)	1332 (20%)	6703 (69%)	
Yes	2472 (83%)	498 (17%)	2970 (31%)	
Social				0.000
No	3220 (78%)	920 (22%)	4140 (43%)	
Yes	4623 (84%)	910 (16%)	5533 (57%)	
Disability				0.000
No	6138 (84%)	1183 (16%)	7321 (76%)	
Yes	1705 (72%)	647 (28%)	2352 (24%)	
Chronic disease				0.000
No	1904 (88%)	251 (12%)	2155 (22%)	
Yes	5939 (79%)	1579 (21%)	7518 (78%)	
Pain				0.000
No	6508 (84%)	1196 (16%)	7704 (80%)	
Yes	1335 (68%)	634 (32%)	1969 (20%)	

Table 2. Baseline characteristics of participants by risk of ADL disability.

disability, with each one-unit increase in the DS score associated with a 6% increase in the risk of developing ADL disability (HR = 1.062, 95% CI: 1.054–1.069). This association persisted even after adjusting for multiple confounding factors (HR = 1.033, 95% CI: 1.025–1.042).

Subgroup analyses and interaction test

In this study, we examined the relationship between Activities of Daily Living (ADL) as the independent variable and depressive symptoms (DS) as the dependent variable. The results were visualized using a forest plot to present subgroup analyses stratified by various covariates and their interaction effects. After adjusting for age, gender, education, marital status, residence, alcohol consumption, smoking, social activity, chronic diseases, disability, and pain, the association between ADL and DS remained statistically significant across all subgroups. Notably, education level, social activity, and disability demonstrated significant stratification differences, suggesting that these factors may modulate the impact of ADL on DS. However, while these covariates influenced the relationship to some extent, they did not substantially alter the fundamental association between ADL and DS. This finding underscores the robust and direct effect of ADL on DS risk. Our results indicate that although

covariates such as education, social activity, and disability play a moderating role in the relationship between ADL and DS, the core association remains strong and consistent. These insights enhance our understanding of how ADL influences depressive symptoms and highlight potential areas for targeted interventions to mitigate DS risk in vulnerable populations (Fig. 2).

In this study, we investigated the relationship between DS as the independent variable and ADL disability as the dependent variable. The results were visualized using a forest plot to illustrate subgroup analyses stratified by various covariates and their interaction effects. After adjusting for age, gender, education level, marital status, residence, alcohol consumption, smoking habits, social activity, chronic diseases, disability, and pain, the association between DS and ADL disability remained statistically significant across all subgroups. Notably, age, education level, marital status, residence, social activity, disability, and pain demonstrated significant stratification differences, indicating that these factors may modulate the impact of DS on ADL disability. However, while these covariates influenced the relationship to some extent, they did not substantially alter the fundamental association between DS and ADL disability. This finding highlights the robust and direct effect of DS on ADL disability risk. Our results suggest that although covariates such as age, education, marital status, residence, social activity, disability, and pain play a moderating role in the relationship between DS and ADL disability, the core association remains strong and consistent. These insights enhance our understanding of how depressive symptoms influence activities of daily living and underscore potential areas for targeted interventions to mitigate ADL disability risk in vulnerable populations (Fig. 3).

Sensitivity analysis

To further validate our findings, we conducted a sensitivity analysis based on Model 4. Participants with baseline values for ADL disability and depressive symptoms DS below the 15th percentile were excluded. The results of this sensitivity analysis (Figs. 4 and 5) demonstrated that the relationship between ADL disability and DS remained consistent with the findings from Model 3, as detailed in Table 3. Specifically, after excluding

