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Educational attainment modifies the association between stroke history and orientation impairment among middle-aged and older Chinese adults: a cross-sectional study of CHARLS 2018

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Abstract

Background

Stroke contributes to cognitive impairment, but vulnerability varies. Education, a proxy for cognitive reserve and social advantage, may modify stroke-related orientation problems; evidence in China is limited. We examined whether education modifies the association between stroke history and orientation impairment in the 2018 China Health and Retirement Longitudinal Study (CHARLS).

Methods

We analyzed 2018 CHARLS participants aged ≥ 45 years. Orientation was assessed by five items (score 0–5); impairment was defined as score ≤ 3. Education was grouped as low, middle, or high. We fitted multivariable logistic regression with a stroke-by-education interaction and compared models using likelihood ratio tests; we also reported education-stratified adjusted odds ratios and marginally standardized predicted probabilities. Sensitivity analyses varied impairment thresholds and missing-data approaches.

Results

Among 16,972 participants, 869 (5.1%) reported physician-diagnosed stroke and 6,736 (39.7%) had orientation impairment. Evidence of effect modification was observed (interaction likelihood ratio test p = 0.049). In education-stratified models, stroke was associated with higher odds of impairment in the high-education group (adjusted odds ratio 1.51, 95% confidence interval 1.04–2.20), whereas estimates in the low and middle groups were closer to null. Predicted probabilities showed the largest stroke–no stroke contrast in the high-education group. Findings were directionally consistent across sensitivity analyses.

Conclusions

Educational attainment may modify the association between stroke history and orientation impairment in a large community sample of Chinese adults. The results highlight heterogeneity in post-stroke cognitive vulnerability and support risk-stratified cognitive surveillance, while longitudinal studies are needed to clarify temporality and mechanisms.

Contributions to the Literature

Text box 1. Contributions to the Literature

- Education can shape how stroke relates to everyday disorientation, not just overall cognition.
- Using a large national Chinese survey, we test this “who is most vulnerable” question at population level.
- We show that simple orientation questions may behave differently across education groups, which matters for community screening.
- The results point to more targeted post-stroke cognitive monitoring and motivate longitudinal confirmation.

Background

Stroke remains one of the most important causes of long-term disability and loss of healthy life years worldwide, and its burden is particularly salient in rapidly aging populations(1). Beyond motor and sensory sequelae, cognitive impairment after stroke is increasingly recognized as a major driver of functional dependence, reduced quality of life, caregiver burden, and health-care utilization(2). Cognitive consequences of stroke are clinically diverse, ranging from mild deficits that affect complex daily tasks to more severe impairment that compromises independent living(3). Among the cognitive domains affected, orientation—the ability to correctly identify time, place, and person—is fundamental, easily assessed in large surveys, and closely related to global cognitive status and everyday functioning(4, 5). Orientation deficits often signal broader cognitive vulnerability and may reflect both vascular brain injury and underlying neurodegenerative processes(6, 7).

Despite the well-established link between stroke and cognitive impairment, post-stroke cognitive outcomes are notably heterogeneous(8). Individuals with similar cerebrovascular events can display markedly different cognitive trajectories and cross-sectional cognitive profiles. This heterogeneity suggests that factors beyond the stroke event itself—including demographic characteristics, baseline cognitive resources, comorbid vascular risk factors, and social determinants—shape cognitive vulnerability(9–14). Identifying modifiers of the stroke–cognition association is therefore important for two reasons: (1) it can clarify mechanisms (e.g., reserve or resilience processes versus differential risk exposure), and (2) it can help target prevention and rehabilitation strategies to high-risk subgroups(15, 16).

Educational attainment is frequently used as a proxy for cognitive reserve, reflecting lifelong accumulation of cognitive and social resources through formal education and associated opportunities(17, 18). The cognitive reserve framework posits that individuals with greater reserve may tolerate brain pathology more effectively, maintain cognitive performance through compensatory strategies, or delay clinical manifestation of impairment(19–23). Under this framework, education could buffer the cognitive impact of stroke, implying a weaker association between stroke history and cognitive impairment among individuals with higher educational attainment(24, 25). However, alternative mechanisms could generate different patterns in population-based cross-sectional analyses. For

example, education is strongly correlated with socioeconomic conditions, health behaviors, access to health care, and survival, which can introduce selection and detection differences across education groups(26–29). In addition, stroke is a heterogeneous condition, and the distribution of stroke subtypes and management may differ by education. These factors could, in some settings, produce an apparently stronger association among highly educated individuals(30–32).

Empirically, evidence for education as an effect modifier of the stroke–cognition relationship has been inconsistent. Some studies support a protective “reserve” role, while others find limited or domain-specific modification, and many investigations are restricted by clinical cohorts, limited generalizability, or insufficient subgroup sizes(33–36). Moreover, evidence in older Chinese adults remains comparatively sparse. This gap is important because China has experienced rapid demographic aging and substantial cerebrovascular disease burden, alongside pronounced cohort differences in educational opportunity(37). In nationally representative samples, individuals with low education may also differ systematically in vascular comorbidity profiles, lifestyle factors, and access to secondary prevention. These features make China a particularly relevant context for examining whether education modifies stroke-associated cognitive vulnerability(38).

The China Health and Retirement Longitudinal Study (CHARLS) provides an appropriate setting to address this question. CHARLS is a large, population-based survey of middle-aged and older adults that includes standardized cognitive items and extensive information on sociodemographic characteristics and vascular-related health conditions(39). While CHARLS does not contain neuroimaging-based adjudication of cerebrovascular pathology, it offers a pragmatic and policy-relevant opportunity to evaluate effect modification at the population level using consistently measured variables. Orientation items within CHARLS capture core cognitive functioning in a way that is feasible for large-scale epidemiologic analyses and can serve as an interpretable proxy for cognitive impairment risk in community settings.

