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Bidirectional association between grip strength and cognitive function in Chinese older adults: a nationwide cohort study

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Abstract

Background The rapid increase in the elderly population in China has led to the dual challenges of cognitive decline and physical functional decline. Grip strength, a key indicator of physical function, may have a bidirectional relationship with cognitive function. However, research on the association and bidirectional dynamics between the two, especially in the elderly population in China, remains limited.

Objective This study aims to investigate the longitudinal bidirectional associations between grip strength, global cognitive function, mental intactness, and episodic memory, and to examine the trajectory of these indicators over time.

Methods This study is based on the China Health and Retirement Longitudinal Study (CHARLS), which included 4,442 eligible individuals aged 60 and above, spanning from 2011 to 2015. Grip strength was measured using a standardized dynamometer, while global cognitive function was assessed through mental intactness and episodic memory metrics. Cross-lagged panel models and linear mixed-effects models were employed to assess the bidirectional associations between grip strength, global cognitive function, mental intactness, and episodic memory, controlling for various confounding factors, including sociodemographic characteristics.

Results During the 4-year follow-up, individuals with greater baseline grip strength exhibited higher scores in global cognitive function ($\beta = 0.055$, $p = 0.001$), mental intactness ($\beta = 0.048$, $p = 0.006$), and episodic memory ($\beta = 0.049$, $p = 0.011$) at follow-up. Baseline global cognitive function, mental intactness ($\beta = 0.024$, $p = 0.019$), and episodic memory ($\beta = 0.040$, $p < 0.001$) also significantly predicted grip strength at follow-up ($\beta = 0.041$, $p < 0.001$). A comparison of the cross-lagged coefficients revealed that the effect of baseline grip strength on episodic memory was significantly greater than the reverse pathway ($\Delta\chi2 = 5.089$, $p = 0.024$). The linear mixed-effects model analysis further confirmed this result, showing that lower baseline cognitive function and weaker grip strength independently predicted the accelerated decline of both over time.

Conclusion This study provides new evidence for the longitudinal bidirectional relationship between grip strength, global cognitive function, mental intactness, and episodic memory in the Chinese elderly population, emphasizing the importance of improving both grip strength and cognitive function. Notably, baseline grip strength has a stronger effect on subsequent episodic memory than the reverse pathway, which carries important public health implications. Maintaining optimal grip strength may be an effective intervention strategy to delay age-related cognitive decline.

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Keywords Bidirectional relationship, Grip strength, Cognitive function, Cross-lagged panel model, Linear mixed-effects model

Introduction

Amid the wave of globalization, population aging has become a critical challenge for global public health, especially in Asia, where China is undergoing rapid demographic shifts. Data from the 2021 National Population Census reveal that China's population aged 60 and above has reached 264 million, comprising 18.7% of the total population. This highlights the escalating burden of age-related chronic diseases [1–4]. Cognitive function, a pivotal determinant of quality of life among older adults, deteriorates with age [5], elevating the risk of various chronic conditions [6, 7]. Grip strength, a straightforward metric of muscle strength and functional capacity [8], correlates with adverse health outcomes in older adults, including depression [9], cognitive decline [10], sarcopenia [11], cardiovascular disease [12], and mortality [13].

Cognitive function and grip strength often decline concurrently in older adults, suggesting a possible interrelationship between the two [14, 15]. The concurrent decline of these functions poses substantial challenges to the health and well-being of older adults, placing added strain on public health systems. Previous cross-sectional studies have identified significant links between cognitive function and grip strength among older adults [16, 17]. In contrast, longitudinal studies offer deeper insights into the temporal dynamics of this relationship, emphasizing variations across different populations. For example, a 7-year longitudinal study on Mexican–American older adults demonstrated that cognitive decline predicts subsequent reductions in grip strength [18]. The longitudinal epidemiological study in the Dutch elderly population also found a significant association between poorer cognitive function at baseline and subsequent decline in grip strength [19]. An observational cohort study in Chicago offered contrasting evidence, proposing that weaker grip strength could serve as an early indicator of cognitive decline [20].

Findings from the Health and Retirement Study suggest that declining grip strength is linked to the onset of cognitive impairment among older adults in the United States [21]. Similarly, a longitudinal study in Japanese older adults revealed that lower grip strength predicts cognitive decline over a decade [22]. The bidirectional longitudinal association between cognitive function and grip strength has attracted significant research interest. A European multicenter study demonstrated that grip strength is closely linked with multiple cognitive functions over time [23]. Longitudinal research in Sweden and the United States has further underscored this bidirectional relationship, with one study indicating that weaker grip strength could accelerate cognitive decline in adults aged 65 years and older [24]. Another study reported a significant association between cognitive decline and subsequent decreases in grip strength [25]. Notably, a prospective cohort study of older adults in Leiden, the Netherlands, demonstrated that cognitive decline precedes reductions in grip strength, with no evidence supporting the reverse [26].

The interplay between cognitive function and grip strength represents a pivotal focus in geriatric medicine research. Although existing literature highlights a potential link between these variables, the temporal sequence governing this relationship remains ambiguous. Limitations in existing methodologies, particularly the reliance on conventional statistical models such as linear mixed-effects models, impede a nuanced understanding of the bidirectional dynamic relationship between grip strength and cognitive function. These methods typically examine unidirectional effects and fail to account for the intricate interactions and temporal dynamics between the two. Furthermore, most studies have been conducted in Western populations, whose distinct socioeconomic contexts, cultural practices, and nutritional statuses differ markedly from those in China. These disparities may substantially influence the relationship between cognitive function and grip strength, necessitating careful application and interpretation in Chinese older adults. To the best of our knowledge, no systematic investigation has explored the longitudinal bidirectional relationship between grip strength and cognitive function in Chinese older adults, nor has it clarified the temporal sequence of these changes.

Study objective

In the light of those mentioned above, this study aims to employ a cross-lagged panel design to explore the longitudinal bidirectional relationship between cognitive function and grip strength in Chinese community-dwelling older adults and uncover the temporal patterns of these changes. Clarifying the temporal sequence between cognitive decline and grip strength reduction will enhance our understanding of their potential causal relationship, providing robust evidence for developing targeted prevention and intervention strategies to address aging-related health challenges, and more important, will provide valuable insights for public health policymakers and clinicians.