Characteristic	Category	Haz. ratio	[95% conf.	interval]	P_value
Age	Below 65	1.179	1.138	1.222	0.449
	Above 65	1.155	1.109	1.202	
Gender	Female	1.136	1.097	1.176	0.147
	Male	1.183	1.134	1.234	
Education	Below primary school	1.111	1.072	1.152	0.015
	Primary school	1.172	1.110	1.237	
	Secondary school	1.179	1.073	1.296	
	High school and above	1.247	1.126	1.381	
Marry	Other conditions	1.160	1.095	1.229	0.960
	Married/cohabiting	1.162	1.127	1.198	
Residence	Urban	1.174	1.120	1.231	0.465
	Rural	1.149	1.112	1.188	
Alcohol drinker	-No	1.152	1.117	1.188	0.590
	-Yes	1.172	1.109	1.239	
Smoking status	-No	1.154	1.120	1.189	0.324
	-Yes	1.193	1.124	1.267	
Social	-No	1.126	1.086	1.168	0.011
	-Yes	1.208	1.161	1.258	
Disability	-No	1.181	1.128	1.236	0.112
	-Yes	1.127	1.088	1.167	
Chronic disease	-No	1.240	1.118	1.376	0.159
	-Yes	1.148	1.116	1.181	
Pain	-No	1.175	1.132	1.221	0.001
	-Yes	1.068	1.024	1.114	

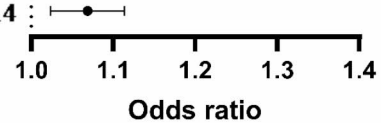

Fig. 2. Forest Plot of Subgroup Analysis for the Effect of ADL on DS Risk.

Characteristic	Category	Haz. ratio	[95% conf.	interval]	P_value
Age	Below 65	1.073	1.063	1.082	0.000
	Above 65	1.043	1.031	1.055	
Gender	Female	1.060	1.050	1.069	0.403
	Male	1.053	1.040	1.066	
Education	Below primary school	1.042	1.032	1.053	0.008
	Primary school	1.062	1.046	1.079	
	Secondary school	1.070	1.052	1.089	
	High school and above	1.069	1.037	1.101	
Marry	Other conditions	1.035	1.018	1.053	0.003
	Married/cohabiting	1.065	1.056	1.073	
Residence	Urban	1.072	1.059	1.086	0.029
	Rural	1.054	1.045	1.063	
Alcohol drinker	-No	1.059	1.050	1.068	0.770
	-Yes	1.061	1.047	1.076	
Smoking status	-No	1.062	1.054	1.071	0.602
	-Yes	1.058	1.043	1.073	
Social	-No	1.053	1.042	1.063	0.047
	-Yes	1.068	1.057	1.079	
Disability	-No	1.068	1.059	1.078	0.000
	-Yes	1.039	1.027	1.051	
Chronic disease	-No	1.055	1.032	1.079	0.820
	-Yes	1.058	1.050	1.066	
Pain	-No	1.061	1.051	1.072	0.000
	-Yes	1.028	1.016	1.040	

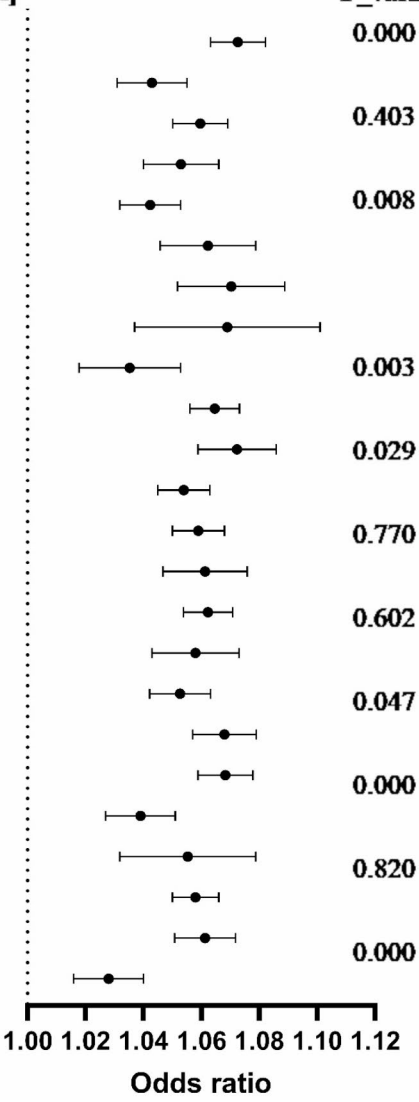

Fig. 3. Forest Plot of Subgroup Analysis for the Effect of DS on ADL Risk.

participants with baseline ADL and DS values below the 15th percentile, the sensitivity analysis confirmed that the association between ADL disability and DS persisted and aligned with the primary model. This consistency highlights the robustness of our Cox proportional hazards regression analysis and reinforces the reliability of our conclusions regarding the relationship between ADL disability and DS.