In this study, we used CHARLS 2018 cross-sectional data to examine the association between self-reported physician-diagnosed stroke history and orientation impairment, and to test whether this association differs by educational attainment. We implemented multivariable regression models including a stroke-by-education interaction term to formally assess effect modification. Given that cross-sectional analyses can be sensitive to modeling assumptions and missing-data handling, we additionally conducted a set of robustness checks, including alternative effect measures, different missing-data strategies, and sensitivity analyses using alternative thresholds for defining orientation impairment. Together, these analyses were designed to provide a transparent assessment of whether education modifies the stroke–orientation relationship in this national survey sample and to evaluate the stability of findings across reasonable analytic choices.

Methods

We analyzed 2018 CHARLS participants aged ≥45 years. Orientation was assessed by five items (score 0–5); impairment was defined as score ≤3. Education was grouped as low, middle, or high. We fitted multivariable logistic regression with a stroke-by-education interaction and compared models using likelihood ratio tests; we also reported education-stratified adjusted odds ratios and marginally standardized predicted probabilities. Sensitivity analyses varied impairment thresholds and missing-data approaches.

This study was a cross-sectional analysis based on the 2018 wave of the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative survey of Chinese adults aged ≥45 years. CHARLS collects standardized information on sociodemographic characteristics, health conditions, and cognitive function through face-to-face interviews using structured questionnaires.

Study population

We constructed the analytic sample from participants interviewed in 2018. Individuals were included if they had available data to derive the orientation score and its impairment indicator, and had non-missing information on stroke history, educational attainment, and core demographic covariates used for adjustment (age, sex, and hukou status). Participants with missing values in these core variables were excluded. For several additional covariates with substantial missingness, we retained participants in the primary analysis by creating an explicit “Missing” category (see Missing data handling).

Exposure: stroke history

Stroke history was defined using self-reported physician diagnosis. Participants were classified as having a history of stroke (“Yes”) if they reported a prior physician-diagnosed stroke; otherwise, they were classified as “No.” Participants with missing or indeterminate responses were excluded.

Effect modifier: educational attainment

Educational attainment was categorized into three levels according to the CHARLS education coding and the Chinese education system: low, middle, and high education. Education was treated as an effect modifier of the association between stroke history and orientation impairment and was modeled as a categorical variable with three levels.

Outcome: orientation impairment

Orientation was assessed using five CHARLS orientation items (dc001_w4, dc002_w4, dc003_w4, dc005_w4, and dc006_w4); dc004_w4 was not part of the orientation item set and was not used. An orientation score was constructed by summing the number of correctly answered items (range 0–5). The primary outcome, orientation impairment, was defined as an orientation score ≤3 (t3). For sensitivity analyses, we also evaluated alternative thresholds: ≤2 (t2) and ≤4 (t4).

Covariates

We selected covariates a priori based on clinical relevance and prior literature, including age, sex, hukou (urban/rural registration), vascular comorbidities (hypertension, diabetes, and heart attack), smoking, alcohol consumption, and marital status. Smoking status was coded as ever versus never using the CHARLS smoking variable (da059), with missingness retained as an explicit category. A three-level smoking classification (current/former/never; da061_w4) was considered; however, da061_w4 had substantial missingness in the analytic sample (37.2% non-missing), so the ever/never definition was used in the main analyses. To account for within-cluster correlation in CHARLS, we used cluster-robust standard errors at the community level (or household level when community identifiers were unavailable). Hypertension, diabetes, and heart attack were defined based on self-reported physician diagnosis in CHARLS health modules (yes/no), with missing responses coded as 'Missing'. Hypertension had a relatively high proportion of missing responses (~25%). To minimize loss of information and maintain comparability across models, we retained a "Missing" category in the primary analyses and evaluated robustness using complete-case and multiple-imputation sensitivity analyses.

Effect modification was evaluated by including a stroke×education interaction term in multivariable models and testing it using likelihood ratio tests. To facilitate interpretation, we additionally reported (i) education-stratified adjusted stroke associations estimated within each education stratum and (ii) marginally standardized predicted probabilities obtained by g-computation.

Sensitivity analyses were pre-specified to address key analytic concerns: (1) alternative thresholds for dichotomizing impairment (≤2/≤3/≤4), (2) alternative missing-data strategies (complete-case vs multiple imputation), (3) alternative effect scales and link functions (modified Poisson models for relative risks), and (4) alternative model forms acknowledging the ordinal/count nature of orientation responses, including ordinal logistic regression for the 0–5 orientation score and quasi-Poisson/negative binomial models for the count of orientation errors (5–score).

Statistical analysis

We summarized participant characteristics by education category and described the distribution of orientation impairment. The primary association between stroke history and orientation impairment was evaluated using multivariable logistic regression. To assess effect modification by educational attainment, we fitted an interaction model including a multiplicative interaction term between stroke history and education, adjusting for all covariates. Adjusted odds ratios (ORs) and 95% confidence intervals (CIs) were reported.

Evidence for interaction was assessed using a likelihood ratio test (LRT) comparing the interaction model to a nested model without the interaction term but with identical covariate adjustment. In addition, to facilitate interpretation, we estimated education-stratified stroke effects by fitting separate covariate-adjusted logistic regression models within each education stratum and reporting the stratum-specific adjusted ORs for stroke history.

CHARLS employs a multistage sampling design; design weights and other complex-design variables are typically used when the objective is to produce nationally representative descriptive estimates. In the present study, the primary objective was etiologic—estimating covariate-adjusted associations and testing effect modification (stroke × education)—rather than producing population-representative prevalence estimates. The analytic dataset available for this secondary analysis did not include survey weights or the full set of design variables, precluding fully design-based, survey-weighted analyses. Therefore, we fitted unweighted regression models and accounted for within-cluster correlation using cluster-robust standard errors at the community level (or household level when community identifiers were unavailable). Robust variance estimation addresses correlated observations and statistical inference but does not restore population representativeness; accordingly, descriptive estimates should be interpreted as pertaining to the analytic sample rather than as nationally representative values.

