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Cross-sectional study of activity habits, socioeconomic status, and cognitive performance in central China's adult population

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Activity habits has been demonstrated to confer cognitive benefits. However, the extent to which these activities can mitigate cognitive disparities in older adults resulting from socioeconomic inequality remains unclear. We assessed cognitive performance and leisure activities in participants aged ≥ 65 years from 31 urban and 48 rural communities in Central China. A life-cycle composite socioeconomic status (SES) index incorporating education, occupational prestige, disposable income, and healthcare facility proximity categorized participants into low-, middle-, and high-SES groups. Logistic and linear regression models were employed to examine the associations between leisure activities and cognition, stratified by sex and age across different SES groups. This cross-sectional survey had a total of 8,597 eligible participants aged ≥ 65 years (mean age: 72.2 years, female: 55.1%). Compared to those of high SES, individuals with middle (*OR* = 1.86, 95% *CI*: 1.57–2.19) and low SES (*OR* = 3.62, 95% *CI*: 2.83–4.64) exhibited a higher prevalence of cognitive impairment and lower cognitive performance. Physical activity and cognitive leisure activity (PA and CLA) demonstrated a linear association with global and sub-domain cognitive performance, with a combined correlation with global cognition (β = 0.13, 95% *CI*: 0.10–0.15) being higher than that of CLA (β = 0.09, 95% *CI*: 0.07–0.11) and PA (β = 0.04, 95% *CI*: 0.02–0.06); our analysis revealed a stronger association between leisure activities and cognitive performance in low-SES individuals, with a notable effect size (combined: β = 0.35, 95% *CI*: 0.25–0.45; CLA: β = 0.27, 95% *CI*: 0.19–0.35 and PA: β = 0.09, 95% *CI*: 0.00–0.16) and in the > 70 years group, both (combined: β = 0.45, 95% *CI*: 0.31–0.59; CLA: β = 0.35, 95% *CI*: 0.24–0.47 and PA: β = 0.12, 95% *CI*: 0.02–0.22) and higher in men (combined: β = 0.39, 95% *CI*: 0.24–0.54; CLA: β = 0.30, 95% *CI*: 0.19–0.40 and PA: β = 0.09, 95% *CI*: -0.03–0.20). Our findings indicate that leisure activities are significantly associated with cognitive performance among older adults across all SES groups, particularly those in low SES categories. This study supports engagement in cognitively stimulating activities to prevent dementia in older adults of low SES.

Keywords Physical activity, Cognitive leisure activity, Socioeconomic status (SES), Cognition, Older adult

Abbreviations

SES	Socioeconomic status
PA	Physical activity
CLA	Cognitive leisure activities
MoCA	Montreal Cognitive Assessment, Chinese version
ADL	Activities of Daily Living Scale
MMSE	Mini-Mental State Examination
SD	Standard deviation
ANOVA	Analysis of variance
EHR	Electronic health records

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AVLT	Auditory Verbal Learning Test
BNT	The Boston Naming Test
STT-A	The Shape Trails Test A
DST	The Digit Span Test
CSC	Childhood socioeconomic status

An increasing number of studies have suggested behavioral correlates of socioeconomic status (SES) in specific neurocognitive systems. Existing evidence indicates that SES, defined individually or jointly by parents' educational level, occupation, and income in early life, affects children's brain structure and cognitive abilities, with high-SES brains exhibiting superior regulatory functions and more efficient neurocognitive processing patterns[1,2]. Brain development can affect the trajectory of cognitive decline in late life through cognitive behavioral patterns and cognitive reserve[3]. Some scholars have proposed that the factors contributing to differences in brain cognitive aging are not limited to early life, but are the result of multiple life processes defined by SES; that is, SES at different stages of life continues to affect the brain in various ways, resulting in a cumulative effect that ultimately impacts the trajectory of cognitive function in later life[4].

Based on the high plasticity of the brain, cognitive reserve is believed to be acquired through stimulating activities or experiences throughout one's life[5]. However, current research on the cognitive impact of lifestyle factors, such as physical activity (PA) and cognitive leisure activities (CLA), has yielded inconsistent results, with some studies suggesting benefits in preventing cognitive impairment[6,7], while others finding no significant effects[8,9]. This inconsistency may be due to the lack of consideration for population differences in SES, sex, and age. Additionally, existing studies are predominantly focused on developed countries, with limited data from low- and middle-income countries.

Given the high prevalence of cognitive decline in older adults, it is crucial to examine the associations between PA, CLA, and cognitive health outcomes, with particular attention to SES differences. Cognitive decline imposes significant burdens, including memory loss and increased medical costs[10]. Research shows that older adults with lower SES experience faster cognitive decline[11].Furthermore, both physical activity and cognitive leisure activities have been demonstrated to have positive impacts on cognitive function[12,13]. While PA and CLA are known to benefit cognitive function, their impact across different SES groups remains unclear. Thus, exploring these relationships is essential for understanding cognitive decline and developing targeted interventions to improve cognitive health and reduce SES-related disparities.

This study utilizes baseline data from the Hubei Memory and Aging Cohort Study (HMACS) to elucidate the associations between cognitively stimulating activities (PA and CLA) and cognitive performance of groups of different SES, and to provide new perspectives on healthy aging in low- and middle-income countries.