Discussion

The findings of this study provide robust evidence for a bidirectional relationship between ADL disability and depressive symptoms DS among middle-aged and older adults in China. Our results demonstrate that ADL disability significantly increases the risk of developing DS, while DS is also associated with a higher risk of ADL disability. These associations remained statistically significant even after adjusting for a comprehensive set of sociodemographic, lifestyle, and health-related covariates. The consistency of these findings across multiple models and sensitivity analyses further underscores the robustness of the observed relationships. Notably, covariates such as education level, social activity engagement, and pre-existing disability were found to moderate the impact of ADL on DS, whereas factors such as age, marital status, and chronic pain influenced the association between DS and ADL. Our findings are consistent with those of previous studies[19,34], reinforcing the generalizability of these associations across diverse populations. Previous longitudinal research has clearly indicated that existing disability exerts a more substantial influence on the development of depressive symptoms, while the lagged effect of depressive symptoms on subsequent disability is comparatively weaker[34]. These results highlight the complex interplay between functional limitations and mental health in aging populations, suggesting that interventions targeting either domain may yield reciprocal benefits.

In the process of exploring the risk of ADL disability, our research results clearly show that DS greatly increase the risk of the occurrence of ADL disability. Meanwhile, age is also a highly significant influencing factor. The

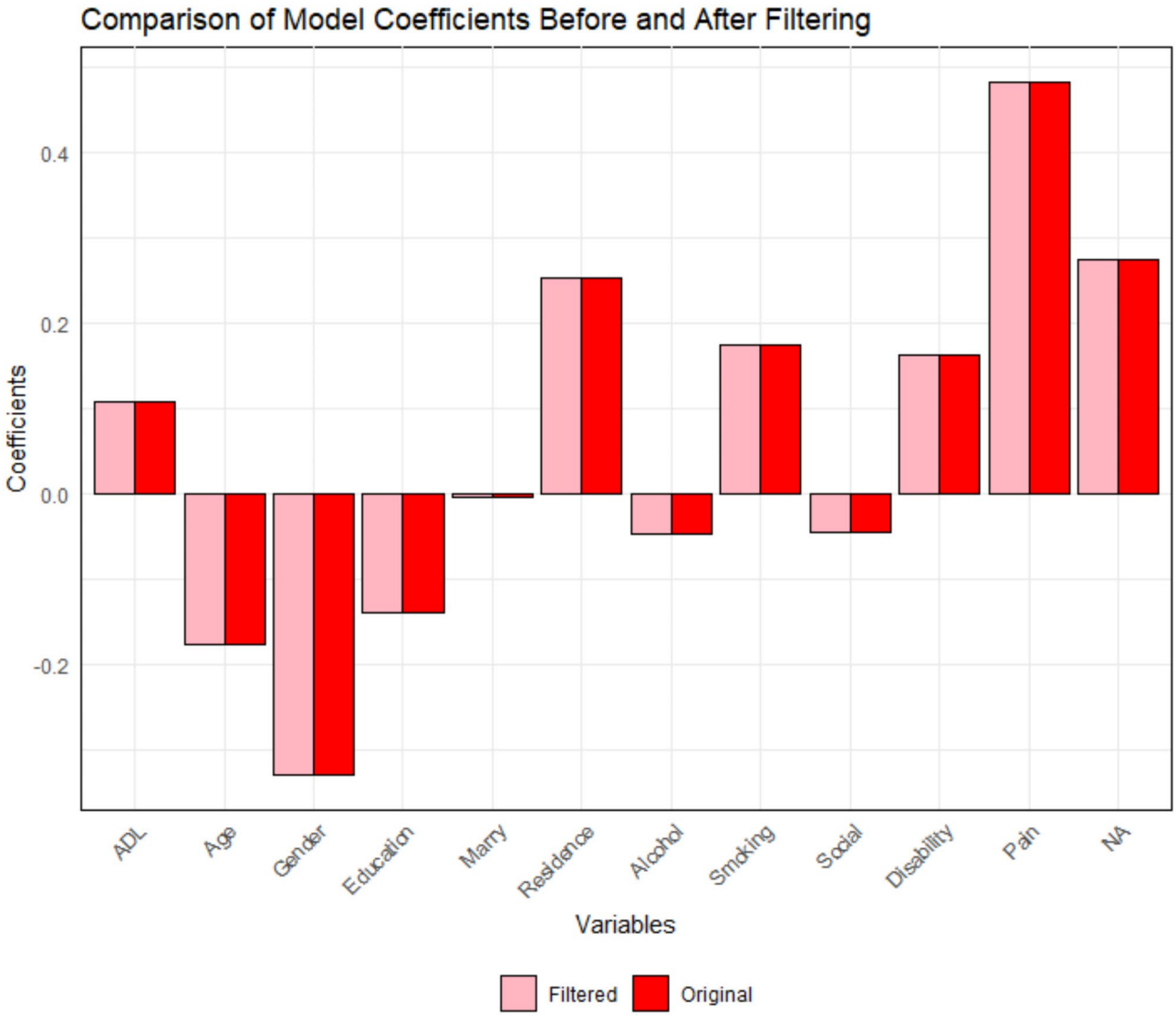

Fig. 4. comparison chart for the Effect of ADL on DS Risk.