Methods

Data source

The data analyzed in this study were sourced from the China Health and Retirement Longitudinal Survey (CHARLS) [27]. Conducted and managed by Peking University, CHARLS is a large-scale interdisciplinary initiative designed to collect high-quality microdata representative of Chinese households and individuals aged 45 years or older. The dataset encompasses a wide array of variables, including demographic information, health status, physical measurements, family structure, financial support, healthcare utilization, insurance, employment and retirement status, economic metrics (e.g., income, consumption, and personal assets), and community characteristics. This dataset serves as a vital resource for interdisciplinary research on aging-related challenges, and for further details on the CHARLS initiative and its research methodology could directly access to its official website at https://charls.pku.edu.cn/.

This study utilized data from two CHARLS survey waves conducted in 2011 and 2015, with the 2011 wave serving as the baseline. The baseline cohort comprised 17,711 participants. To ensure the accuracy and reliability of our analysis, we conducted rigorous screening of the sample, excluding participants who were lost to follow-up in subsequent surveys (n= 1,428), those under the age of 60 (n= 1,481), and those with missing or abnormal data for key variables. Specifically, we excluded participants with missing cognitive function information (n= 6,096), missing grip strength information (n= 1,565), and missing covariate information, including gender, age, education level, marital status, smoking status, alcohol consumption, activities of daily living, household registration, income, chronic diseases, self-rated health, and depressive symptoms (n= 2,699). Ultimately, 4,442 eligible older adults were included in the analysis (Fig. 1).

Measurements

Cognitive function

CHARLS assesses global cognitive function through two key components: mental intactness and episodic

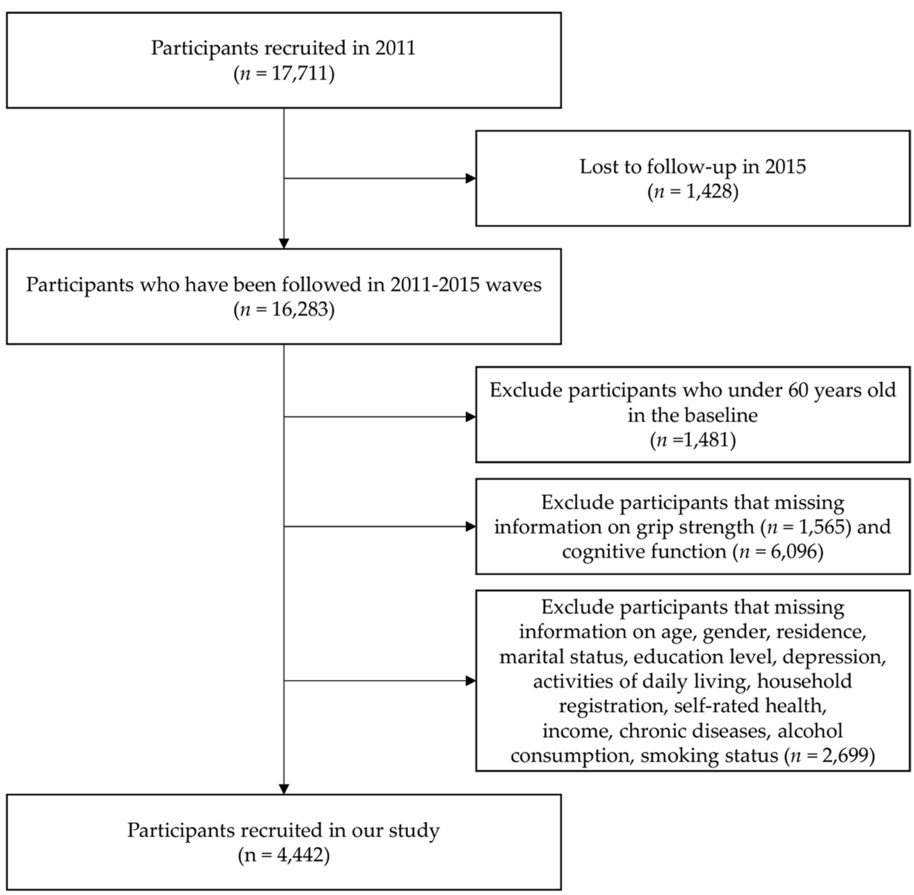

Fig. 1 Flow of participants into study sample

memory. Mental intactness assessment includes telephone interviews and drawing tests. The telephone interview primarily employs the Telephone Interview for Cognitive Status (TICS), comprising 11 questions to assess time orientation and numerical calculation ability. Time orientation involves asking participants to identify the current date (year, month, day, and season) as well as the day of the week. Numerical calculation ability is assessed by instructing participants to subtract 7 from 100 consecutively, up to five times. Participants receive one point for each correct response or calculation, with the total TICS score ranging from 0 to 10 points. The drawing test is conducted during face-to-face interviews to evaluate participants' visuospatial ability, requiring them to replicate a pair of overlapping pentagons. Interviewers present a drawing to the participants and ask them to reproduce it using paper and pencil. One point is awarded for a successful replication. The mental intactness score is derived by summing the TICS and drawing test results, with a maximum score of 11 points [28]. Episodic memory is measured via tests of immediate and delayed word recall. Participants are tasked with repeating ten Chinese nouns presented by the interviewer and recalling them again after a five-minute interval. The episodic memory score is calculated as the average number of correctly recalled words across immediate and delayed recall tests, capped at 10. Combining mental intactness and episodic memory scores produces a total cognitive function score ranging from 0 to 21, with higher scores reflecting superior cognitive ability [29]. These cognitive assessment tools have been validated in older Chinese populations, demonstrating robust reliability and validity [30]. In this study, the internal consistency of the cognitive function measure was good, with a Cronbach's α coefficient of 0.832.

Grip strength

Grip strength in the CHARLS study was measured using a standardized dynamometer (Model: WL-1000, Guangdong Yuejian, Nantong, China), reported in kilograms. Prior to measurement, researchers demonstrated the correct procedure. Participants were instructed to stand (or sit/lie down if unable to stand), grip the dynamometer as firmly as possible for several seconds, and then release while maintaining a 90° elbow angle. Each hand was tested twice, with the highest value recorded as the grip strength measure [29].