Methods

Study design and participants

The Hubei Memory & Aging Cohort Study (HMACS) (registered in June 2018; Clinical Trial Registration No: ChiCTR1800019164) is an ongoing community-based prospective dynamic cohort study funded by the Ministry of Science and Technology of China and the National Natural Science Foundation of China[14]. This study employed a random selection process to identify 31 urban communities across four districts in Wuhan, and 48 rural villages from four towns in Dawu County, Hubei Province. The study population comprised individuals aged 65 years and older residing in these selected areas, provided that they had existing electronic health records (EHR) at local healthcare facilities. Participants engaged in extensive face-to-face interviews lasting approximately 90 min and underwent a battery of neuropsychological cognitive function assessments at baseline. Exclusion criteria encompassed long-term bedridden status, severe mental health conditions (including major depressive disorder, bipolar disorder, and schizophrenia), life-threatening illnesses, and severe sensory impairments that would impede assessment procedures. The study protocol was approved by the Medical Ethics Committee of Wuhan University of Science and Technology (Approval No: 201845), and was conducted in strict accordance with the Declaration of Helsinki principles for medical research involving human subjects, the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines[15], and all applicable national regulations. All participants provided written informed consent prior to enrollment.

Full-cycle integrated SES

In this study, we developed a comprehensive full-cycle integrated SES. This index incorporates multiple factors spanning an individual's lifetime: educational attainment in early life, occupational prestige scores[16] during midlife, disposable income in later years, and proximity of current residence to healthcare facilities. The occupational prestige scores were derived from a weighted reputation assessment of 81 professions established by the Institute of Sociology at the Chinese Academy of Social Sciences in 2001. This assessment utilized survey data collected from 12 provinces and municipalities in China. To categorize SES, we employed the latent class analysis procedure (PROC LCA) in SAS, which yielded three distinct strata: high, middle, and low SES (Table S3, Figure S2).

Physical activity and cognitive leisure activity (PA and CLA)

PA encompasses voluntary bodily exertions undertaken to promote physiological health and enhance physical fitness, distinct from occupational or essential activities. CLA comprises recreational pursuits engaged in pleasure and relaxation, with the objective of stimulating cognitive development. PA was evaluated on a scale (0–27 points) considering frequency, duration, and intensity, whereas CLA was assessed similarly (0–27 points) based on frequency, duration, and activity classification (Table S1). The scoring system for both PA and CLA was designed to capture the overall engagement in these activities, with higher scores indicating greater involvement.

Specifically, each dimension (frequency, duration, and intensity/classification) was assigned a maximum score of 3 points, resulting in a total maximum score of 27 points for each activity type. The combined score was computed by aggregating the PA and CLA scores, with all metrics subsequently standardized. The maximum score of 27 represents the highest possible level of engagement in both PA and CLA, reflecting an individual's comprehensive involvement in these activities across all dimensions[17,18].The composed score was computed by aggregating the PA and CLA scores, with all metrics subsequently standardized.

Covariates

Other covariates included sex (self-reported as male or female), age, residence, marital status (currently with/without a spouse), personality traits, number of siblings, number of social friends, smoking status, drinking status, and medical history (hypertension, diabetes, heart disease, cerebrovascular diseases, insomnia, and depression) (Table S1).

Cognitive impairment and cognitive function

A comprehensive battery of neuropsychological assessments was employed to evaluate the cognitive function of study participants. Global cognitive performance was measured using Chinese-adapted versions of the Mini-Mental State Examination (MMSE) and the Montreal Cognitive Assessment-Basic (MoCA-B), both scored from 0 to 30, with higher scores indicating better function. Specific cognitive domains were evaluated using the Auditory Verbal Learning Test (AVLT) for memory, the Boston Naming Test (BNT) for language, the Shape Trails Test A (STT-A) for processing speed, and the Digit Span Test (DST) for attention. The AVLT scores are based on the number of words correctly recalled, while the BNT is scored based on the number of items correctly named on the first attempt, with scores ranging from 0 to 30. The STT-A measures completion time, with lower scores indicating better performance, and the DST scores are based on the number of correctly repeated digits. Cognitive impairment (including Mild Cognitive Impairment and dementia) was identified according to Petersen RC criteria[19] and the "2018 Guidelines for the Diagnosis and Treatment of Dementia and Cognitive Disorders in China"[20]. These tests have demonstrated good reliability and validity, with Cronbach's α ranging from 0.70 to 0.94[21–25] (Table S2).

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics 26.0 (SPSS IBM Corp., Armonk, NY, USA) and R version 4.3.2. Statistical significance was set at p-value < 0.05 (two-tailed). Categorical variables are expressed as n (%), while continuous variables are reported as means (SD) for normal distributions. Cognitive-related scores (MoCA-B, AVLT, BNT, DST, and STT-A) were subjected to normality testing before standardization. The mean was computed for cognitive function with multiple assessment dimensions. Group comparisons were conducted using analysis of variance (ANOVA) and chi-square tests. Logistic regression models were employed to examine the relationships between SES and global/domain-specific cognitive impairment. SES was treated as the independent variable, while global and domain-specific cognitive impairment were defined as the dependent variables. The analyses were conducted across four models, with SES included in all models and covariates introduced progressively: Model 1 included no covariates (crude model); Model 2 adjusted for sociodemographic factors; Model 3 further adjusted for social interactions and lifestyle factors; and Model 4 included additional adjustments for chronic diseases. The associations between PA and CLA scores and cognitive performance (global, memory, language, attention function, and processing speed) were investigated using general linear models across the entire sample and various SES groups. Further stratification was performed according to sex and age. In these models, the independent variables included PA and CLA scores, while the dependent variables were the cognitive performance measures. All models were adjusted for potential confounders, including age, sex, residence, marital status, personality, number of living siblings, number of close friends, smoking status, alcohol consumption, hypertension, diabetes, hyperlipidemia, coronary artery disease, cerebrovascular disease, depression, and insomnia. To ensure the robustness of our results, several sensitivity analyses were performed. These analyses included:1. The use of multiple imputation to address missing variables in the original dataset.2. The exclusion of participants with Parkinson's disease, stroke, or musculoskeletal disorders, as these conditions may affect cognitive function and physical activity.