Age-restricted analysis (≥65 years)

Because cognitive impairment risk and clinical relevance increase with older age, we repeated the primary interaction analysis in participants aged ≥65 years. Using the same outcome definition, exposure definition, covariate set, and variance estimation strategy as the main analysis, we refitted (i) the multivariable logistic regression with a stroke-by-education interaction, (ii) the nested model without the interaction for the likelihood ratio test, and (iii) education-stratified adjusted stroke odds ratios. We additionally estimated marginally standardized predicted probabilities within the ≥65-year subgroup using the same g-computation procedure as in the main analysis.

Predicted probabilities (marginal standardization)

To present absolute risk patterns, we estimated marginally standardized predicted probabilities of orientation impairment across combinations of stroke history (yes/no) and education level (low/middle/high). Predicted probabilities were computed by setting stroke and education to specific values for all participants while keeping their observed covariates unchanged, then averaging model-based predicted risks over the analytic sample (g-computation). Uncertainty intervals were obtained using Monte Carlo simulation based on the fitted model coefficients and the robust variance–covariance matrix (nsim = 800 draws). The slightly lower predicted probability among stroke survivors in the low-education group likely reflects measurement limitations (floor effects) and/or selection processes in cross-sectional survivor samples rather than a protective effect of stroke.

Missing data handling and sensitivity analyses

The primary analysis used an indicator approach to handle missing covariate data. For categorical covariates (e.g., smoking, alcohol consumption, and marital status), we created an explicit “Missing” category; for vascular comorbidities (hypertension, diabetes, and heart attack), missing values were coded as a separate level (“Missing”) alongside “Yes” and “No.” This strategy was chosen to preserve sample size and maintain comparability across models. We assessed the robustness of the findings through a series of sensitivity analyses, including repeating the primary logistic regression in complete

cases only; conducting multiple imputation by chained equations (MICE; m = 10 imputations, maxit = 10 iterations) for missing covariates using variable-appropriate models (predictive mean matching for continuous variables, and logistic/multinomial regression for categorical variables), while not imputing the outcome, exposure, education, sex, or hukou, and pooling estimates using Rubin's rules; fitting modified Poisson regression models with a log link and robust standard errors to estimate risk ratios (RRs) under the same interaction structure and covariate adjustment; re-running the main models using alternative outcome thresholds (t2/t3/t4); and performing a targeted leave-one-out analysis to evaluate the stability of interaction estimates in the high-education, stroke-positive subgroup, whereby for computational feasibility a random subset of up to 120 observations from this subgroup was iteratively excluded one at a time and the resulting distribution of interaction estimates and LRT p-values was summarized. Overall, complete-case and multiple-imputation analyses yielded directionally consistent estimates with the primary analysis, supporting the robustness of our conclusions to missing-data assumptions.

Software

All analyses were conducted in R. Statistical models were fitted using base R functions, and cluster-robust variance estimation was implemented using standard robust variance procedures. Tables and figures were generated programmatically for reproducibility.

Results

Among 16,972 participants, 869 (5.1%) reported physician-diagnosed stroke and 6,736 (39.7%) had orientation impairment. Evidence of effect modification was observed (interaction likelihood ratio test p=0.049). In education-stratified models, stroke was associated with higher odds of impairment in the high-education group (adjusted odds ratio 1.51, 95% confidence interval 1.04–2.20), whereas estimates in the low and middle groups were closer to null. Predicted probabilities showed the largest stroke–no stroke contrast in the high-education group. Findings were directionally consistent across sensitivity analyses.

A total of 16,972 participants from CHARLS 2018 were included in the primary analytic sample. Overall, 869 participants (5.1%) reported a physician-diagnosed history of stroke, and 6,736 (39.7%) met the criteria for orientation impairment (orientation score ≤3). Educational attainment was distributed as Low: 11,183 (65.9%), Middle: 3,699 (21.8%), and High: 2,090 (12.3%).

Table 1. Baseline characteristics by educational attainment (CHARLS 2018; N=16,972)

Characteristic	Low	Middle	High
N	11183	3699	2090
Age, mean (SD)	63.7 (10.6)	58.4 (8.4)	59.3 (8.9)
Sex, n (%)			
Male	4462 (39.9%)	2219 (60.0%)	1310 (62.7%)
Female	6721 (60.1%)	1480 (40.0%)	780 (37.3%)
Hukou, n (%)			
Rural	9940 (88.9%)	2685 (72.6%)	860 (41.1%)
Urban	1243 (11.1%)	1014 (27.4%)	1230 (58.9%)
Stroke history, n (%)	533 (4.8%)	204 (5.5%)	132 (6.3%)
Hypertension (Yes), n (%)	1290 (11.5%)	416 (11.2%)	211 (10.1%)
Diabetes (Yes), n (%)	600 (5.4%)	195 (5.3%)	116 (5.6%)
Heart attack (Yes), n (%)	745 (6.7%)	265 (7.2%)	159 (7.6%)
Smoking, n (%)			
Never	6493 (58.1%)	2264 (61.2%)	1277 (61.1%)
Ever	4680 (41.8%)	1432 (38.7%)	812 (38.9%)
Missing	10 (0.1%)	3 (0.1%)	1 (0.0%)
Alcohol, n (%)			
Never	5852 (52.3%)	1998 (54.0%)	1120 (53.6%)
Less than monthly	861 (7.7%)	282 (7.6%)	165 (7.9%)
Monthly or more	892 (8.0%)	256 (6.9%)	161 (7.7%)
Missing	3578 (32.0%)	1163 (31.4%)	644 (30.8%)
Marital status, n (%)			
Married	8464 (75.7%)	3091 (83.6%)	1794 (85.8%)
Not Married	2637 (23.6%)	600 (16.2%)	293 (14.0%)
Missing	82 (0.7%)	8 (0.2%)	3 (0.1%)

Note: Values are n (%) unless otherwise specified.