Control variables

This study systematically addressed potential confounders linked to grip strength and cognitive function among older adults. Drawing on existing literature, we adjusted for sociodemographic characteristics, health-related behaviors, and health outcomes that might affect grip strength and cognitive function [31, 32]. Sociodemographic variables encompassed age, gender (1 =male, 2= female), residence type (1 =urban, 2= rural), marital status (1 =married, 2= unmarried), educational attainment (1 =primary school or below, 2= junior high, 3= senior high or vocational, 4= college or above), household registration (1 =agricultural, 2= non-agricultural, 3= unified resident registration), and personal income (1 =income present, 2= no income). Health behavior variables included smoking status (1 =current smoker, 2= former smoker, 3= never smoked) and alcohol consumption (1 =drinker, 2= non-drinker). Health outcomes encompassed self-rated health (1 =very good, 2= good, 3= fair, 4= poor, 5= very poor), the number of chronic conditions (1 =none, 2= one, 3= two or more), limitations in activities of daily living (ADL), and depression severity. Depression severity was evaluated using the 10-Item Center for Epidemiologic Studies Depression Scale, where higher scores reflect more severe depression. To minimize model complexity, all covariates were analyzed using data from the 2011 wave.

Statistical analysis

Means (standard deviations) were used to describe continuous variables, while categorical variables were represented as frequencies (percentages) to comprehensively summarize the sample characteristics. To investigate the bidirectional relationship between grip strength and cognitive function among older adults, we developed a cross-lagged model and sequentially adjusted for multiple covariates. Specifically, standardized coefficients were reported for four models: a crude model and three progressively adjusted models—Model 1 without adjustments and Model 2 adjusted for age and gender. Model 3 additionally accounted for residence, marital status, education level, household registration, and individual income, alongside age and gender. Finally, Model 4 included further adjustments, incorporating smoking and drinking status, self-rated health, ADL limitations, number of chronic diseases, and depression severity. Figure 2A presents the overall modeling strategy, detailing six paths and their respective coefficients.

The analysis focused on two cross-lagged paths, represented by the coefficients $\beta_{CL\text{-}1}$ and $\beta_{CL\text{-}2}$. The coefficient $\beta_{CL\text{-}1}$ quantifies the effect of grip strength at the initial time point (T1) on cognitive function at the subsequent time point (T2), whereas $\beta_{CL\text{-}2}$ evaluates the reciprocal impact of cognitive function at T1 on grip strength at T2. The temporal sequence was established by comparing the standardized cross-lagged coefficients. To assess whether significant differences exist between the two cross-lagged path coefficients, a chi-square test (χ^{2}) was employed.

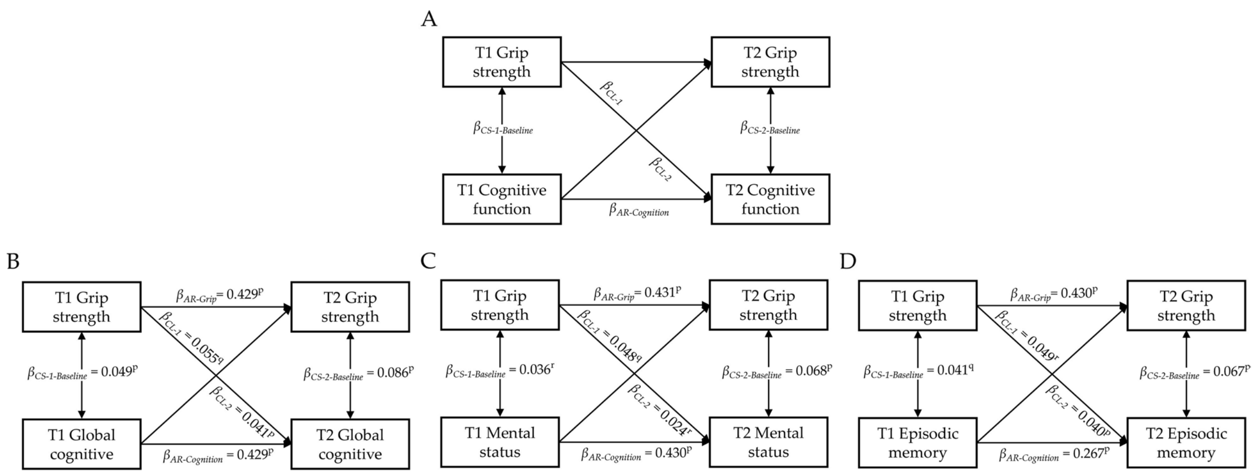

Fig. 2 Cross-lagged panel models of grip strength and cognitive function. **A** General modeling strategy for the cross-lagged panel model. **B** Cross-lagged panel model for grip strength and global cognitive function. **C** Cross-lagged panel model for grip strength and mental intactness. **D** Cross-lagged panel model for grip strength and episodic memory. The values in the figure represent standardized regression coefficients, with $\beta_{\text{AR-Grip}}$ and $\beta_{\text{AR-Cognition}}$ denoting autoregressive paths, $\beta_{\text{CL-1}}$ and $\beta_{\text{CL-2}}$ indicating cross-lagged paths, and $\beta_{\text{CS-1-Baseline}}$ and $\beta_{\text{CS-2-Baseline}}$ representing cross-sectional paths

Specifically, a baseline model and a constrained model were constructed, with chi-square values (χ^2) and degrees of freedom (df) recorded for each. The significance of the difference between the two path coefficients was evaluated by calculating the chi-square difference ($\Delta\chi^2$) and the degree of freedom difference (Δdf), with reference to the chi-square distribution table. A significant difference between the two path coefficients is indicated if the $\Delta\chi^2$ exceeds the critical value of 3.841. Additionally, the cross-sectional relationship between grip strength and cognitive function was quantified, with $\beta_{\text{CS-1-Baseline}}$ at T1 reflecting the baseline correlation and $\beta_{\text{CS-2-Baseline}}$ at T2 representing their association at the subsequent time point. Autoregressive coefficients for grip strength and cognitive function from T1 to T2, denoted as $\beta_{\text{AR-Grip}}$ and $\beta_{\text{AR-Cognition}}$, were also calculated. These coefficients indicate the intrinsic stability of each variable across time points. The goodness-of-fit of the model was assessed using the Comparative Fit Index (CFI), the Standardized Root Mean Square Residual (SRMR), and the Root Mean Square Error of Approximation (RMSEA). A model was deemed to exhibit good fit if the CFI values exceeded 0.90, while SRMR and RMSEA values were below 0.08 [33, 34]. Linear mixed-effects models were employed to visually illustrate the longitudinal associations between grip strength, cognitive function, and aging.