Results

Participant characteristics

As of June 2024, a total of 10,306 HMACS participants had completed the baseline survey. The study sample was selected based on the following criteria: inclusion of individuals aged 65 years or older, with complete data on PA, CLA, education, occupation, and income. Exclusions were made for individuals under 65 years of age ($n = 2$), those with missing data on PA or CLA ($n = 1{,}105$), education ($n = 156$), occupation ($n = 203$), and income ($n = 243$). After these exclusions, a final sample of 8,597 eligible participants was included with a mean age of 72.2 (SD 6.0) years and a mean years of education of 7.9 (SD 5.2) years in the study (Figure S1). Of these, 4735 (55.1%) were female and 3008 (35.0%) were rural residents; 1683 (19.6%) were of low SES, 3507 (40.8%) were of middle SES, and 3407 (39.6%) were of high SES; 2673 (31.1%) were cognitively impaired. Those with low SES were mostly female, older in age, residing in rural areas, unmarried, with low educational attainment, introverted, and with significantly reduced standardized cognitive abilities (both general and domain-specific) (Table 1).

Association between SES and cognitive impairment

The analysis revealed a low to moderate correlation among the elements of SES, with correlation coefficients ranging from 0.42 to 0.70 (Table S4). The SES and their domain-specific components scores exhibited higher values in the non-cognitive dysfunction group compared to the cognitive dysfunction group (Table S5).The fully

Variable	Participants *n* (%)	Low SES *n* (%)	Middle SES *n* (%)	High SES *n* (%)	χ^2/F	*P*
Demographic characteristics						
Total	8597 (100)	1683 (19.6)	3507 (40.8)	3407 (39.6)	NA	NA
Sex						
Male	3862 (44.9)	669 (39.8)	1466 (41.8)	1727 (50.7)	77.798	**<0.001**
Female	4735 (55.1)	1014 (60.2)	2041 (58.2)	1680 (49.3)		
Age at baseline, mean (SD), y	72.24 ± 6.00	73.62 ± 5.78	71.66 ± 5.86	72.16 ± 6.13	62.347	**<0.001**
Residence						
City	5589 (65.0)	17 (1.0)	2228 (63.5)	3344 (98.2)	4679.009	**<0.001**
Rural	3008 (35.0)	1666 (99.0)	1279 (36.5)	63 (1.8)		
Education, mean (SD), years	7.89 ± 5.23	1.41 ± 2.52	6.64 ± 3.85	12.38 ± 2.85	6891.906	**<0.001**
Personality and social factors						
Spouse						
Yes	6386 (74.8)	948 (56.6)	2564 (73.6)	2874 (85.0)	482.642	**<0.001**
No	2155 (25.2)	727 (43.4)	920 (26.4)	508 (15.0)		
Personality						
Reserved	1406 (17.7)	321 (20.9)	575 (17.9)	510 (16.1)	17.660	**0.001**
Neutral	3270 (41.3)	614 (39.9)	1303 (40.5)	1353 (42.7)		
Sociable	3248 (41.0)	603 (39.2)	1341 (41.7)	1304 (41.2)		
Siblings						
No	4141 (48.8)	636 (38.1)	1855 (53.8)	1650 (49.0)	111.873	**<0.001**
Yes	4345 (51.2)	1035 (61.9)	1592 (46.2)	1718 (51.0)		
Number of close friends						
None	1892 (22.4)	820 (49.7)	839 (24.4)	233 (7.0)	1554.801	**<0.001**
1–2	1448 (17.2)	368 (22.3)	657 (19.1)	423 (12.6)		
3–5	2450 (29.1)	300 (18.2)	973 (28.3)	1177 (35.2)		
≥6	2643 (31.3)	162 (9.8)	967 (28.1)	1514 (45.2)		
Physical and lifestyle behaviors						
Smoking status						
Current/past	2359 (27.5)	470 (28.0)	979 (27.9)	910 (26.7)	1.525	0.466
Never	6227 (72.5)	1209 (72.0)	2525 (72.1)	2493 (73.3)		
Drinking status						
Current/past	2348 (27.4)	571 (34.0)	969 (27.7)	808 (23.8)	59.331	**<0.001**
Never	6231 (72.6)	1109 (66.0)	2531 (72.3)	2591 (76.2)		
Physical activities (PA)						
Never	2399 (27.9)	996 (59.2)	985 (28.1)	418 (12.3)	1285.144	**<0.001**
≤2 times/week	711 (8.3)	145 (8.6)	263 (7.5)	303 (8.9)		
3–6 times/week	448 (5.2)	66 (3.9)	165 (4.7)	217 (6.4)		
Every day	5039 (58.6)	476 (28.3)	2094 (59.7)	2469 (72.5)		
Cognitive leisure activities (CLA)						
Never	3840 (44.7)	1358 (80.7)	1677 (47.8)	805 (23.6)	1636.986	**<0.001**
≤2 times/week	622 (7.2)	103 (6.1)	281 (8.0)	238 (7.0)		
3–6 times/week	727 (8.5)	61 (3.6)	324 (9.2)	342 (10.0)		
Every day	3408 (39.6)	161 (9.6)	1225 (34.9)	2022 (59.3)		
ADL	21.39 ± 3.39	23.05 ± 4.38	21.41 ± 3.57	20.55 ± 2.06	331.529	**<0.001**
Comorbidities						
Hypertension	5526 (64.3)	1043 (62.0)	2274 (64.9)	2209 (64.9)	5.007	0.082
Diabetes	1508 (17.6)	218 (13.0)	629 (18.0)	661 (19.5)	32.550	**<0.001**
Hyperlipidemia	2128 (24.9)	238 (14.2)	887 (25.4)	1003 (29.5)	142.035	**<0.001**
Coronary artery disease	1453 (17.0)	333 (19.9)	536 (15.4)	584 (17.2)	16.432	**<0.001**
Cerebrovascular disease	1755 (20.5)	398 (23.7)	705 (20.2)	652 (19.2)	14.438	**0.001**
Depression	463 (5.6)	178 (10.7)	168 (5.0)	117 (3.6)	107.554	**<0.001**
Insomnia	3421 (44.6)	828 (49.6)	1499 (46.3)	1094 (39.6)	48.734	**<0.001**
Z-PA/CLA and Z-SESs, mean (SD)						
Z-PA	0.00 ± 1.00	− 0.62 ± 0.57	0.03 ± 1.02	0.27 ± 1.01	505.015	**<0.001**
Z-CLA	0.00 ± 1.00	− 0.58 ± 0.60	− 0.02 ± 1.04	0.31 ± 0.99	500.380	**<0.001**
Continued						