Main association and evidence of interaction (stroke × education)

Effect modification by education was supported by converging evidence from the interaction test (LRT p=0.049), education-stratified adjusted stroke estimates, and marginally standardized predicted probabilities, with directionally consistent findings across sensitivity analyses.

In the primary interaction model, higher educational attainment was associated with lower odds of orientation impairment among participants without stroke (Middle vs Low: OR 0.77, 95% CI 0.70–0.84; High vs Low: OR 0.76, 95% CI 0.67–0.87). Because the stroke coefficient pertains to the reference stratum (low education), stroke associations should be interpreted using education-specific estimates from interaction terms and/or stratified models rather than as a single overall effect.

The interaction terms suggested that the association of stroke with orientation impairment differed by educational attainment. Relative to the low-education group, the stroke effect was stronger among those with high education (stroke × high education interaction OR 1.67, 95% CI 1.11–2.52; p=0.014). The interaction term for middle education was weaker and not statistically significant (OR 1.13, 95% CI 0.79–1.61; p=0.505).

Table 2. Main model for orientation impairment (orientation score ≤3; N=16,972): adjusted ORs, interaction LRT, and education-stratified stroke ORs (compact)

Section	Term	Effect (OR, 95% CI)	P value
Main model (OR)	stroke (within Low education; reference stratum)	0.87 (0.72–1.04)	0.131
Main model (OR)	Middle vs Low (among No-stroke)	0.77 (0.70–0.84)	<0.001
Main model (OR)	High vs Low (among No-stroke)	0.76 (0.67–0.87)	<0.001
Main model (OR)	Stroke:educationMiddle	1.13 (0.79–1.61)	0.505
Main model (OR)	Stroke:educationHigh	1.67 (1.11–2.52)	0.014
Interaction (LRT)	P(interaction) [LRT]	Not applicable	0.049
Stratified stroke effect (OR)	Stroke effect within Low	0.85 (0.71–1.02)	0.088
Stratified stroke effect (OR)	Stroke effect within Middle	1.00 (0.72–1.38)	0.977
Stratified stroke effect (OR)	Stroke effect within High	1.51 (1.04–2.20)	0.032

Note: ORs are adjusted for age, sex, hukou status, hypertension, diabetes, heart attack, smoking, alcohol consumption, and marital status. P(interaction) is from the likelihood ratio test (LRT). In the interaction

model, the "Stroke" coefficient reflects the stroke–outcome association within the reference education group (Low). Education coefficients compare education groups among participants without stroke.

Education-stratified stroke effects (within-stratum adjusted ORs)

To facilitate interpretation of the interaction, we further estimated the adjusted association between stroke history and orientation impairment within each educational stratum (models adjusted for the same covariates within each stratum). The stroke–orientation impairment association was:

Low education: OR 0.85 (95% CI 0.71–1.02; p=0.088)

Middle education: OR 1.00 (95% CI 0.72–1.38; p=0.977)

High education: OR 1.51 (95% CI 1.04–2.20; p=0.032)

Overall, the stroke–orientation impairment association differed by education: it was most evident in the high-education group, while estimates in the low- and middle-education groups were closer to the null with wider uncertainty.

Predicted probabilities from marginal standardization

Marginally standardized predicted probabilities (g-computation) from the interaction model further illustrated this effect modification pattern. Among participants without stroke, the predicted probability of orientation impairment decreased with higher education (Low 0.418; Middle 0.364; High 0.354). However, among participants with stroke, the predicted probability was highest in the high-education group (Low 0.384; Middle 0.373; High 0.442). The predicted probability difference comparing stroke versus no stroke varied by education, consistent with effect modification: the contrast was minimal in the middle-education group and most pronounced in the high-education group.

To aid absolute-scale interpretation, Figure 3 presents marginally standardized predicted probabilities in the full analytic sample (N=16,972), and absolute risk differences are reported for participants aged ≥65 years; the corresponding predicted-probability plot for the ≥65 subgroup is shown in Supplementary Figure S2.

Subgroup analysis among participants aged ≥65 years and absolute effects

In participants aged ≥65 years, the overall interaction test was not statistically significant (LRT p=0.289). Although confidence intervals were wider in this restricted sample, education-stratified estimates suggested stronger stroke-associated orientation impairment in the middle- and high-education groups (adjusted OR 2.18 [95% CI 1.21–3.94] and 2.46 [1.36–4.46], respectively), compared with the low-education group (1.27 [0.87–1.86]). On the absolute scale, the marginal risk differences (stroke vs no stroke) were 0.044 (95% CI −0.010 to 0.094) in the low-education group, 0.117 (0.039 to 0.196) in the middle-education group, and 0.138 (0.052 to 0.229) in the high-education group. The marginally standardized predicted probabilities for the ≥65 subgroup are presented in Supplementary Figure S2.

Sensitivity analyses

Modified Poisson regression (RR scale)

To assess whether the observed effect modification was sensitive to the odds-ratio scale, we repeated the analysis using modified Poisson regression with robust standard errors to estimate risk ratios (RRs). On the RR scale, the overall interaction test was attenuated (likelihood ratio test p=0.154), although the direction of effect modification remained consistent with the primary logistic models. Relative to low education, higher educational attainment was associated with a lower risk of orientation impairment (Middle: RR 0.80, 95% CI 0.75–0.85; High: RR 0.79, 95% CI 0.70–0.89). At the term level, the stroke × high education interaction remained >1 and statistically significant (RR 1.38, 95% CI 1.11–1.72; Wald p=0.003), whereas the stroke × middle education interaction was weaker and not statistically significant (RR 1.13, 95% CI 0.99–1.30; Wald p=0.074). The main effect of stroke in the interaction model was not statistically significant on the RR scale (RR 0.92, 95% CI 0.83–1.02). In additional sensitivity analyses treating the orientation score as an ordinal outcome (proportional odds model) and modeling the number of orientation errors using quasi-Poisson and negative binomial regressions, the stroke-by-education interaction showed a broadly similar direction, but estimates were less precise and interaction tests were not statistically significant.

