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Interactive Effects of Falls, Cognitive Function, and Cardiometabolic Multimorbidity on ADL Impairment in Older Adults: Cross-National Comparison with an ICU Perspective

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Abstract

Background

ADL impairment is a significant public health issue, especially in older ICU patients, where factors like falls, cognitive decline, and cardiometabolic multimorbidity (CMM) are compounded by critical conditions. The combined effects of these factors on ADL and their cross-country differences in ICU settings are not well understood. This study explores their independent and interactive associations with ADL impairment among older adults in China and the US, particularly those in ICU care, to improve understanding of functional recovery and long-term outcomes.

Methods

Data were obtained from CHARLS 2015 (n=6,136) and HRS 2014 (n=7,988) for adults aged ≥60. ADL disability was the outcome, with exposures including falls, cognitive z-scores, and CMM (≥2: hypertension, heart disease, stroke). Hierarchical logistic models assessed associations, focusing on a significant four-way interaction (fall × cognition × CMM × country).

Results

Falls (OR=2.100), poorer cognition (OR=0.781), and CMM (OR=1.669) independently increased ADL impairment. A significant interaction (OR=0.796) revealed cohort-specific patterns. In CHARLS, falls had stronger effects on ADL impairment at higher cognitive levels, while in HRS-CMM, falls consistently increased ADL impairment across cognitive tertiles. No interactions were found in non-CMM groups.

Conclusion

Falls, cognition, and CMM are key predictors of ADL impairment. Cognitive modulation of the fall-ADL relationship differs by country, highlighting the need for context-specific, multimorbidity-focused strategies to maintain functional independence.

Key Words

ADL, falls, cognitive function, CMM

Introduction

Functional independence, measured by Activities of Daily Living (ADL), is crucial for older adults' well-being, with ADL impairment linked to poor health outcomes and increased public health burdens[1]. Falls, cognitive impairment, and cardiometabolic multimorbidity (CMM) are key contributors: falls cause injury and decline, cognitive deficits hinder functioning, and CMM exacerbates limitations through accumulated stress[2]. In older adults, particularly those in intensive care units (ICUs), these factors are amplified. ICU settings, characterized by immobility, sedation, and severe conditions, worsen physical and cognitive decline, increasing the risk of ADL impairment. Falls, cognitive issues, and CMM complicate functional recovery, making ICU care crucial for managing ADL disability.

While each factor independently predicts ADL impairment, their interactions remain understudied. Cognitive decline may increase fall risk, and CMM can affect both physical and cognitive capabilities, creating complex pathways influencing outcomes. However, these interactions are not well understood[3, 4]. Cross-national comparisons are limited, despite differences in risk factors, healthcare systems, and aging contexts. Datasets from CHARLS and HRS offer a unique opportunity to explore whether these relationships are consistent across countries or reflect context-specific mechanisms.

This study investigates the independent and interactive effects of falls, cognitive function, and CMM on ADL impairment in older adults in China and the US, aiming to inform context-specific strategies for maintaining functional independence in aging populations.