Variable	Participants *n* (%)	Low SES *n* (%)	Middle SES *n* (%)	High SES *n* (%)	χ^2/F	*P*
Z-Combined	0.00 ± 0.78	− 0.60 ± 0.46	0.01 ± 0.79	0.29 ± 0.72	901.161	**<0.001**
Z-Education	0.00 ± 1.00	− 1.24 ± 0.48	− 0.24 ± 0.74	0.86 ± 0.54	6891.903	**<0.001**
Z-Job score	0.00 ± 1.00	− 0.86 ± 0.16	− 0.58 ± 0.48	1.02 ± 0.73	9413.739	**<0.001**
Z-Medical distance	0.00 ± 1.00	− 1.65 ± 0.85	0.27 ± 0.61	0.56 ± 0.12	9198.596	**<0.001**
Z-Family income	0.00 ± 1.00	− 1.38 ± 0.45	− 0.16 ± 0.80	0.79 ± 0.45	6801.621	**<0.001**
Z- (SES)*	− 0.01 ± 0.83	− 1.28 ± 0.22	− 0.19 ± 0.40	0.81 ± 0.26	25049.819	**<0.001**
Cognition and Z-Cognition, mean (SD)						
Cognitive state						
Normal	5924 (68.9)	697 (41.4)	2358 (67.2)	2867 (84.2)	1087.387	**<0.001**
MCI [a]	2079 (24.2)	678 (40.3)	910 (25.9)	491 (14.4)		
Dementia	594 (6.9)	308 (18.3)	239 (6.8)	47 (1.4)		
MoCA-B	22.08 ± 6.33	15.12 ± 6.02	21.76 ± 5.70	25.85 ± 3.40	2617.394	**<0.001**
MMSE	26.20 ± 4.72	21.03 ± 5.41	26.19 ± 4.23	28.75 ± 1.93	2320.169	**<0.001**
Z-Memory	− 0.06 ± 0.90	− 0.69 ± 0.69	− 0.14 ± 0.86	0.35 ± 0.81	524.947	**<0.001**
Z-Language	0.00 ± 0.88	− 0.45 ± 0.82	− 0.10 ± 0.81	0.29 ± 0.86	438.741	**<0.001**
Z-Attention	0.00 ± 0.89	− 0.74 ± 0.64	− 0.07 ± 0.80	0.53 ± 0.74	985.592	**<0.001**
Z- Processing Speed [b]	0.00 ± 1.00	− 1.05 ± 0.90	− 0.14 ± 0.93	0.46 ± 0.76	701.241	**<0.001**

Table 1. The characteristics of the baseline participants about different SES groups. Note: Continuous variables are presented as mean (SD) and categorical variables as number (percentage). Differences between two groups were analyzed by Chi-square tests for categorical variables and T or variance or the Wilcoxon rank sum tests for numerical variables. P-value corrected by Bonferroni. [a]Mild Cognitive Impairment. [b]Reverse Standard Score.