Complete-case analysis

In complete-case logistic regression (excluding individuals with missing values rather than using explicit “Missing” categories), the direction of effects was similar, and the interaction for stroke × high education remained evident, though with wider uncertainty (interaction OR 2.85, 95% CI 1.20–6.75; p=0.017). The main stroke term was not significant (OR 0.83, 95% CI 0.61–1.12), consistent with the primary finding that the stroke association depended on education stratum.

Multiple imputation

In multiple imputation analyses (m = 10 imputations; maxit = 10; pooled estimates), results were consistent with the primary model. The stroke × high education interaction remained statistically significant (pooled interaction OR 1.68, 95% CI 1.13–2.50; p=0.012). Education remained inversely associated with orientation impairment in the MI analyses, with pooled estimates similar to but slightly attenuated compared with the primary model (Middle vs Low: OR 0.78, 95% CI 0.72–0.85; High vs Low: OR 0.81, 95% CI 0.70–0.95).

Sensitivity analyses using ordinal and count models

Treating the orientation score (0–5) as an ordinal outcome, ordinal logistic regression yielded directionally consistent interaction patterns, although the overall interaction test was not statistically significant (LRT p=0.182). Modeling the number of orientation errors (5−score) as a count outcome produced similar qualitative conclusions: the interaction term was not statistically significant under quasi-Poisson regression (Wald p=0.249) or negative binomial regression (LRT p=0.223). Collectively,

ordinal and count models yielded directionally consistent interaction patterns with wider uncertainty, suggesting the main finding is not driven solely by dichotomization.

Leave-one-out stability analysis (subsampled)

To assess whether the interaction findings were driven by influential observations in the relatively small “High education & Stroke” cell, we conducted a subsampled leave-one-out stability analysis by drawing up to 120 observations from that cell and iteratively refitting the model after excluding one observation at a time. The baseline interaction estimate for stroke × high education was OR 1.673 with an overall interaction LRT p-value of 0.049. Across the LOO refits, the interaction OR varied within a narrow range (1.634–1.699), and the interaction LRT p-value ranged from 0.041 to 0.065, suggesting that the interaction signal was not dominated by a single influential observation.

Discussion

Principal findings

In this cross-sectional analysis of CHARLS 2018, the association between self-reported stroke history and orientation impairment differed by educational attainment. Importantly, the effect-modification signal was supported by converging evidence across complementary approaches—model-based interaction testing, education-stratified adjusted stroke estimates, and marginally standardized predicted probabilities—rather than relying on a single p-value. Sensitivity analyses using alternative impairment thresholds, missing-data strategies, and models that respect the ordinal/count nature of orientation responses yielded directionally consistent findings, suggesting that the observed pattern is robust to reasonable analytic choices.

Clinical and public health implications

Although this study is cross-sectional, the observed effect modification by education suggests that post-stroke cognitive screening may need to account for clinically relevant heterogeneity rather than assuming a uniform risk profile across socioeconomic strata. In community and outpatient settings where brief screening is common, individuals with a history of stroke and higher educational attainment may still exhibit a meaningful excess probability of orientation impairment, supporting proactive follow-up and repeated assessment rather than relying on presumed protection from cognitive reserve alone. Conversely, in lower-education groups, brief orientation items may have limited discriminatory capacity due to floor effects, indicating that complementary cognitive domains or more sensitive tools may be needed to better capture subtle deficits. Importantly, these implications hold under two plausible interpretations: if the pattern reflects true differences in stroke-associated orientation vulnerability across education strata, it motivates risk-stratified surveillance and tailored screening approaches; if it instead reflects differential detection or survivor/selection processes, it underscores that cross-sectional estimates of post-stroke cognitive impairment may be biased in education-specific ways and should be

interpreted cautiously. In either case, longitudinal studies are needed to clarify temporality, mechanisms, and optimal screening strategies across educational strata.

Interpretation and potential mechanisms

These findings are cross-sectional and reflect observed differences in a brief, thresholded orientation measure; therefore, they should not be interpreted as causal effects of education on post-stroke cognition. Although education is often discussed as a proxy for cognitive reserve, our cross-sectional pattern does not contradict the reserve framework. In this setting, higher education is associated with a lower baseline probability of impairment among those without stroke, which can make stroke-related deviation more visible on relative (multiplicative) scales. In addition, brief orientation items may be less sensitive at the lower end of performance (floor effects) and more discriminating among higher-functioning participants, and cross-sectional survivor samples may introduce education-differential selection (e.g., survival/participation) that can attenuate associations in lower-education stroke survivors. Finally, reserve may delay clinical manifestation until pathology is more advanced; thus, when impairment is observed among highly educated stroke survivors, it may reflect a subgroup with greater underlying burden, yielding a stronger observed association in cross-section.

1) Ceiling/floor effects and outcome sensitivity across education strata

Orientation items are brief and may exhibit limited ability to discriminate mild impairment among individuals with low education. In the low-education group, baseline performance may already cluster near the impairment threshold, producing a “floor effect” that compresses variability and reduces the observable incremental impact of stroke on the binary impairment definition(40). Conversely, among high-education participants, baseline orientation performance is expected to be higher with more room to decline before crossing the impairment threshold(41). If stroke-related cognitive changes affect orientation, the binary definition may more sensitively capture stroke-associated impairment in higher-education participants—especially when the non-stroke high-education group has a relatively low baseline probability of impairment, making stroke-related deviation more detectable on a relative scale.

2) Differential detection and reporting of stroke and cognitive problems

Stroke history in CHARLS is self-reported (physician diagnosis), which may be subject to differential ascertainment. Individuals with higher education may have better access to healthcare, higher health literacy, or greater likelihood of receiving and recalling a formal diagnosis of stroke—especially for milder events(42). At the same time, more educated participants (and their families) may be more likely to recognize and report subtle cognitive changes(43). These pathways can create differential measurement patterns that amplify observed associations in higher-education strata even if the underlying biological effect is similar.