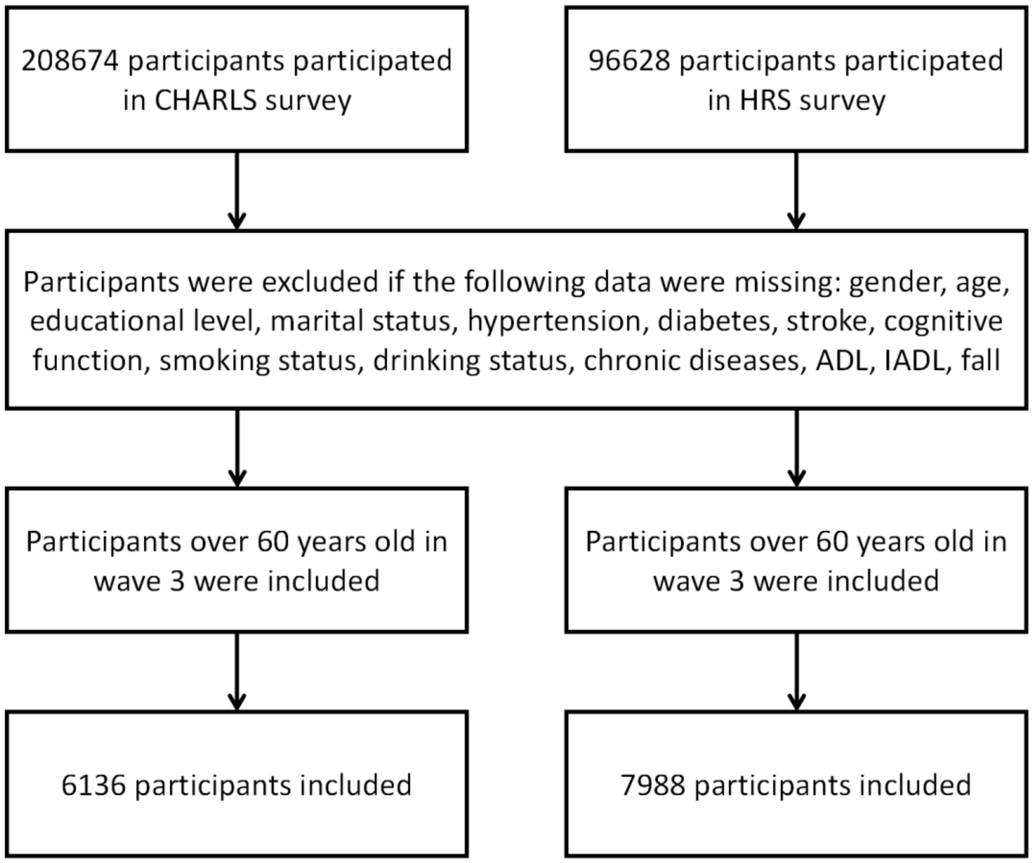
Methods

Study Design and Data Collection

This study utilized cross-sectional data from two large-scale, nationally representative longitudinal cohort studies of middle-aged and older adults: the CHARLS and the HRS in the United States. The National School of Development at Peking University provided the data sets in the CHARLS. The original CHARLS study was approved by the Institutional Review Board (IRB) of Peking University (approval number: IRB00001052-11015 for the household survey and IRB00001052-11014 for blood samples)[5]. The HRS has been approved by the University of Michigan Institutional Review Board in the United States (IRB number: HUM0061128)[6]. All participants provided written informed consent. The original survey data involved in this study were sourced from the CHARLS database (https://charls.charlsdata.com/) and HRS database (https://hrs.isr.umich.edu/data-products).

Data from CHARLS wave 3 (2015) and HRS wave 12 (2014) were used. The analytical sample included community-dwelling individuals aged 60 years and older who had complete data on all study variables. After applying these criteria, the final sample comprised 6,136 participants from CHARLS and 7,988 participants from HRS (Figure 1).

Figure 1. Flowchart of Study Participant Selection



ADL disability was defined as having difficulty performing at least one of six basic tasks (bathing, dressing, eating, toileting, transferring, and indoor walking); otherwise, participants were classified as non-disabled. Exposures included: (1) self-reported falls within the past two years; (2) cognitive function, assessed using shared CHARLS–HRS tests (episodic memory, orientation, visuospatial ability) and standardized within cohorts as z-scores, with higher scores indicating better cognition; and (3) cardiometabolic multimorbidity (CMM), defined as having two or more of hypertension, heart disease, or stroke. Covariates included gender, age, education (primary or less, secondary/high school, college or higher), marital status (married vs. not), smoking (ever vs. never), and drinking status (ever vs. never).

Statistical Analysis

Descriptive statistics were generated for all variables, with continuous data summarized as mean ± SD and categorical data as counts and percentages. Baseline differences between CHARLS and HRS were tested using independent t-tests and Chi-squared tests. Binary logistic regression was used to examine associations between falls, cognitive function, CMM, and ADL impairment. A hierarchical modeling strategy was applied: Model 1 included sociodemographic covariates and country; Model 2 added main exposures; Model 3 added all two-way interactions; and Model 4 incorporated all three-way and four-way interactions. Continuous variables (age, cognition) were grand-mean centered before interaction construction. Because a significant four-way interaction (fall × cognition × CMM × country) emerged in Model 4, stratified logistic regressions were conducted by country and CMM status (CHARLS_CMM0, CHARLS_CMM1, HRS_CMM0, HRS_CMM1). For HRS_CMM1, simple effects of falls were further evaluated across cognitive tertiles (low, medium, high) based on mean ± SD z-score ranges. All stratified models adjusted for sociodemographic covariates. Odds ratios and 95% CIs were reported. Analyses were performed in Stata 17.0, with $p < 0.05$ considered statistically significant.