Variables	Model 1		Model 2		Model 3		Model 4	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
SES (Ref: High)								
Middle	2.59 (2.31, 2.91)	**<0.001**	2.39 (2.07, 2.75)	**<0.001**	1.99 (1.72,2.31)	**<0.001**	1.86 (1.57, 2.19)	**<0.001**
Low	7.51 (6.57, 8.59)	**<0.001**	4.74 (3.82, 5.89)	**<0.001**	3.68 (2.93, 4.62)	**<0.001**	3.62 (2.83, 4.64)	**<0.001**

Table 2. Association of socioeconomic status with cognitive impairment at baseline. Note: Results were derived from multivariate logistic regression models. Model 1: Crude Model; Model 2: Demographic Adjusted Model (adjusted variables: age, sex, residence, marital status and personality); Model 3:On the basis of model 2, social interaction and living habits were further adjusted (further adjusted variables : living siblings, number of close friends, smoking, drinking, physical activity and intellectual activity); Model 4: Full Covariate Adjusted Model (further adjusted variables : smoking, drinking, hypertension, diabetes, hyperlipidemia, coronary artery disease, cerebrovascular disease, depression, and insomnia). *OR* odds ratio, *CI* confidence interval.

adjusted model indicated that, in comparison to the high-SES group, the prevalence of cognitive impairment was significantly higher, and the odds ratio (OR) for cognitive impairment was 1.86 (95% CI: 1.57–2.19) in the middle-SES group and 3.62 (95% CI: 2.83–4.64) in the low-SES group (Table 2).

Association of PA and CLA with cognitive performance

Leisure activities, including PA, CLA, and their combined scores, demonstrated a linear association with global and subdomain cognitive performance. The combined PA and CLA scores showed a stronger correlation with global cognition ($\beta = 0.13$, 95% CI: 0.10–0.15) compared to CLA alone ($\beta = 0.09$, 95% CI: 0.07–0.11) and PA alone ($\beta = 0.04$, 95% CI: 0.02–0.06). This association with global cognition was stronger in the low SES population, with combined scores showing a β of 0.35 (95% CI: 0.25–0.45), compared to middle SES ($\beta = 0.13$, 95% CI: 0.10–0.17) and high SES ($\beta = 0.05$, 95% CI: 0.02–0.08). For CLA, the β values were 0.27 (95% CI: 0.19–0.35) in low SES, 0.09 (95% CI: 0.06–0.11) in middle SES, and 0.04 (95% CI: 0.02–0.06) in high SES. For PA, the β values were 0.09 (95% CI: 0.00–0.16) in low SES, 0.05 (95% CI: 0.02–0.07) in middle SES, and 0.01 (95% CI: -0.01–0.03) in high SES.(Fig. 1, Table S6).

In terms of cognitive domains, combined PA and CLA scores were associated with memory function ($\beta = 0.10$, 95% CI: 0.06–0.15), while CLA alone showed a β of 0.07 (95% CI: 0.03–0.10) and PA alone showed a β of 0.04 (95% CI: 0.01–0.07). Combined scores were also associated with language function ($\beta = 0.03$, 95% CI: 0.00–0.06) across all participants.(Fig. 1, Table S6).

Age-stratified analyses revealed stronger associations in participants aged > 70 years compared to those ≤ 70 years. For the > 70 years group, the combined β was 0.20 (95% CI: 0.16–0.24), CLA β was 0.12 (95% CI: 0.09–