development of depression may, to some extent, contribute to the deterioration of ADL disability. This is most likely due to the chronic somatic symptoms associated with depression, such as persistent fatigue. As time goes by, these symptoms will gradually aggravate the degree of physical disability[35]. Elderly people with a depressive tendency often adopt a dysfunctional coping attitude when facing stress. This attitude not only leads to a decrease in enthusiasm and a low mood but also may trigger a series of problems, including ADL disability and other clinical somatic diseases. These symptoms, in turn, will exacerbate the degree of depression, thus forming a vicious cycle[36]. The underlying reason may be that as the age increases, the risk of chronic diseases rises rapidly, thereby accelerating the occurrence of ADL disability[37]. Consistent with previous research results, education has a significant impact on the risk of ADL disability. Among the elderly population in China, there are obvious socioeconomic differences in the aspect of functional health. These differences are particularly prominent in the manifestation of the decline in ADL ability and can be almost entirely attributed to the differences in educational levels. Similarly, previous studies have shown that well - educated elderly people tend to have stronger health awareness, which is closely related to better ADL function[38]. A possible reason is that well - educated elderly people may have more favorable family conditions and can obtain medical services in a timely manner[39]. As they age, their ADL ability will inevitably decline, and this effect may be more prominent in the population over 80 years old[40]. When it comes to the factor of place of residence, research shows that a good living environment can help individuals develop a healthier lifestyle. Compared with rural areas, urban residents usually have higher incomes, better educational levels, and more convenient access to medical services[41].

In the study of the risk of depressive symptoms, our research results indicate that ADL disability is significantly associated with depressive symptoms in the elderly population in China, which is consistent with the conclusions of previous studies[20]. Research shows that those with severely restricted ADL usually have poor physical health and a high level of anxiety about their own conditions. This not only deteriorates their emotional

