

J-shaped association between dietary thiamine intake and the risk of cognitive decline in cognitively healthy, older Chinese individuals

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ABSTRACT

Background The prospective association of dietary thiamine intake with the risk of cognitive decline among the general older adults remains uncertain.

Aims To investigate the association between dietary thiamine intake and cognitive decline in cognitively healthy, older Chinese individuals.

Methods The study included a total of 3106 participants capable of completing repeated cognitive function tests. Dietary nutrient intake information was collected through 3-day dietary recalls and using a 3-day food-weighed method to assess cooking oil and condiment consumption. Cognitive decline was defined as the 5-year decline rate in global or composite cognitive scores based on a subset of items from the Telephone Interview for Cognitive Status–modified.

Results The median follow-up duration was 5.9 years. There was a J-shaped relationship between dietary thiamine intake and the 5-year decline rate in global and composite cognitive scores, with an inflection point of 0.68 mg/day (95% confidence interval (CI): 0.56 to 0.80) and a minimal risk at 0.60–1.00 mg/day of dietary thiamine intake. Before the inflection point, thiamine intake was not significantly associated with cognitive decline. Beyond the inflection point, each unit increase in thiamine intake (mg/day) was associated with a significant decrease of 4.24 (95% CI: 2.22 to 6.27) points in the global score and 0.49 (95% CI: 0.23 to 0.76) standard units in the composite score within 5 years. A stronger positive association between thiamine intake and cognitive decline was observed in those with hypertension, obesity and those who were non-smokers (all $p < 0.05$).

Conclusions This study revealed a J-shaped association between dietary thiamine intake and cognitive decline in cognitively healthy, older Chinese individuals, with an inflection point at 0.68 mg/day and a minimal risk at 0.60–1.00 mg/day of dietary thiamine intake.

INTRODUCTION

Dementia is one of the leading causes of death and disability and is projected to affect 139 million people worldwide by 2050,¹ resulting in a substantial social and economic burden.² Given that there is currently no cure

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Research findings on the relationship between dietary thiamine intake and cognitive function in the general older population are inconsistent and are based mainly on the evidence from cross-sectional and case–control studies. The prospective association of dietary thiamine intake with the risk of cognitive decline in the general older population remains uncertain.

WHAT THIS STUDY ADDS

⇒ In cognitively healthy, older Chinese individuals, there was a J-shaped association between dietary thiamine intake and cognitive decline, with an inflection point at 0.68 mg/day and a minimal risk at 0.60–1.00 mg/day.
⇒ Beyond the inflection point, the positive association of dietary thiamine intake with cognitive decline was significantly stronger in those with obesity, hypertension and those who were non-smokers.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our study highlights the importance of maintaining optimal dietary thiamine intake levels in the general older population to prevent cognitive decline.

for dementia, preventing cognitive decline is particularly important, especially through targeting easily modifiable nutritional and behavioural factors in the population.

Thiamine (vitamin B₁) is an essential water-soluble B vitamin involved in energy metabolism, neurotransmitter synthesis and secretion. Previous clinical trials with small sample sizes have reported that thiamine treatment (5–600 mg/day) can improve cognitive function in patients with cognitive impairment or mild dementia (n=70),³ in maintenance haemodialysis patients with cognitive impairment (n=50)⁴ and in patients with alcohol dependence (n=107).⁵ Of note,

these trials mainly focused on the effects of high-dose thiamine supplementation or intramuscular injection,³⁻⁵ rather than dietary thiamine derived from foods in the general population. However, findings on the association between dietary thiamine intake and cognitive function in the older population were inconsistent and mainly based on the evidence from cross-sectional and case-control studies.⁶⁻⁹ Therefore, the prospective association of dietary thiamine intake with the risk of cognitive decline in the general older population remains uncertain. To address these knowledge gaps, this study aimed to investigate the relationship between dietary thiamine intake and cognitive decline in cognitively healthy, older Chinese individuals.