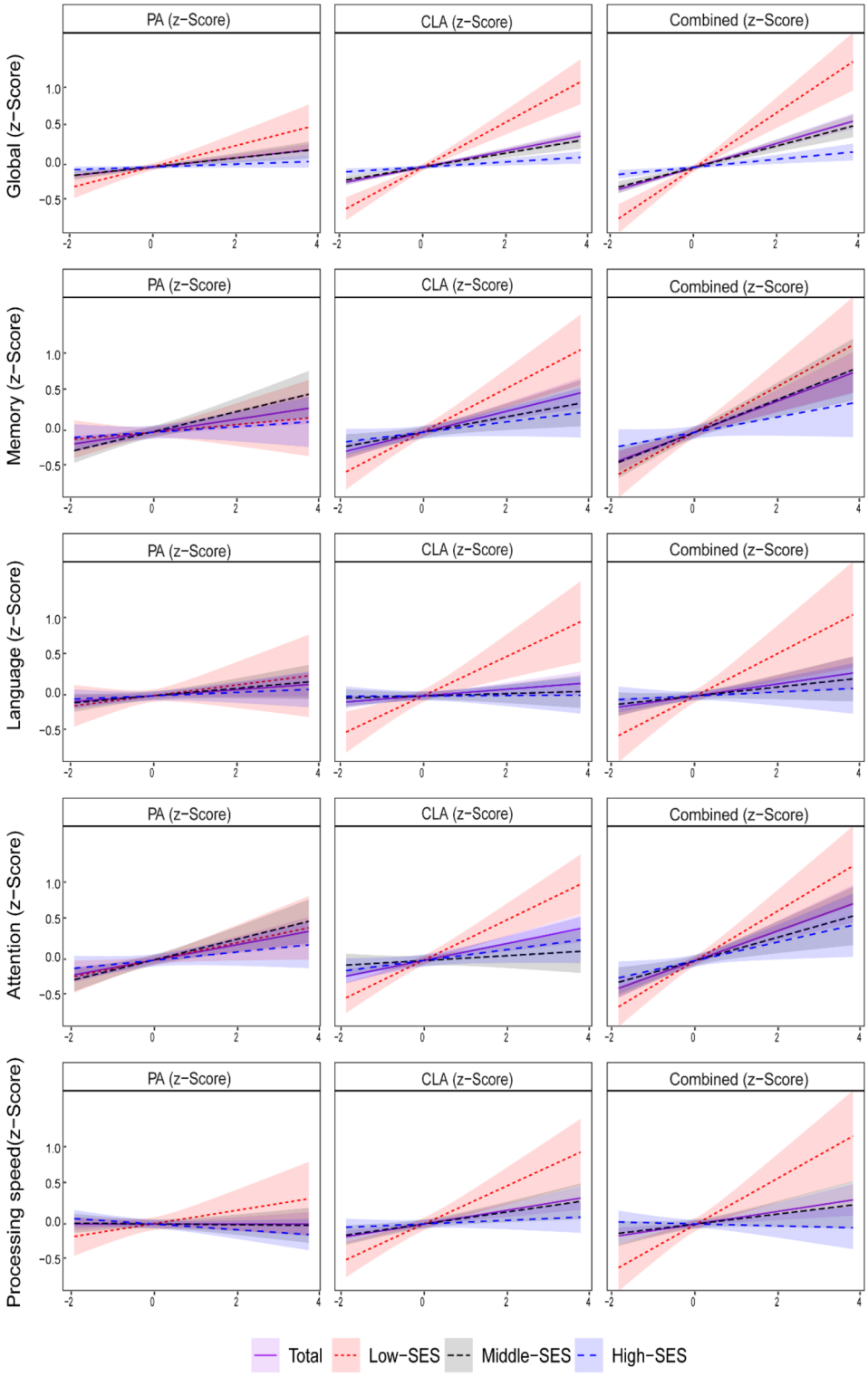

Fig. 1. Association of PA/CLA and cognitive function by socioeconomic status. Note: All models were adjusted for age, sex, residence, marital status, personality, living siblings, number of close friends, smoking, drinking, physical activity, intellectual activity, hypertension, diabetes, hyperlipidemia, coronary artery disease, cerebrovascular disease, depression, and insomnia.

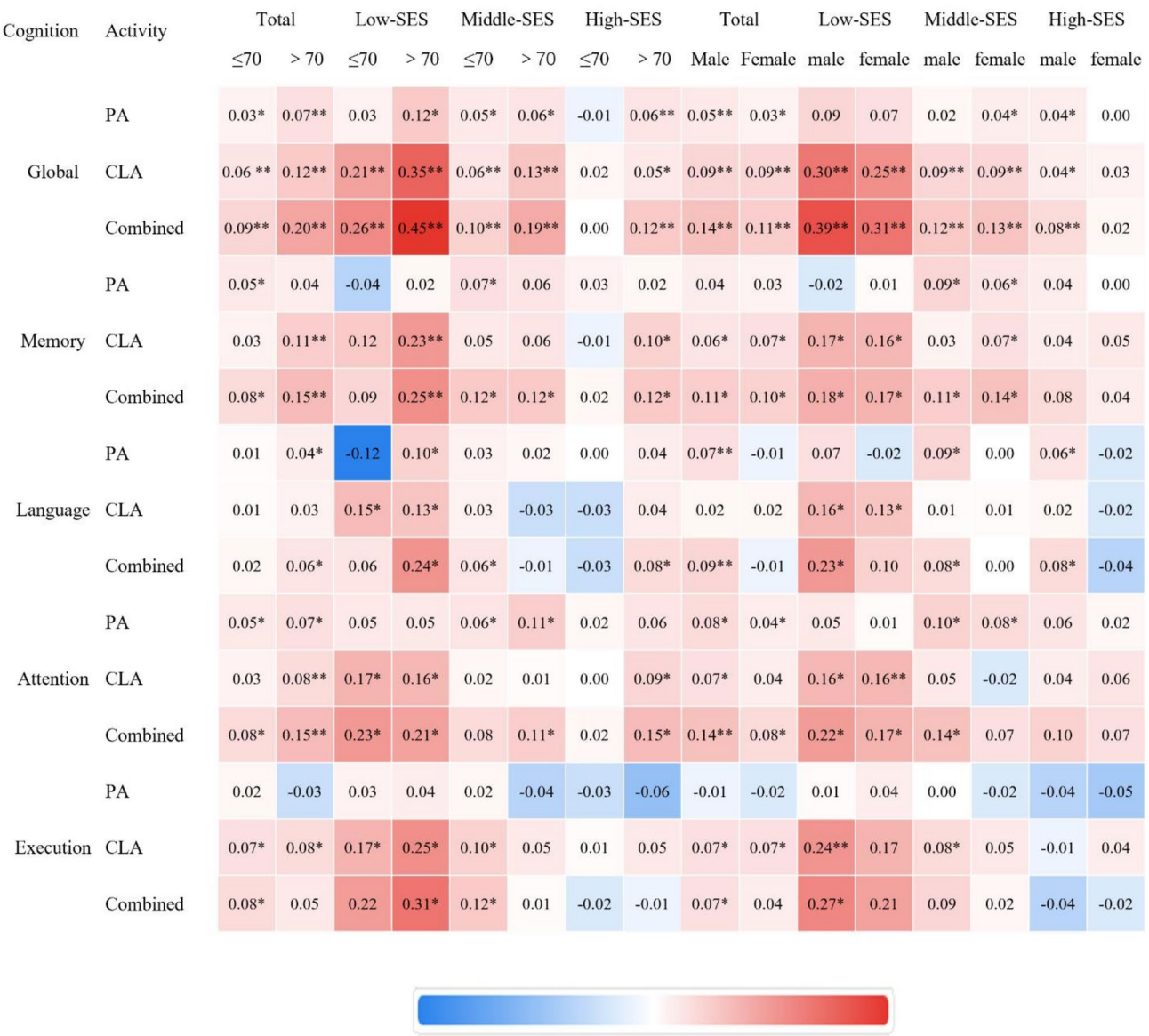

Fig. 2. Association of PA/CLA and cognitive function by socioeconomic status, sex group and age group. $^{**}P < 0.001$, $^{*}P < 0.05$. Note: All models were adjusted for age, sex, residence, marital status, personality, living siblings, number of close friends, smoking, drinking, physical activity, intellectual activity, hypertension, diabetes, hyperlipidemia, coronary artery disease, cerebrovascular disease, depression, and insomnia.