To enhance the robustness of the study findings, we performed a series of sensitivity analyses incorporating diverse analytical approaches and model adjustments. Initially, 11 distinct chronic diseases were individually controlled for, rather than relying exclusively on the total chronic disease count as employed in Model 4. Subsequently, additional relevant variables were incorporated in addition to the confounders already adjusted in Model 4, aiming to address as many other potential confounding factors as possible. These variables encompassed social engagement [35], social support (with support, without support) [36], healthcare (with care, without care) [37], housing structure (multi-story or single-story), water supply (municipal or none), indoor temperature conditions (comfortable or uncomfortable), and household air pollution (entirely clean energy use, partially clean energy use, or exclusively solid fuel use) [38]. Furthermore, to minimize bias arising from potential reverse causation, participants exhibiting abnormally low grip strength or global cognitive function scores at baseline (below two standard deviations below the mean) were excluded from the analysis. Lastly, to mitigate bias from attrition and incomplete responses, we applied multiple imputation to fill missing data, generating several complete datasets to compare with the analysis of the original dataset. All statistical analyses were performed using IBM-SPSS 22.0 software with its AMOS module and R software (version 4.4.2). For the primary analyses, statistical significance was set at a two-tailed p-value of less than 0.05. To account for multiple comparisons across different cognitive domains (global cognitive function, episodic memory, and mental intactness), we applied the Bonferroni correction, setting the significance level at $p < 0.0167$ (0.05/3). Results with p-values below this threshold were considered statistically significant.

Results

Participant characteristics

Baseline characteristics of the eligible participants in 2011 (N= 4,442) are summarized in Table 1. Participants had a mean age of 70.7 years (SD =7.46), with 2,323 males and 2,119 females. Around 57.2% of older adults reported an educational attainment of primary school or below. A majority of older adults resided in rural areas (89.8%), were married (91.7%), and reported no personal income (82.8%). Overall, a significant proportion of older adults self-reported smoking (32.7%) or alcohol consumption (36.2%) in the past month. In the first wave cohort, the average grip strength score among older adults was 34.7, indicating generally low grip strength levels. The mean global cognitive score was 12.9, including an average episodic memory score of 4.15 and a mean mental intactness score of 8.84. Additional details on the baseline characteristics of older adults are available in Table 1.

Table 1 Baseline characteristics of participants (N= 4,442)

Variables	Mean (SD)/*N* (%)
Age (years)	70.7 (7.46)
Gender	
Male	2 323 (52.3)
Female	2 119 (47.7)
Residence	
Urban	3 991 (89.8)
Rural	451 (10.2)
Marital status	
Married	4 075 (91.7)
Unmarried	367 (8.30)
Education level	
Primary school or below	2 540 (57.2)
Junior high school	1 229 (27.7)
Senior high school or vocational school	585 (13.2)
College or above	88 (2.0)
Household registration	
Rural	3 459 (77.9)
Non-agricultural	954 (21.5)
Unified resident household	29 (0.70)
Income	
With income	766 (17.2)
Without income	3 676 (82.8)
Smoking status	
Current smoker	1 454 (32.7)
Former smoker	442 (10.0)
Never smoker	2 546 (57.3)
Alcohol consumption	
Drinker	1 607 (36.2)
Non-drinker	2 835 (63.8)
Number of chronic diseases	
No chronic diseases	1 433 (32.3)
1 Chronic disease	1 357 (30.5)
At least 2 chronic diseases	1 652 (37.2)
Self-rated health	
Excellent	167 (3.80)
Good	581 (13.1)
Fair	1 540 (34.7)
Poor	1591 (35.8)
Depression level	7.57 (6.03)
ADL limitations	5.40 (1.28)
Social participation	2.30 (2.74)
T1 Grip strength	34.7 (10.1)
T2 Grip strength	32.2 (9.36)
T1 Global cognitive function	12.9 (2.88)
T2 Global cognitive function	12.7 (2.86)
T1 Mental intactness	8.84 (2.14)
T2 Mental intactness	8.65 (2.18)
T1 Episodic memory	4.15 (1.42)
T2 Episodic memory	4.07 (1.35)

SD standard deviation, *ADL* activities of daily living

Bidirectional relationship between grip strength and cognitive function

The results of the cross-lagged panel model analysis between grip strength and cognitive function are summarized in Table 2. Preliminary analyses of Models 1 to 3 indicate that the standardized structural regression coefficients for all paths were statistically significant (refer to Table 2). Following comprehensive adjustments for potential confounders, the strength of associations diminished, though most retained statistical significance (see Table 2 for further details). Consequently, this study emphasizes the analytical results derived from Model 4. Additionally, across all models, the autoregressive paths for grip strength and cognitive function were statistically significant, with coefficients significantly deviating from zero, indicating temporal stability and persistent effects of the variables [39].

Figure 2B illustrates the cross-lagged model results between grip strength and global cognitive function in Model 4. This model demonstrated a strong fit to the data (CFI =1.000, SRMR =0.002, RMSEA =0.040). Cross-sectional analyses indicated a significant positive association between grip strength and global cognitive function at both time points (β= 0.049, p< 0.001; β= 0.086, p< 0.001). Regarding causality, grip strength at T1 significantly forecasted global cognitive function at T2 (β= 0.055, p= 0.001), while global cognitive function at T1 significantly forecasted grip strength at T2 (β= 0.041, p< 0.001). Although the standardized path coefficient from T1 grip strength to T2 global cognitive function exceeded that of the reverse path, the

Table 2 Results of cross-lagged regression analysis between grip strength and cognitive function