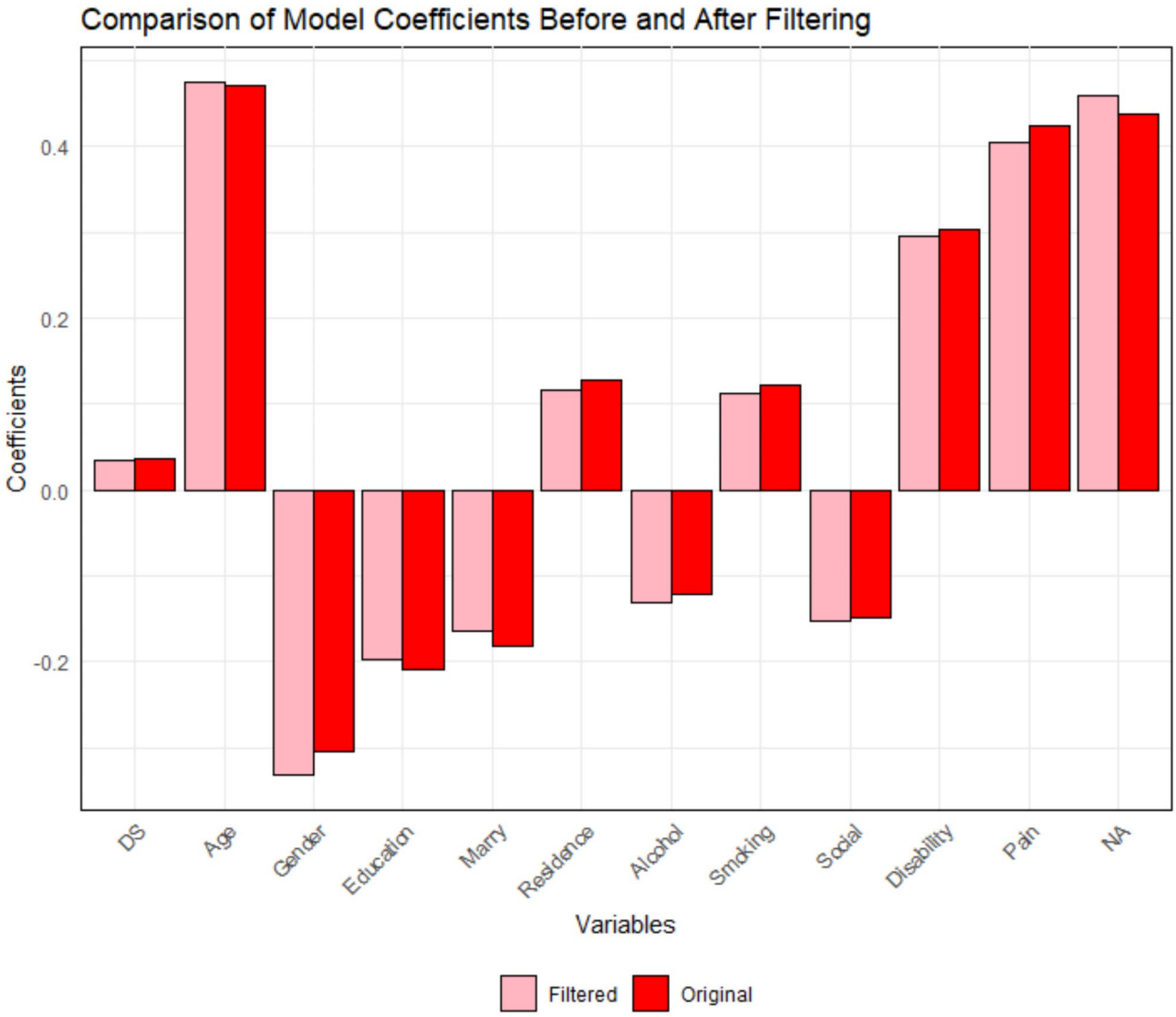

Fig. 5. comparison chart for the Effect of DS on ADL Risk.