0.15), and PA β was 0.07 (95% CI: 0.04–0.11). For the ≤70 years group, the combined β was 0.09 (95% CI: 0.06–0.12), CLA β was 0.06 (95% CI: 0.03–0.08), and PA β was 0.03 (95% CI: 0.01–0.05).(Fig. 2, Table S7).

When stratified by SES and age, the strongest association was observed in the low SES group aged > 70 years, with combined $\beta = 0.45$ (95% CI: 0.31–0.59), CLA $\beta = 0.35$ (95% CI: 0.24–0.47), and PA $\beta = 0.12$ (95% CI: 0.02–0.22).(Fig. 2, Table S7).

Sex-stratified analyses showed higher associations in males compared to females. For males, the combined β was 0.14 (95% CI: 0.10–0.18), CLA β was 0.09 (95% CI: 0.06–0.12), and PA β was 0.05 (95% CI: 0.02–0.08). For females, the combined β was 0.11 (95% CI: 0.08–0.14), CLA β was 0.09 (95% CI: 0.06–0.11), and PA β was 0.03 (95% CI: 0.01–0.05).(Fig. 2, Table S8).

In the low SES male subgroup, the combined β was 0.39 (95% CI: 0.24–0.54), CLA β was 0.30 (95% CI: 0.19–0.40), and PA β was 0.09 (95% CI: -0.03–0.20), indicating the highest association among all subgroups. (Fig. 2, Table S8).

Sensitivity analyses

Several sensitivity analyses were performed to ensure the robustness of the results. These analyses included (1) the use of multiple imputation to address some of the missing variables in the original dataset, and (2) the exclusion of patients with Parkinson's disease, stroke, or musculoskeletal disorders, which may affect cognitive

function and physical activity. The results of all sensitivity analyses were consistent with the main findings of the study (Tables S9, S10).

Discussion

Our findings highlight the differential associations between SES, PA, CLA, and both global cognition and domain-specific cognitive performance. The combined effect of PA and CLA showed a stronger association with global, memory, and language function compared to either activity alone, with a more pronounced benefit in low SES populations. These results align with recent investigations[26–28] underscore the importance of both PA and CLA in promoting cognitive health across different SES groups.

At present, there is no consensus regarding the indicators utilized to define "low SES." However, researchers have posited that SES influences cognition, which can be elucidated through three models: latent period, pathway, and dose-response models[29]. Childhood socioeconomic status (CSC), characterized by parental education, occupation, and income, can impact brain structure and function[30]. However, the relationship between CSC and cognitive decline in later life remains inconclusive, with the most studies failing to establish a direct link[31–33]. Recent evidence suggests that while low educational attainment is associated with increased dementia risk, this link is significantly attenuated when accounting for cognitive test scores.

A large study of 207,814 Norwegian men demonstrated that low cognitive scores in early adulthood were associated with a two fold risk of later dementia diagnosis, independent of educational level[34]. This highlights the importance of cognitive ability as a critical factor in predicting cognitive decline. Furthermore, research from Denmark has shown that household income, as a proxy for SES, is associated with higher levels of cognitive function[35]. Longitudinal studies have also indicated that early-life SES can have lasting effects on cognitive performance in later years[36,37]. These findings suggest that while childhood CSC may influence cognitive development, subsequent environmental and experiential factors can significantly modify these effects. Therefore, predicting cognitive function in old age based solely on childhood SES may be insufficient.

While utilizing single indicators to proxy SES during childhood has scientific merit, it does not account for changes in an individual's SES across different life stages. Australian researchers have found that a relative socioeconomic advantage/disadvantage index calculated at the neighborhood level was associated with lower dementia risk scores in higher SES groups[38]. In this study, SES was comprehensively assessed utilizing representative indicators from various life stages (early, middle, late, and current). The decision was made to exclude childhood SES based on parental status, as all participants' parents experienced a tumultuous period prior to the establishment of the People's Republic of China, during which instability due to war, famine, and disease could have resulted in premature mortality and significant recall bias. Furthermore, the use of a single temporal point (income and community characteristics) to proxy for SES was avoided, as many participants underwent a period of rapid economic development in China, leading to substantial fluctuations in their employment, income, and living conditions.