Results

Characteristics of Study Participants

Table 1 summarizes baseline characteristics for CHARLS (n=6,136) and HRS (n=7,988) participants, showing substantial demographic differences. CHARLS participants were younger (67.36 ± 6.01 vs. 75.38 ± 7.08 years, $p < 0.0001$) and included more males (56.3% vs. 39.3%, $p < 0.0001$). Educational levels differed markedly: 90.4% of CHARLS respondents had primary education or below, whereas 30.3% of HRS participants had secondary or higher education ($p < 0.0001$). Marital status also varied, with 80.5% married in CHARLS compared with 53.5% in HRS ($p < 0.0001$).

Table 1. Characteristics of Study Participants in CHARLS and HRS Datasets.

Characteristics	CHARLS (N=6136)	HRS (N=7988)	***p***
Age, years, Mean ± SD	67.36 ± 6.01	75.38 ± 7.08	<0.0001
Gender, n (%)			<0.0001
Male	3459 (56.3%)	3141 (39.3%)	
Female	2677 (43.6%)	4847 (60.6%)	
Education Level, n (%)			<0.0001
Primary or less	5552 (90.4%)	1460 (18.2%)	
Secondary/High School	455 (7.4%)	4721 (59.1%)	
College or higher	129 (2.1%)	1807 (22.6%)	
Marital Status, n (%)			<0.0001

Characteristics	CHARLS (N=6136)	HRS (N=7988)	***p***
Married	4943 (80.5%)	4277 (53.5%)	
Not Married	1193 (19.4%)	3711 (46.4%)	
Smoking Status, n (%)			0.0002
Ever smoker	3179 (51.8%)	4393 (54.9%)	
Never smoker	2957 (48.1%)	3595 (45.0%)	
Drinking Status, n (%)			0.0693
Ever drinker	3095 (50.4%)	3906 (48.8%)	
Never drinker	3041 (49.5%)	4082 (51.1%)	
Cognitive Function, Mean ± SD	0.05 ± 0.81	-0.22 ± 1.03	0.3820
ADL Difficulty, n (%)	1348 (21.9%)	1591 (19.9%)	0.0030
IADL Difficulty, n (%)	1391 (22.6%)	1334 (16.7%)	<0.0001
CMM, n (%)	380 (6.1%)	1268 (15.8%)	<0.0001
Fall, n (%)	2134 (34.7%)	2744 (34.3%)	0.6047

Health behaviors and outcomes showed mixed patterns across cohorts. Smoking differed slightly but significantly (p = 0.0002), while drinking status was similar (p = 0.0693). Cognitive function z-scores did not differ meaningfully (CHARLS: 0.05 ± 0.81; HRS: −0.22 ± 1.03, p = 0.3820). ADL difficulty (21.9% vs. 19.9%, p = 0.0030) and IADL difficulty (22.6% vs. 16.7%, p < 0.0001) were more common in CHARLS. In contrast, CMM (15.8% vs. 6.1%) and arthritis (69.8% vs. 45.6%) were substantially more prevalent in HRS (both p < 0.0001). Falls were nearly identical between cohorts (34.7% vs. 34.3%, p = 0.6047), as was hip fracture prevalence (p = 0.0627).

Hierarchical Binary Logistic Regression Models for ADL Impairment

Table 2 summarizes hierarchical logistic regression results for ADL impairment. In Model 1, ADL impairment was significantly associated with older age, female gender, lower education, unmarried status, and smoking. HRS participants had higher odds of impairment than CHARLS participants (OR = 1.644, p < 0.001). Model 2 added fall, cognitive function, and CMM, all of which were independently significant: fall (OR = 2.100), better cognition (OR = 0.781), and CMM (OR = 1.669), with improved model fit. Model 3 introduced two-way interactions, identifying significant effects for cognition × CMM (OR = 0.892) and CMM × country (OR = 0.569). Model 4 incorporated all higher-order interactions and revealed a significant four-way interaction—fall × cognition × CMM × country (OR = 0.796, p = 0.040)—indicating that the joint influence of these factors on ADL impairment differs between cohorts. A significant three-way interaction (fall × cognition × CMM) also emerged (OR = 1.583, p < 0.001), warranting stratified analyses.

Table 2. Hierarchical Binary Logistic Regression Models for Predicting ADL Impairment.