3) Survival and selection mechanisms (collider bias in cross-sectional samples)

Cross-sectional analyses of stroke survivors inherently condition on survival and participation. If individuals with low education experience more severe strokes, higher mortality, or greater disability that reduces survey participation, the low-education stroke group observed in CHARLS 2018 may represent a selected subset of comparatively healthier survivors(44, 45). Such selection can attenuate the measured association between stroke and cognitive impairment in the low-education group. By contrast, a higher-education stroke group may include a broader spectrum of stroke severity and post-stroke trajectories, potentially strengthening the observed association with cognition(46). This selection mechanism is a well-known concern in survivor cohorts and can produce paradoxical effect patterns across socioeconomic strata.

4) Education as a proxy for multiple correlated factors

Educational attainment is not only a marker of cognitive reserve but also correlates with lifetime occupational complexity, income, healthcare access, and vascular risk profiles(47, 48). Any of these factors can interact with stroke recovery, rehabilitation access, and post-stroke cognition. For example, better survival after stroke among higher-education individuals could result in more survivors living long enough to manifest chronic cognitive sequelae captured by the survey, whereas severe cases in lower-education strata may be underrepresented in the observed sample(49–51).

Comparison with existing evidence

Prior studies have generally supported an association between stroke and subsequent cognitive impairment, while evidence on socioeconomic or educational effect modification has been mixed across settings and outcome definitions(52–55). Differences in cognitive measures, case ascertainment of stroke, and sample composition (e.g., clinic-based vs community-based survivors) may partly explain heterogeneity across studies(56, 57). Our findings add population-based evidence from older Chinese adults and suggest that education may shape observed post-stroke cognitive vulnerability, at least for brief orientation measures commonly used in large surveys.

Strengths

This study has several strengths. We leveraged a large national survey of middle-aged and older adults in China, providing broad coverage of the target population. We implemented a consistent modeling strategy with interaction testing, stratum-specific estimates to aid interpretability, and complementary effect scales (OR and RR). We also conducted multiple sensitivity analyses addressing missing data (complete-case and multiple imputation), alternative modeling (modified Poisson), and stability of the interaction signal through leave-one-out refits in the key subgroup.

Limitations

Despite the strengths of using a large, national survey-based dataset and a pre-specified interaction framework, several limitations should be considered when interpreting our findings. First, the cross-sectional design does not permit causal inference or establish temporal ordering between stroke and

cognitive impairment, and reverse causation cannot be excluded if cognitive impairment influences health reporting or the likelihood of receiving a stroke diagnosis. Second, stroke history was based on self-reported physician diagnosis, which may be subject to misclassification, and differential diagnosis, recall, or healthcare access by educational attainment could bias estimates of both the main association and effect modification. Third, our outcome was derived from a brief set of orientation items and operationalized using a binary threshold, which may not fully capture the multidimensional nature of vascular cognitive impairment or post-stroke cognitive deficits (e.g., executive function and processing speed), and may be susceptible to education-related measurement differences such as floor/ceiling effects. Fourth, residual confounding is possible because CHARLS does not provide detailed clinical information on stroke subtype, severity, recency, rehabilitation exposure, or neuropsychiatric comorbidities (e.g., depression) that could influence cognitive performance and recovery trajectories. Finally, selection processes inherent to cross-sectional survivor samples may have influenced our estimates if stroke-related mortality, disability, or survey non-response differed by education level, potentially leading to collider or survivor bias and attenuating associations in some strata.

Finally, although CHARLS is a complex, nationally representative survey, the de-identified analytic files available for this secondary analysis did not include the full set of design variables required for design-based variance estimation (e.g., strata and primary sampling units). We therefore used cluster-robust standard errors at the community/household level as a pragmatic approach to account for within-cluster correlation. While this does not replace fully survey-weighted, design-based inference, it accounts for within-cluster correlation and is commonly used in secondary analyses when complete design information is unavailable.

Future directions

Future studies should validate these findings using longitudinal follow-up (e.g., CHARLS 2018–2020 cohort analyses) to assess incident cognitive decline after baseline stroke and to better address selection and temporality. Incorporating richer cognitive batteries and domain-specific outcomes would clarify whether effect modification is specific to orientation or reflects broader post-stroke cognitive vulnerability. Where possible, linking to clinical records or using more detailed stroke measures (severity, recurrence, time since event) would reduce misclassification and improve mechanistic interpretation.

Conclusions

Educational attainment may modify the association between stroke history and orientation impairment in a large community sample of Chinese adults. The results highlight heterogeneity in post-stroke cognitive vulnerability and support risk-stratified cognitive surveillance, while longitudinal studies are needed to clarify temporality and mechanisms.

Abbreviations

CHARLS, China Health and Retirement Longitudinal Study; OR, odds ratio; RR, risk ratio; CI, confidence interval; LRT, likelihood ratio test; MI, multiple imputation.

Declarations

Ethics approval and consent to participate

The CHARLS study was approved by the relevant institutional ethics committee, and all participants provided written informed consent prior to participation. The CHARLS study procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision). The current study is a secondary analysis of de-identified public-use data and involved no direct contact with participants.

Consent for publication

Not applicable.