SES is currently regarded as a proxy indicator for cognitive reserve, which is not static; positive lifestyle habits developed over a lifetime can enhance cognitive reserve[39]. This conclusion is corroborated by numerous studies demonstrating that individuals who do not experience cognitive decline are more likely to report regular exercise and higher levels of social engagement[40]. Elevated cognitive leisure activity levels are associated with increased cognitive reserve, which can mitigate the development of mild cognitive impairment and Alzheimer's disease[41]. However, these studies did not consider the SES differences in the cognitive effects of PA and CLA. Therefore, we posit that cognitive reserve is determined by SES over a lifetime but can be enhanced through positive lifestyle choices. Few population-based studies have focused on SES differences in terms of how beneficial lifestyle habits improve cognitive performance and reduce cognitive decline. Li R, et al.[42] investigated the relationship between SES and dementia incidence using UK Biobank data and found that only a small portion (3.2%) of socioeconomic inequalities in dementia risk was mediated by healthy lifestyle factors (smoking, alcohol consumption, physical activity, and diet). Another cohort study of 334 227 adults from the UK Biobank did not find a protective effect of PA on cognitive function. This finding is also thought to be related to selection bias or relatively young samples at follow-up[43]. In contrast, our study not only focused on PA and CLA, which are currently considered more effective for cognitive stimulation, but also considered differences in SES across the lifespan of older adults in an underdeveloped country (China).

The combined effect of PA and CLA showed a stronger association with global, memory, and language function compared to either activity alone, with a more pronounced benefit in low SES populations. In recent years, there has been a growing interest in examining the impact of SES, PA, and CLA on cognitive function, particularly in specific cognitive domains such as memory, language, and executive function. Our findings are in line with these studies, further highlighting the potential role of PA and CLA in cognitive function across different SES groups. Specifically, we found that the combined effect of PA and CLA was particularly pronounced in the domains of memory and language function. This is consistent with prior research. For instance, Yi Q et al.[44] found a moderate positive correlation between PA and cognitive function ($r = 0.437$), which was partially mediated by cardiovascular endurance. Additionally, Haverkamp BF's[45] review indicated that physical exercise could significantly improve memory and language abilities. These results suggest that PA and CLA may exert positive effects on cognitive function through different mechanisms. PA may support brain function by improving cardiovascular health[46], while CLA may directly stimulate neural pathways[47]. Moreover, the combined effect of PA and CLA was more pronounced in individuals with lower SES, possibly due to their lower cognitive reserve[48].

In our study, the correlation between PA/CLA and cognitive functioning was stronger in men and ≥ 70 in the low SES population compared to women and those < 70 years old. According to substitution theory[49], which suggests that the effects of alternative resources (PA and CLA) are more pronounced when key information (SES) is limited, the higher correlation of PA/CLA on cognitive performance is reflected in low SES, advanced age, and females, as these groups have lower primary resources, whereas our study showed that it was stronger in

males than in females, and we believe that the main reasons for this result are that in our study, a certain level of educational support is necessary for effective implementation of PA and CLA, and consequently, improvement of cognitive functioning. Currently, the education level of Chinese older adults over 65 years old is generally low (7.89, SD 5.23), especially among those with lower SES (1.41, SD 2.52). Among them, women have the lowest level of education (0.6, SD 1.7). The very low level of education may be associated with the lower cognitive stimulation response to PA/CLA in women.

This study was limited by a number of inherent factors. First, because HMACS participants did not complete the full population follow-up survey, cross-sectional analyses alone could not indicate causal relationships between variables; second, SES and lifestyle habit-related indicators, relied on self-reported data, which may not be sufficiently accurate. Third, this study used four proxy indicators from different time periods to assess SES and assigned equal weights to them in the analysis, which may not fully capture the complex relationship between SES and cognitive functioning. Fourth, the limited representativeness of the sample in central China affects the generalizability of the findings, as there may be significant differences in SES between the SES categories in these regions and those in high-income or developed countries; a broader study is needed to address this limitation. Fifth, the study may have attenuated the observed socioeconomic disparities in cognitive performance and physical/cognitive leisure activity associations, given that participants excluded due to missing data disproportionately belonged to disadvantaged socioeconomic groups. Finally, our study is the broad classification of PA and CLA based on frequency, duration, and intensity. This approach may not fully capture the unique contributions of different types of activities to cognitive function. Future studies should consider more detailed categorization and analysis of specific activities to better understand their effects.

Conclusions

In summary, older adults with lower SES face higher rates of cognitive impairment and poorer cognitive performance. However, engaging in physical activity (PA) and cognitive leisure activities (CLA) can mitigate these effects by enhancing cognitive reserve, especially PA combined CLA. This study supports initiatives in developing countries to improve SES for disadvantaged populations. Such efforts may include societal interventions like expanding elderly access to health insurance or improving healthcare infrastructure. Additionally, individual-level strategies that promote health, such as increased PA/CLA participation, could effectively address cognitive impairments linked to low SES and reduce the burden of cognitive decline in aging populations.

Data availability

The Brain Science and Advanced Technology Institute (BSATI) atWuhan University of Science and Technology values the dissemination of research findings and data sharing. BSATI prioritizes data access for HMACS study researchers owing to their significant contributions. Upon review and approval by BSATI review committee, data will be disclosed based on specific recommendations. BSATI supports sharing certain information under confidentiality and privacy protection conditions; however, the HMACS project is not yet finalized, and research data is not publicly shared or linked. Access requests should be directed to the corresponding author (chengguirong@wust.edu.cn).

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Author contributions

J-J.L., D.S., S-Q.T., J-Q.Q., Y-X.Z., JY.H., Q-Y.Z., and S-J.W.: investigation; methodology and data curation. G-R.C.,Q-W., Z-C.H., D.S., and S-Q.T.: data curation; formal analysis and writing original draft. Y.Z.: conceptual; funding acquisition; project administration; supervision; writing review and editing. G-R.C. and Z-C.H. are the guarantors for the paper.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics approval
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Additional information
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