METHODS

This research used data from the China Health and Nutrition Survey (CHNS), a public database. The data and study materials can be found on its official website (<http://www.cpc.unc.edu/projects/china>). Each CHNS participant provided written informed consent.¹⁰

Population and study design

Details of the study design and key results of CHNS have been previously published.¹¹⁻¹³ Briefly, CHNS is an ongoing multipurpose longitudinal open cohort study initiated in 1989, with follow-up conducted every 2-4 years. A multistage, random cluster approach was used to draw the sample from nine provinces or autonomous cities. The provinces include Heilongjiang (enrolled in 1997), Liaoning, Shandong, Henan, Jiangsu, Hubei, Hunan, Guizhou and Guangxi, and the three largest autonomous cities were Beijing, Shanghai and Chongqing, with the latter enrolled in 2011. By 2011, the provinces included in CHNS represented 47% of China's population.¹¹ The CHNS follow-up rounds were completed in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011 and 2015.

In 1997, 2000, 2004 and 2006, cognitive function was assessed repeatedly for participants aged ≥ 55 years who were capable of completing cognitive function tests, representing the cognitively healthy, older Chinese population. We conducted a prospective cohort based on the four rounds of data. Participants with only one survey wave were excluded. Of the remaining participants with at least two rounds of survey data ($n=3119$), the first survey round was considered as the baseline. In addition, 13 participants with extreme dietary energy data (male: >4200 or <600 kcal/day; female: >3600 or <500 kcal/day) were also excluded.¹⁴ The final analysis included a total of 3106 participants (figure 1).

Dietary nutrient intakes

Dietary measurements in CHNS have been previously published.^{11, 14} Briefly, both individual and household-level dietary data were collected in each survey round. Individual diet data were collected by trained investigators through a 24-hour dietary recall on three consecutive days randomly allocated from Monday to Sunday. The allocated days were almost evenly distributed across the week for each sampling unit. Given that cooking oil and condiments are integral to Chinese cuisine and are added during cooking and preparation, their consumption was assessed by examining changes in household inventory over the same 3 days with a weighting technique. Specifically, on each of the three consecutive days, interviewers conducted a household visit to weigh and record the household food inventories, including food purchased and discarded, as well as individuals' proportion of food consumption. The cooking oil and condiments consumed at the household level were allocated to each individual according to their consumption proportion. Nutrient intake was calculated using the Chinese food composition tables. The accuracy of the 24-hour dietary recall designed to assess energy and nutrient intake has been validated.¹⁵

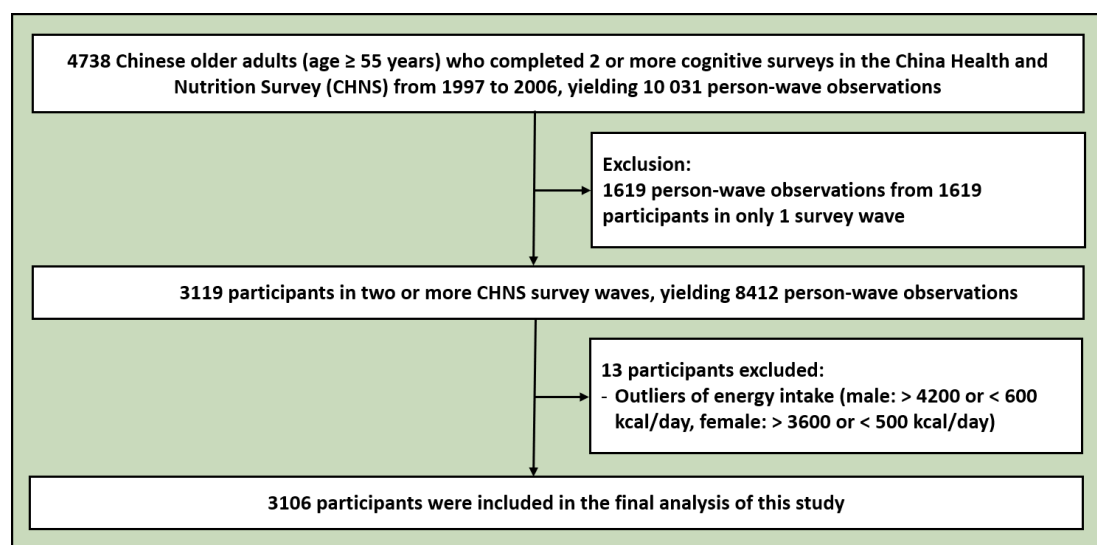


Figure 1 Flowchart of the study.