Availability of data and materials

The data that support the findings of this study are available from the China Health and Retirement Longitudinal Study (CHARLS) repository (http://charls.pku.edu.cn/), subject to registration and the data use policy.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

CS and FL conceived the research question and designed the study. CS led data curation, constructed analytic variables, developed and validated the statistical code, conducted the primary and sensitivity analyses, generated the figures and tables, and drafted the initial manuscript. QY and TJ assisted with variable construction, data harmonization, and verification of analytic datasets, and contributed to interpretation of findings and preparation of supplementary materials. LW provided methodological

guidance on model specification, interaction assessment, and robustness analyses, and critically revised the manuscript for important intellectual content. FW and XS contributed to the clinical and public health interpretation of results and assisted with manuscript revision. BW supported data checking and interpretation and provided input on presentation of results. JG, WL, and ZY contributed to methodological input, literature contextualization, and critical revision of the manuscript. FL served as the corresponding author, provided overall supervision and project administration, and oversaw manuscript development. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Figures

Figure 1. Observed prevalence of orientation impairment
By stroke history and educational attainment (Wilson 95% CI)

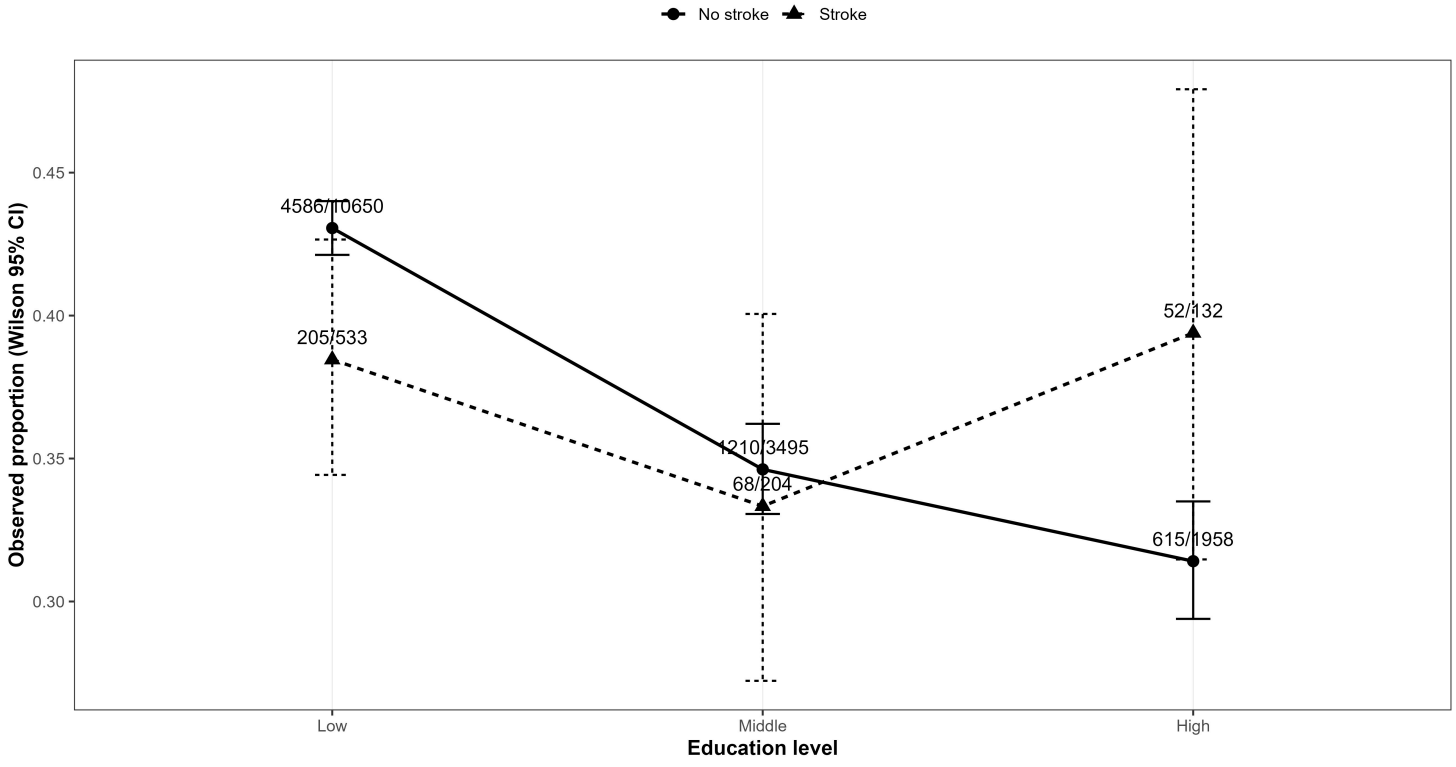


Figure 1

Observed prevalence of orientation impairment by education and stroke status.