Grip and cognition results	Grip → cognition[b]	Cognition → grip[b]	Cross sectional[b]		Autoregressive[b]		Fit indices	RMSEA[j]	SRMR[k]
	$\beta_{CL\text{-}1}$[c]	$\beta_{CL\text{-}2}$[d]	$\beta_{CS\text{-}1\text{-}Baseline}$[e]	$\beta_{CS\text{-}2\text{-}Baseline}$[f]	$\beta_{AR\text{-}Grip}$[g]	$\beta_{AR\text{-}Cognition}$[h]	CFI[i]		
Global cognitive scores									
Model 1[l]	0.113[p]	0.086[p]	0.224[p]	0.249[p]	0.707[p]	0.523[p]	0.996	0.067	0.012
Model 2[m]	0.083[p]	0.065[p]	0.118[p]	0.144[p]	0.445[p]	0.515[p]	0.999	0.053	0.006
Model 3[n]	0.067[p]	0.053[p]	0.085[p]	0.110[p]	0.441[p]	0.445[p]	0.999	0.045	0.003
Model 4[o]	0.055[q]	0.041[p]	0.049[p]	0.086[p]	0.429[p]	0.429[p]	1.000	0.040	0.002
Mental intactness scores									
Model 1[l]	0.119[p]	0.079[p]	0.233[p]	0.249[p]	0.708[p]	0.500[p]	0.996	0.069	0.013
Model 2[m]	0.072[p]	0.048[p]	0.097[p]	0.119[p]	0.449[p]	0.495[p]	0.999	0.049	0.005
Model 3[n]	0.057[p]	0.035[p]	0.066[p]	0.087[p]	0.444[p]	0.443[p]	0.999	0.040	0.003
Model 4[o]	0.048[q]	0.024[r]	0.036[r]	0.068[p]	0.431[p]	0.430[p]	1.000	0.032	0.002
Episodic memory scores									
Model 1[l]	0.072[p]	0.054[p]	0.104[p]	0.126[p]	0.721[p]	0.349[p]	0.998	0.043	0.009
Model 2[m]	0.088[p]	0.058[p]	0.094[p]	0.113[p]	0.448[p]	0.325[p]	0.999	0.049	0.006
Model 3[n]	0.066[p]	0.050[p]	0.070[p]	0.086[p]	0.442[p]	0.278[p]	0.999	0.038	0.003
Model 4[o]	0.049[r]	0.040[p]	0.041[q]	0.067[p]	0.430[p]	0.267[p]	1.000	0.032	0.002

[a] Refer to Fig. 2 for a visual representation of the longitudinal associations

[b] Standardized regression coefficients

[c] $\beta_{CL\text{-}1}$ represents the cross-lagged regression coefficient for T1 grip strength predicting T2 cognitive function

[d] $\beta_{CL\text{-}2}$ represents the cross-lagged regression coefficient for T1 cognitive function predicting T2 grip strength

[e] $\beta_{CS\text{-}1\text{-}Baseline}$ denotes the cross-sectional association between grip strength and cognitive function at T1

[f] $\beta_{CS\text{-}2\text{-}Baseline}$ denotes the cross-sectional association between grip strength and cognitive function at T2

[g] $\beta_{AR\text{-}Grip}$ represents the autoregressive coefficient for grip strength

[h] $\beta_{AR\text{-}Cognition}$ represents the autoregressive coefficient for cognitive function

[i] CFI: Comparative Fit Index

[j] RMSEA: Root Mean Square Error of Approximation

[k] SRMR: Standardized Root Mean Square Residual

[l] Model 1 was unadjusted

[m] Model 2 adjusted for age and gender

[n] Model 3 adjusted for age, gender, residence, marital status, education level, household registration status, and personal income

[o] Model 4 further adjusted for smoking status, alcohol consumption, self-rated health, ADL limitations, number of chronic diseases, and depression

[p] $p < 0.001$

[q] $p < 0.01$

[r] $p < 0.05$

difference did not reach statistical significance ($\Delta\chi2 = 1.746$, p for difference $= 0.186$).

Figure 2C displays the cross-lagged model findings for grip strength and mental intactness in Model 4. The model demonstrated a strong fit (CFI = 1.000, SRMR = 0.002, RMSEA = 0.032), reflecting a high degree of alignment with the data. Cross-sectional analysis indicated a significant positive relationship between grip strength and mental intactness at both time points ($\beta = 0.036$, $p = 0.018$; $\beta = 0.068$, $p < 0.001$). In terms of causality, grip strength at T1 significantly forecasted mental intactness at T2 ($\beta = 0.048$, $p = 0.006$), while mental intactness at T1 significantly forecasted grip strength at T2 ($\beta = 0.024$, $p = 0.019$). However, although the standardized path coefficient from T1 grip strength to T2 mental intactness exceeded the reverse, the difference did not attain statistical significance ($\Delta\chi2 = 1.076$, p for difference $= 0.299$).

Figure 2D presents the cross-lagged model findings between grip strength and episodic memory in Model 4. The model demonstrated a satisfactory fit (CFI = 1.000, SRMR = 0.002, RMSEA = 0.032), confirming its adequacy in explaining the data. Cross-sectional analysis revealed significant positive relationships between grip strength and episodic memory at both time points ($\beta = 0.041$, p = 0.006; $\beta = 0.067$, $p = 0.001$). Importantly, the standardized path coefficient from T1 grip strength to T2 episodic memory exceeded the reverse path, and this

Table 3 Sensitivity analysis of the cross-lagged relationship between grip strength and cognitive function

Grip and cognition	Grip → cognition[b]	Cognition → grip[b]	Cross sectional[b]		Autoregressive[b]		Fit indices	RMSEA[j]	SRMR[k]
	β_{CL-1}[c]	β_{CL-2}[d]	$\beta_{CS-1-Baseline}$[e]	$\beta_{CS-2-Baseline}$[f]	$\beta_{AR-Grip}$[g]	$\beta_{AR-Cognition}$[h]	CFI[i]		
Controlling for 11 specific chronic diseases at baseline rather than merely the total number of chronic diseases									
Global cognitive scores	0.054[q]	0.053[p]	0.221[p]	0.250[p]	0.433[p]	0.445[p]	1.000	0.045	0.001
Mental intactness scores	0.048[q]	0.034[p]	0.229[p]	0.248[p]	0.435[p]	0.442[p]	1.000	0.041	0.001
Episodic memory scores	0.051[q]	0.050[p]	0.103[p]	0.129[p]	0.434[p]	0.277[p]	1.000	0.036	0.001
Adjusting for additional residential environment—related and other variables									
Global cognitive scores	0.056[q]	0.035[p]	0.224[p]	0.248[p]	0.428[p]	0.425[p]	1.000	0.040	0.001
Mental intactness scores	0.050[q]	0.021[r]	0.234[p]	0.249[p]	0.429[p]	0.429[p]	1.000	0.034	0.001
Episodic memory scores	0.049[r]	0.034[p]	0.102[p]	0.124[p]	0.428[p]	0.260[p]	1.000	0.031	0.001
Excluding participants with extremely low baseline grip strength or global cognitive function scores or both									
Global cognitive scores	0.056[q]	0.045[p]	0.206[p]	0.240[p]	0.432[p]	0.410[p]	1.000	0.040	0.002
Mental intactness scores	0.049[q]	0.028[q]	0.214[p]	0.240[p]	0.433[p]	0.409[p]	1.000	0.035	0.002
Episodic memory scores	0.048[q]	0.041[p]	0.091[p]	0.118[p]	0.432[p]	0.263[p]	1.000	0.032	0.002