Model	Haz.ratio	[95%conf. interval]		*P* > |z|
DS incidence				
Model_1	1.163	1.132	1.194	0.000
Model_2	1.158	1.127	1.190	0.000
Model_3	1.139	1.108	1.171	0.000
Model_4	1.090	1.058	1.123	0.000
ADL disability incidence				
Model 1	1.062	1.054	1.069	0.000
Model 2	1.056	1.049	1.064	0.000
Model 3	1.049	1.041	1.057	0.000
Model 4	1.033	1.025	1.042	0.000

Table 3. Cox proportional hazards regression model results for DS and ADL disability incidence.

state but also substantially increases the likelihood of developing depression[42]. Moreover, ADL disability can be regarded as a stressor. If the elderly continuously encounter difficulties in meeting social and instrumental needs, it may exacerbate their mental health problems and increase the probability of the emergence of depressive symptoms. This long - term stress situation may lead to a further decline in function, forming a vicious cycle

and making the mental health condition even worse[24]. This association may be due to the higher incidence of sleep disorders among the elderly with ADL disability, which in turn increases the occurrence probability of depression[43]. Research indicates that sleep quality plays a crucial mediating role in the relationship between ADL disability and depression. The path from ADL disability to sleep quality and then to depression can explain approximately 20.23% of the magnitude of the impact[44].In addition, the survey conducted on the elderly with cardiovascular diseases shows that the elderly with normal ADL function have a higher life satisfaction, which also reduces their probability of suffering from depression[45]. Life satisfaction has been identified as a mediating factor between ADL function and depressive symptoms in the elderly population. Individuals with better ADL function are more likely to feel that they have the ability to control their lives, which helps to cultivate a sense of self - management and independence[46]. Conversely, the higher life satisfaction resulting from good ADL function can reduce the sense of worthlessness or despair, thereby reducing the risk or severity of depression[47]. When the elderly maintain or improve their ability to independently complete daily tasks, this positive self - assessment can enhance their overall life satisfaction. Therefore, improving life satisfaction can serve as a protective barrier against depression, helping to cultivate a positive mindset, enhance psychological resilience, and establish new life goals, thus reducing the occurrence of depression. Furthermore, the elderly with stronger ADL function may be more involved in social activities and maintain a closer social network[48]. The role of social support in enhancing life satisfaction and preventing depression through providing emotional support, reducing feelings of isolation, and cultivating a sense of belonging has been widely recognized[49].

Our study not only extends the findings on bidirectional associations between DS and ADL impairment but also provides a stronger foundation for research in this field. It deepens our understanding of the interaction mechanisms between these two health issues and offers a robust scientific basis for the development of effective intervention strategies.

Limitations

This study has several limitations. First, the reliance on self-reported data may introduce recall bias. Second, the relatively short follow-up period may limit our ability to capture long-term effects. Future studies should address these limitations by using objective measures and longer follow-up periods.

Conclusions

In conclusion, this study provides compelling evidence for a bidirectional relationship between ADL disability and depressive symptoms DS among middle-aged and older adults in China. Our findings highlight that ADL disability significantly increases the risk of DS, while DS also elevates the risk of ADL disability, even after adjusting for a wide range of sociodemographic, lifestyle, and health-related factors. The robustness of these associations was further confirmed through sensitivity analyses and subgroup analyses, which revealed that covariates such as education level, social activity, disability, age, marital status, and pain play important roles in modulating these relationships. These insights underscore the importance of addressing both functional limitations and mental health in aging populations through integrated interventions. Future research should explore the mechanisms underlying these associations and evaluate the effectiveness of targeted strategies to mitigate the reciprocal risks of ADL disability and DS, ultimately improving the quality of life for older adults.

Data availability

The CLHLS questionnaires are available at https://sites.duke.edu/centerforaging/programs/chinese-longitudinal-healthy-longevity-survey-clhls/survey-documentation/questionnaires/. The full datasets used in this analysis are available from the corresponding author upon reasonable request.

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Author contributions

Wenjing Yan made significant contributions to the experimental design, data processing, and analysis, and was involved in drafting the manuscript. Lina Wang, Chao Li, and Yihan Meng contributed to the data analysis and reviewed and revised the initial draft of the manuscript. Qi Guo and Hongjuan Li, as corresponding authors,

jointly led the overall research direction, supervised the entire research process, and reviewed and approved the final version of the manuscript. All authors read and agreed to the published version of the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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