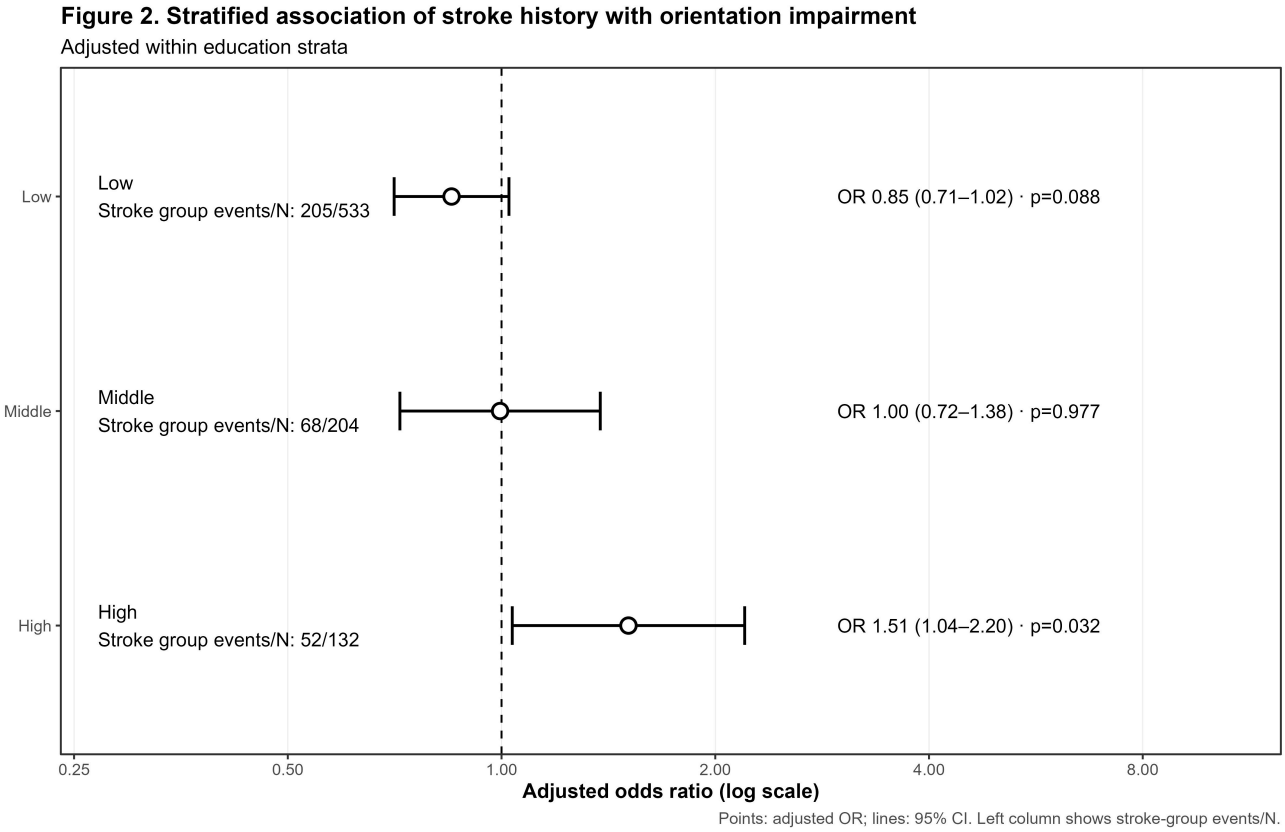


Figure 2

Education-stratified association between stroke history and orientation impairment.

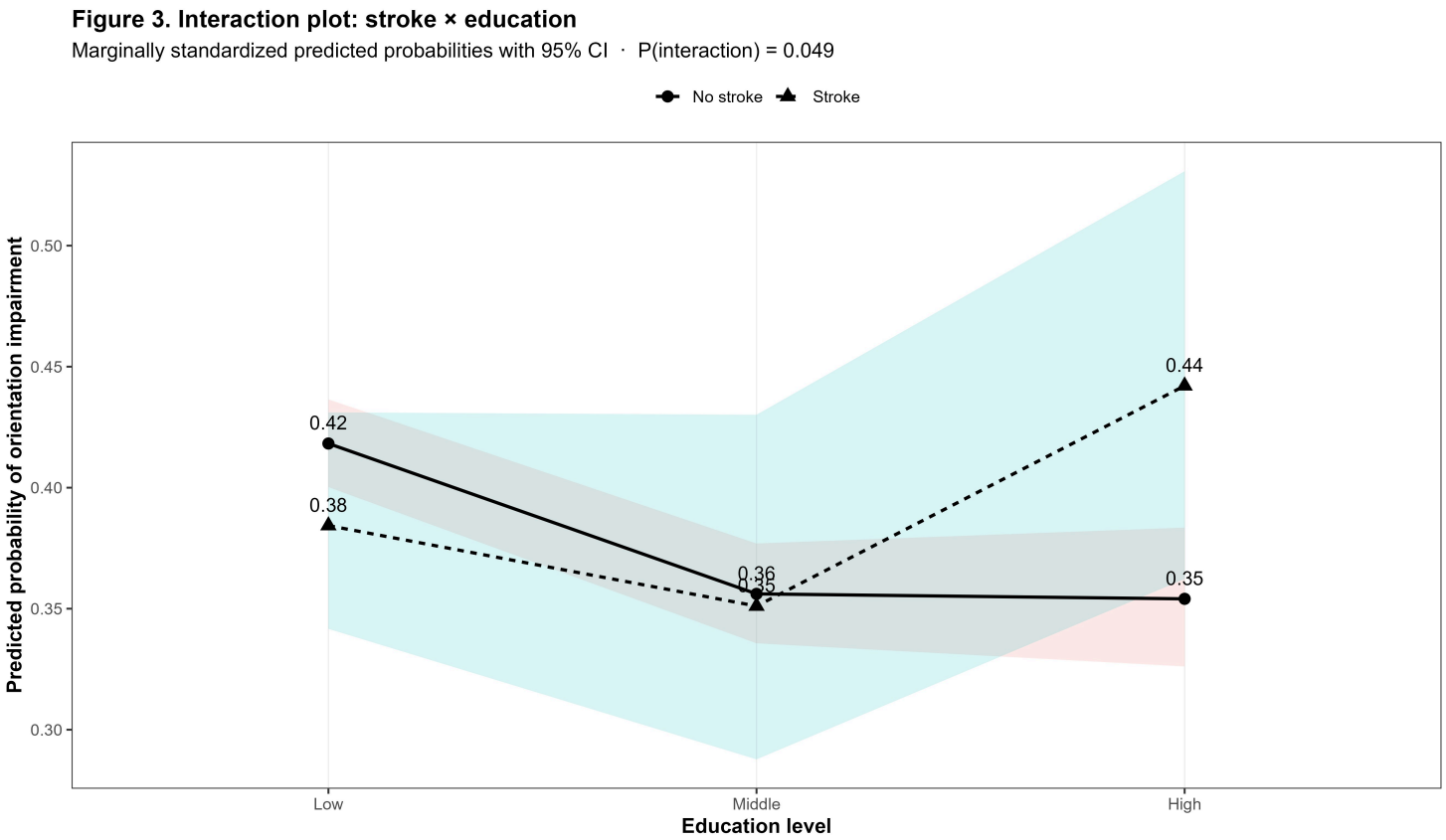


Figure 3

Marginally standardized predicted probabilities of orientation impairment by education and stroke status.

Supplementary Files

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- Sourcedata.zip
- Supplementary.zip
- SupplementaryFigureS2PredictedProbAge65.jpg
- SupplementaryFigureS1LOOStability.jpg