[b] Standardized regression coefficients

[c] β_{CL-1} represents the cross-lagged regression coefficient for T1 grip strength predicting T2 cognitive function

[d] β_{CL-2} represents the cross-lagged regression coefficient for T1 cognitive function predicting T2 grip strength

[e] $\beta_{CS-1-Baseline}$ denotes the cross-sectional association between grip strength and cognitive function at T1

[f] $\beta_{CS-2-Baseline}$ denotes the cross-sectional association between grip strength and cognitive function at T2

[g] $\beta_{AR-Grip}$ represents the autoregressive coefficient for grip strength

[h] $\beta_{AR-Cognition}$ represents the autoregressive coefficient for cognitive function

[i] CFI: Comparative Fit Index

[j] RMSEA: Root Mean Square Error of Approximation

[k] SRMR: Standardized Root Mean Square Residual

[l] Model 1 was unadjusted

[m] Model 2 adjusted for age and gender

[n] Model 3 adjusted for age, gender, residence, marital status, education level, household registration status, and personal income

[o] Model 4 further adjusted for smoking status, alcohol consumption, self-rated health, ADL limitations, number of chronic diseases, and depression, as well as social engagement, social support, and healthcare

[p] $p < 0.001$

[q] $p < 0.01$

[r] $p < 0.05$

difference reached statistical significance ($\Delta\chi 2 = 5.089$, p for difference $= 0.024$), suggesting grip strength may exert a stronger influence on episodic memory (Table 2).

Sensitivity analyses

To ensure the robustness of the findings, we conducted multiple sensitivity analyses. Specifically, after controlling for 11 distinct baseline chronic diseases instead of the total count of conditions, or further adjusting for factors such as social engagement, social support, healthcare, and those related to the living environment (the baseline characteristics of which are provided in Multimedia Appendix 1), all cross-lagged path coefficients remained statistically significant ($p < 0.05$ in all cases; detailed p-values in Table 3). Furthermore, after excluding 67 older adults with exceptionally weak grip strength, low global cognitive function, or both, the associations between grip strength and global cognition, mental intactness, and episodic memory remained consistent with the conclusions drawn from Model 4 (see Table 3 for details). Similarly, when multiple imputation was used to handle missing data, the main findings did not change significantly. This indicates that the associations observed in the initial analysis are robust (see Multimedia Appendix 2). Additionally, a linear mixed-effects model (Fig. 3) was constructed to visually represent the dynamic relationships between grip strength and cognitive function changes in older adults. Results indicated that older adults with baseline grip strength below 1 standard deviation from the mean experienced more rapid declines in global cognitive function, mental intactness, and episodic memory over time (Fig. 3A). The trajectories depicted in Fig. 3B support the findings of this study, illustrating that during follow-up, older adults with baseline cognitive function below 1 standard deviation from the mean demonstrated faster declines in grip strength compared

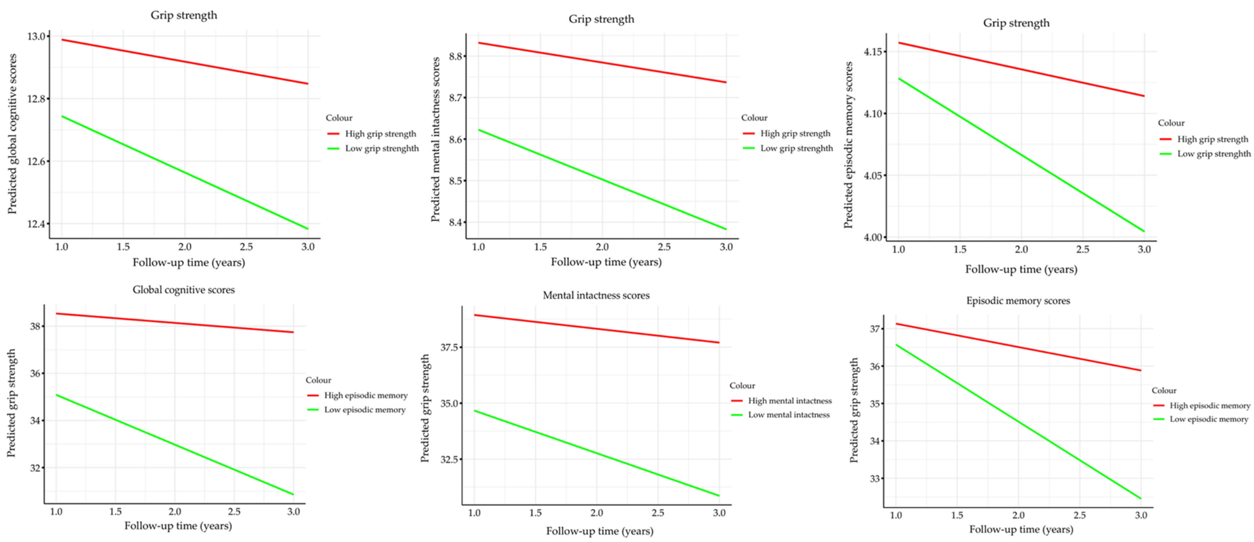

Fig. 3 Trajectory analysis of grip strength and cognitive function in Chinese older adults. Panel (**A**): Predicted scores of global cognitive function, mental intactness, and episodic memory based on a linear mixed-effects model, with the Y-axis displaying estimated cognitive scores predicted by the model. The lines correspond to cognitive scores associated with grip strength values one standard deviation above or below the mean. Panel (**B**): Predicted grip strength values based on a linear mixed-effects model, with the Y-axis displaying estimated grip strength predicted by the model. The lines correspond to grip strength values associated with cognitive scores one standard deviation above or below the mean

to their counterparts with higher cognitive scores. These trajectories offer compelling support for the temporal associations identified by the cross-lagged path models.