Variable	Model 1		Model 2		Model 3		Model 4	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Covariates								
Gender	0.791 (0.713–0.877)	<0.001	0.788 (0.710–0.874)	<0.001	0.788 (0.710–0.874)	<0.001	0.788 (0.710–0.875)	<0.001
Age	1.027 (1.020–1.034)	<0.001	1.027 (1.020–1.034)	<0.001	1.027 (1.020–1.034)	<0.001	1.027 (1.020–1.034)	<0.001
Education	0.689 (0.619–0.766)	<0.001	0.688 (0.619–0.765)	<0.001	0.688 (0.618–0.765)	<0.001	0.687 (0.618–0.765)	<0.001
Marital Status	0.831 (0.765–0.903)	<0.001	0.831 (0.765–0.903)	<0.001	0.831 (0.765–0.903)	<0.001	0.828 (0.762–0.900)	<0.001
Smoking Status	1.160 (1.052–1.280)	0.003	1.159 (1.051–1.279)	0.003	1.159 (1.051–1.279)	0.003	1.159 (1.050–1.278)	0.003
Drinking Status	0.783 (0.713–0.859)	<0.001	0.784 (0.714–0.860)	<0.001	0.784 (0.714–0.860)	<0.001	0.783 (0.713–0.860)	<0.001
Country	0.547 (0.466–0.642)	<0.001	0.545 (0.464–0.640)	<0.001	0.545 (0.464–0.640)	<0.001	0.521 (0.432–0.628)	<0.001
Main Effects								
Fall	2.374 (2.178–2.588)	<0.001	2.272 (2.063–2.503)	<0.001	2.275 (2.064–2.508)	<0.001	2.130 (1.865–2.434)	<0.001
CMM	2.158 (1.914–2.433)	<0.001	2.007 (1.688–2.388)	<0.001	2.016 (1.688–2.407)	<0.001	2.119 (1.547–2.902)	<0.001
Cognitive Function	0.748 (0.714–0.783)	<0.001	0.781 (0.733–0.833)	<0.001	0.780 (0.729–0.833)	<0.001	0.772 (0.693–0.860)	<0.001
Two-Way Interactions								
Fall × Cognitive Function			0.919 (0.843–1.002)	0.056	0.923 (0.839–1.016)	0.102	0.917 (0.780–1.078)	0.294
Fall × CMM			1.128 (0.891–1.429)	0.317	1.118 (0.870–1.437)	0.384	1.124 (0.707–1.788)	0.621
Cognitive Function × CMM			0.971 (0.869–1.085)	0.605	0.982 (0.842–1.146)	0.821	0.677 (0.448–1.023)	0.064
Fall × Country							1.152 (0.948–1.401)	0.155
Cognitive Function × Country							1.009 (0.882–1.155)	0.891
CMM × Country							0.986 (0.670–1.449)	0.941
Three-Way Interactions								
Fall × Cognitive Function × CMM					0.977 (0.783–1.219)	0.834	1.664 (0.940–2.945)	0.080
Fall × Cognitive Function × Country							1.028 (0.840–1.259)	0.787
Fall × CMM × Country							0.893 (0.510–1.564)	0.693
Cognitive Function × CMM × Country							1.532 (0.978–2.400)	0.063
Four-Way Interaction								
Fall × Cognitive Function × CMM × Country							0.529 (0.283–0.989)	0.046

OR: Odds Ratio; 95% CI: 95% Confidence Interval. ADL impairment (binary: 0 = no impairment, 1 = impaired). Country: 0 = CHARLS (China), 1 = HRS (USA). CMM: Cardiovascular Comorbidity. Model 1: Adjusted for all covariates and main effects of fall, CMM, cognitive function, and country. Model 2: Adds all two-way interaction terms. Model 3: Adds the three-way interaction term (Fall × Cognitive Function × CMM). Model 4: Adds all interactions involving the 'country' variable, up to the four-way interaction term.

Stratified Analyses of Fall, Cognitive Function, and CMM Effects on ADL Impairment

Table 3 presents stratified logistic regression results based on the significant four-way interaction. In CHARLS without CMM, both falls (OR = 2.000, $p < 0.001$) and better cognition (OR = 0.765, $p < 0.001$) predicted lower ADL impairment, with no significant fall × cognition interaction. In CHARLS with CMM, falls (OR = 2.500, $p < 0.001$) and cognition (OR = 0.496, $p = 0.001$) remained significant. Although the interaction was nonsignificant overall, simple effects showed a strong fall effect in the high cognition tertile (OR = 4.848), weaker in the medium (OR = 2.871), and nonsignificant in the low tertile. In HRS without CMM, falls (OR = 2.474, $p < 0.001$) and cognition (OR = 0.814, $p < 0.001$) were significant, with no interaction. In HRS with CMM, falls (OR = 2.516, $p < 0.001$) and cognition (OR = 0.801, $p = 0.009$) also predicted ADL impairment, and the interaction remained nonsignificant. Simple effects showed falls consistently elevated ADL impairment across cognitive tertiles (ORs 4.503, 2.715, 2.542).