Discussion

In a four-year longitudinal study of older adults in China, we comprehensively investigated the bidirectional relationship between grip strength and cognitive function. This study identified robust bidirectional relationships between global cognitive function, mental intactness, episodic memory, and grip strength, even after adjusting for baseline values and multiple covariates. Further analysis of standardized cross-lagged coefficients suggested a potentially stronger temporal association from lower baseline global cognitive function and mental intactness to subsequent grip strength decline compared to the reverse direction, though this difference did not reach statistical significance. Moreover, the bidirectional associations between episodic memory and grip strength were significant, with a significant difference in path coefficients from episodic memory to grip strength compared to the reverse direction. Linear mixed-effects models showed that lower baseline cognitive function and weaker grip strength predicted faster declines in both over time. These findings provide novel insights into the complex interplay between cognitive decline and physical functional deterioration, offering a basis for developing targeted preventive and intervention strategies.

Our findings align with earlier cross-sectional studies that identified a positive association between grip strength and cognitive function in older adults. However, longitudinal research provides stronger evidence for clarifying the temporal directionality of this relationship. Two previous longitudinal studies using linear mixed-effects models yielded divergent findings. One study found bidirectional associations between executive function and grip strength in older American individuals [40], while another observed that higher baseline cognitive ability predicted less grip strength decline in older American women, but not vice versa [25]. These discrepancies may arise from variations in participant age, sample size, and heterogeneity in methods used for assessing cognitive function across studies. While these studies offer valuable initial insights, they are limited by their focus on unidirectional temporal associations. To address this, we applied structural equation modeling to construct cross-lagged path models and used linear mixed-effects models to illustrate time-series associations, in line with prior recommendations in the field.

Our findings offer novel insights into age-related dynamics of grip strength and cognitive function. To the best of our knowledge, few studies have explored the longitudinal bidirectional relationship between cognition and grip strength in older adults. Two studies employing structural equation models have similarly identified bidirectional relationships between cognitive decline and reduced grip strength among older adults in the United States and the Netherlands. Specifically, one study with 14,775 participants aged approximately 60 years reported that global cognitive function predicted later grip strength and vice versa [41]. Similarly, another study on older adults aged 85–90 reported reciprocal associations between grip strength and global cognitive function, excluding specific cognitive domains [42]. In our study, we observed bidirectional relationships not only between global cognition and grip strength but also between grip strength and specific domains, including mental intactness and episodic memory. Compared to these two studies, our sample size was larger, and the follow-up duration was longer, which may account for the discrepancies observed. Variations in cognitive assessment methods and participant gender composition may have also contributed to these inconsistencies. Therefore, further studies focusing on Chinese older adults are required to confirm whether these findings persist over longer follow-up periods or in gender-specific populations.

Additionally, our study highlights that the impact of grip strength on episodic memory decline is more pronounced than the reverse relationship. This finding aligns with prior research [40], suggesting that reduced grip strength may contribute to, rather than result from, cognitive decline. However, our analysis contrasts with findings in European older populations [25], which indicate that cognitive decline may precede reduced grip strength. This discrepancy may result from variations in follow-up durations and cognitive assessment methodologies. The follow-up duration in our study was four years, compared to six years in the European study. Regarding cognitive assessment, our study emphasized mental intactness and episodic memory, whereas the European study employed the 3MS, encompassing broader cognitive domains. Thus, the temporal dynamics between cognitive decline and reduced grip strength require further validation in Chinese older populations. Notably, after applying the Bonferroni correction, no significant difference was observed between the association of grip strength with episodic memory decline and its reverse association. This underscores the need for greater caution when interpreting this result. Future studies with larger sample sizes and longer follow-up periods are needed to further validate this finding and ensure the robustness and reliability of the results.

Our findings are consistent with earlier unidirectional longitudinal studies [43–45], which show that poorer baseline cognitive function predicts a decline in grip strength over a four-year period, even after excluding participants with extremely low baseline values. Additionally, declines in specific cognitive domains, including mental intactness and episodic memory, predict reduced grip strength, corroborating previous findings [23, 46]. A prospective cohort study suggests that improvements in cognitive domains, such as phrase memory, verbal fluency, and digit span tests, are positively associated with increased grip strength [47]. Reaction time, a key aspect of mental intactness, is positively associated with grip strength among middle-aged and older adults, as supported by longitudinal research, further reinforcing our findings [48]. While early changes in grip strength have a stronger influence on subsequent cognitive changes than the reverse, the importance of early cognitive changes should not be underestimated. Consistent with prior studies, we reaffirm that higher baseline cognition predicts subsequent grip strength, though with a weaker effect. A recent study similarly revealed that declines in multiple cognitive domains are linked to reduced grip strength over a longer follow-up period than ours [24]. A prospective study of older adults aged 60–76 years yielded similar results, indicating that higher baseline calculation ability, executive function, and memory are linked to stronger grip strength [23]. Consequently, grip strength and cognitive function serve as critical indicators for assessing dementia risk in older adults.

The common cause hypothesis further supports the observed association between grip strength and cognitive function [49, 50]. This hypothesis posits that declines in grip strength and cognitive function share common biological and neurodegenerative pathways that simultaneously affect muscle strength and cognitive ability. Specifically, chronic inflammation, a hallmark of aging, represents a shared mechanism underlying the deterioration of muscle and cognitive functions [51]. Elevated levels of pro-inflammatory cytokines, including IL-6 and TNF-α, are linked to sarcopenia and cognitive impairment, primarily through enhancing muscle catabolism and impairing neural health [52]. Moreover, chronic inflammation may lead to vascular damage, further compromising cognitive function [53]. Mitochondrial dysfunction and oxidative stress contribute to age-related muscle function decline and neurodegenerative disease progression, disrupting energy metabolism and inducing cellular damage, which may reduce grip strength and cognitive ability [54–56]. Neuroendocrine pathways, including alterations in levels of testosterone, insulin, and growth factors, exert influence on both muscle [57] and brain functions. These hormones and growth factors are pivotal in protein synthesis [58, 59], supporting grip strength [52], neuroprotection, and cognitive functions [52, 60]. The deterioration of neuromuscular integration is also a key factor contributing to declines in muscle strength and cognitive function, potentially linked to neurodegenerative processes that simultaneously impact both muscle and brain function [61]. The combined effects of these mechanisms may explain the significant bidirectional relationship between grip strength and cognitive function.

Notably, although the common cause hypothesis emphasizes that the decline in grip strength and cognitive function may share some underlying processes, this does not imply that these processes occur in the same temporal sequence across all individuals. In fact, biological processes may exhibit significant heterogeneity between individuals. For instance, some individuals may first exhibit a decline in muscle strength, with a later decline in cognitive function, while others may experience a decline in cognitive function first, followed by a decline in muscle strength. This heterogeneity may be related to various factors, including genetic background, lifestyle, and environmental influences. Our study found that grip strength declines prior to episodic memory, which may reflect the influence of certain early biomarkers. For example, biological processes such as chronic inflammation and mitochondrial dysfunction may initially affect muscle strength, gradually followed by an impact on cognitive function. The temporal differences observed suggest that when assessing the health of older adults, it is important to consider the dynamic changes of multiple biomarkers, rather than focusing solely on a single indicator. Moreover, this finding suggests that early intervention in the decline of muscle strength may play a significant role in delaying cognitive decline.

Furthermore, several mechanisms potentially elucidate the pronounced impact of grip strength on cognitive function. From a neurobiological standpoint, grip strength is intricately linked to brain structural integrity. Greater grip strength correlates with enhanced gray matter volume, particularly in subcortical regions and the temporal cortex, both critical for maintaining cognitive function [48]. From the perspective of neuromuscular coordination, sustaining grip strength necessitates precise neuromuscular integration. Optimal grip strength may indicate enhanced neuromuscular function, facilitating efficient brain-muscle communication and benefiting cognitive performance [62]. Finally, from a physiological and psychological perspective, grip strength serves as a comprehensive health marker closely linked to both physical and mental well-being. Elevated grip strength supports cognitive preservation and indirectly influences cognition via its role in promoting psychological well-being [48]. In conclusion, declines in grip strength may either precede or coincide with cognitive deterioration in older Chinese adults. Implementing early interventions to preserve grip strength and cognitive function is crucial to mitigating adverse outcomes. Additionally, reduced grip strength may function as a sensitive early marker of cognitive decline, highlighting its significance as a complementary factor to cognition in identifying risks of cognitive decline or functional impairment in older adults.

Strengths and limitations

This study possesses several strengths. Firstly, this study broadened the scope of previous research by transitioning from unidirectional associations to bidirectional relationships, thereby providing fresh insights into the interaction between grip strength and cognitive function in older adults. Secondly, this study utilized data from CHARLS, a nationally representative prospective cohort, which ensures broad applicability and robust generalizability of the findings. The extensive dataset provided by CHARLS facilitated an in-depth exploration of the relationship between grip strength and cognitive function, accounting for a wide range of potential confounding factors. Additionally, this study employed a cross-lagged panel model, surpassing conventional cross-sectional and longitudinal analyses by enabling simultaneous assessment of bidirectional temporal dynamics between grip strength and cognitive function. Compared to existing related studies [63], this research integrated a linear mixed-effects model to effectively visualize the bidirectional temporal relationships between these two factors. Finally, to our knowledge, this is the first study to investigate the temporal sequence of changes in grip strength and cognitive function among older Chinese adults, laying a critical foundation for future research and underscoring the necessity for further validation.

Nonetheless, several limitations of this study warrant consideration. Firstly, cognitive function was assessed using self-reported data, which, despite prior validation [40], may be subject to recall bias or reporting inaccuracies. Future research should employ objective cognitive function assessments to mitigate these biases. Secondly, while statistically significant relationships between grip strength and cognitive function were observed after adjusting for potential confounders, unmeasured variables, such as dietary habits, genetic predisposition, social relationships, psychological resilience, and vitamin D levels, may still have influenced the results. For example, studies have shown that individuals with lower vitamin D levels perform poorly in cognitive function tests [64] and demonstrate reduced grip strength [65]. Future studies should account for these potentially critical confounders to more precisely assess their effects on the relationship between grip strength and cognitive function. Unfortunately, this information is absent from the CHARLS dataset, potentially affecting our findings. Thirdly, as grip strength data extends only to 2015, our analysis was constrained to a 4-year follow-up period, limiting insights into the long-term persistence of the relationship between grip strength and cognitive function. Future research should prolong the follow-up period to gain deeper insights into the long-term dynamics of these variables. Additionally, although the cross-lagged panel model enables the evaluation of directional associations between variables, it does not establish causal relationships. Future research could validate causal pathways through experimental or intervention studies. Lastly, incomplete follow-up for certain individuals in the initial or subsequent assessments of grip strength and cognitive function may have introduced bias. Future studies should strive to improve follow-up rates, thereby minimizing bias and bolstering the reliability of findings. Despite these limitations, this study included a substantial number of eligible participants, offering valuable insights into the relationship between grip strength and cognitive function, while establishing a foundation for future research.

Conclusions

This nationwide cohort study corroborates the longitudinal relationships between grip strength and global cognitive function, mental intactness, and episodic memory among older Chinese adults. Older adults with reduced grip strength face an elevated risk of cognitive decline. Cross-lagged path coefficients indicate that baseline grip strength exerts a stronger influence on subsequent episodic memory compared to the reverse pathway. These findings highlight the necessity of early interventions aimed at improving grip strength and cognitive function, offering fresh insights into elucidating their causal relationship. Maintaining high grip strength could serve as a critical intervention strategy to mitigate age-related cognitive decline.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-23079-3.

Supplementary Material 1.

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Authors' contributions

JFW was responsible for the study concept, and supervision. JFW was responsible for the study design, data analysis, interpretation of the data, and writing of the manuscript. QMC and XX were responsible for supervision. JFW, QMC, and GY reviewed the manuscript. All authors have read and approved the published version of the manuscript.

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Data availability

The data that support the findings of this study are available from the China Health and Retirement Longitudinal Study (CHARLS) data repository (https://charls.pku.edu.cn/).

Declarations

Ethics approval and consent to participate

The Institutional Review Board (IRB) of Peking University thoroughly reviewed and approved all phases of the CHARLS study (Approval No.: IRB 00001052–11015). Informed consent was obtained from all subjects prior to their participation of this study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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