Overall, falls and cognition were robust predictors across groups, but cognitive modulation of the fall–ADL relationship differed between CHARLS and HRS in the presence of CMM, supporting the four-way interaction.

Table 3. Stratified Logistic Regression Analysis of Factors Associated with ADL Impairment in CHARLS and HRS Datasets.

Variable	CHARLS				HRS			
	No CMM		With CMM		No CMM		With CMM	
	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*	OR (95% CI)	*p*
Main Effects								
Fall	2.000 (1.700–2.300)	<0.001	2.500 (1.900–3.200)	<0.001	2.474 (2.141–2.859)	<0.001	2.516 (1.901–3.331)	<0.001
Cognitive Function	0.765 (0.685–0.855)	<0.001	0.496 (0.328–0.749)	0.001	0.814 (0.746–0.888)	<0.001	0.801 (0.682–0.942)	0.007
Interaction Term								
Fall × Cognitive Function		0.336	1.500 (0.900–2.500)	0.102	0.945 (0.837–1.068)	0.366	0.837 (0.668–1.050)	0.124
Simple Effects of Fall on ADL Impairment within CMM-Affected Subgroups by Cognitive Function Tertiles								
Low Cognitive Function			1.683 (0.516–5.490)	0.388			4.503 (2.217–9.144)	<0.001
Medium Cognitive Function			2.871 (1.630–5.057)	<0.001			2.715 (2.035–3.622)	<0.001
High Cognitive Function			4.848 (1.218–19.296)	0.025			2.542 (1.091–5.925)	0.031

OR: Odds Ratio; 95% CI: 95% Confidence Interval. ADL impairment (binary: 0 = no impairment, 1 = impaired). CMM: Cardiovascular Comorbidity. Columns "No CMM" and "With CMM" represent separate logistic regression models stratified by CMM status within CHARLS and HRS datasets respectively. All models were adjusted for gender, age, education, marital status, smoking status, and drinking status.

Discussion

This study examines the individual and interactive effects of falls, cognitive function, and cardiometabolic multimorbidity (CMM) on ADL impairment in older adults using large-scale data from China and the US. The results confirm that falls, lower cognitive function, and CMM are significant independent predictors of ADL impairment, supporting prior research on their contribution to functional decline[7, 8]. This highlights the importance of addressing each factor in clinical and public health efforts to reduce ADL dependence.

A key finding is the four-way interaction (fall × cognitive function × CMM × country), showing that the combined impact of these factors on ADL impairment varies by population and CMM presence. Stratified analyses revealed distinct patterns: in CHARLS (China), falls had a stronger effect on ADL impairment in those with higher cognitive function, suggesting that falls disrupt the compensatory ability of better cognition in Chinese older adults. In contrast, in HRS (US), falls consistently increased ADL impairment across all cognitive levels, indicating a more uniform vulnerability in older adults. These differences may stem from variations in CMM prevalence, healthcare systems, and cultural factors, underlining the role of CMM in shaping outcomes.

These findings emphasize the need for individualized ICU care, as falls, cognitive decline, and multimorbidity increase risks. ICU conditions like immobility and sedation exacerbate physical and cognitive decline, making fall prevention and cognitive support critical for recovery. Tailored interventions are essential. While universal interventions for fall prevention, cognitive health, and CMM management are needed, the interactions identified suggest a personalized approach is necessary[9, 10]. Clinicians should be especially cautious about fall risk in older adults with CMM, as its impact varies with cognitive status and geographic context[11, 12].In China, older adults with CMM and preserved cognition may experience rapid functional decline after a fall, requiring intensive intervention. In the US, falls consistently threaten functional independence for all older adults with CMM. These findings support integrated care models that assess physical, cognitive, and multimorbidity status to tailor interventions, moving away from a "one-size-fits-all" approach[13, 14].

A major strength of this study is the use of two large, nationally representative datasets (CHARLS and HRS), enabling robust analyses and meaningful cross-national comparisons. The hierarchical modeling approach further clarified complex interaction patterns. However, limitations include the cross-sectional design, reliance on self-reported falls, and broad measures of cognitive function and CMM. Future research should adopt longitudinal designs to establish causality, examine dynamic interactions, and develop targeted interventions for high-risk groups. More detailed assessments of individual CMM components and qualitative studies could also deepen understanding of these multifaceted relationships.

Conclusion

Falls, cognitive function, and CMM are significant predictors of ADL impairment. Our findings show that cognitive function’s role in the fall-ADL relationship, especially with multimorbidity, differs between China and the US, highlighting the need for culturally tailored interventions to maintain functional independence.

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