In our study, 3-day average intakes of dietary macronutrients and micronutrients in each round were calculated. Furthermore, to represent the long-term nutrient status of each participant and minimise within-person variation, the cumulative average intake of each nutrient was calculated for each participant using all results up to the last visit and was used in the final analysis.

Covariate measurements

After the participants had rested for 5 min, seated blood pressure was measured by trained research staff using a mercury manometer following standard procedures. Triplicate measurements on the same arm were taken in a quiet and bright room. The mean systolic blood pressure (SBP) and diastolic blood pressure (DBP) of the three independent measures were used in the analysis.

Demographic and lifestyle information was obtained through questionnaires at each follow-up survey, including age, sex, smoking, alcohol consumption, occupation, education level, urban or rural residency, region, concomitant conditions and drug use. Height and weight were measured following standard procedures with calibrated equipment. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Physical activity was collected by staff-administered questionnaires exploring all occupational, transportation, domestic and leisure activities in adults.

Assessment of cognitive function decline

A subset of items from the Telephone Interview for Cognitive Status–modified (TICS-m)¹⁶ was used to measure cognitive performance. The TICS-m can be administered both over the telephone and through face-to-face interviews¹⁷ and has been approved as a strong predictor of cognitive decline,¹⁸ dementia and mild cognitive impairment,¹⁹ even among people with low levels of education or illiteracy.²⁰ The cognitive test consists of three simple tasks, including immediate and delayed recall of a 10-word list (0–10 points for each), counting backward from 20 (0–2 points) and serial seven subtraction five times from 100 (0–5 points), to evaluate verbal memory, attention and calculation, respectively. A higher score in each item indicates better cognitive function, and the global cognitive score ranges from 0 to 27 points. Moreover, to eliminate the influence of the score proportion of the three components on the global score, a composite score in standard units by averaging z scores of verbal memory and other items was also conducted.

During face-to-face interviews, all items used to test cognitive performance were read and/or interpreted in detail by trained and qualified staff. Therefore, as reported in a previous study,¹⁷ participants' vision and literacy skills may not affect their cognitive assessment. However, participants unable to complete the cognitive assessment due to various reasons, such as severe cognitive impairment, were excluded from the study.

The 5-year decline rate in global or composite cognitive scores, which was used to assess the decline of cognitive

function, was calculated as the baseline score minus the last survey score, then divided by the follow-up time (in years) and multiplied by 5. A positive value represents a decline in cognitive function, while a negative value represents an increase in cognitive function.

Statistical analysis

For continuous variables with normal and non-normal distributions, the population characteristics were presented as mean (standard deviation (SD)) and median (25th percentile, 75th percentile), respectively. Differences by categories of dietary thiamine intake (<0.40, [0.40, 0.60), [0.60, 0.80), [0.80, 1.00), [1.00, 1.20), [1.20, 1.40), ≥ 1.40 mg/day) were compared using analysis of variance, or the Kruskal-Wallis test, accordingly. For categorical variables, the population characteristics were presented as proportions; differences by categories of dietary thiamine intake were compared using χ^2 tests.

A restricted cubic spline function was applied to display the relationship between dietary thiamine intake and the 5-year decline rate in global or composite cognitive scores. A two-piecewise linear regression was performed to examine the threshold effect of dietary thiamine intake using R package of *segmented*. The inflection point was determined using the likelihood ratio test and the bootstrap resampling method. The relationship of dietary thiamine intake with the 5-year decline rate in global or composite scores was estimated by linear regression models (β and 95% confidence interval (CI). The models included adjustments for sociodemographic characteristics (age, sex, occupation, region and urban or rural residency), known dementia risk factors (smoking, alcohol consumption, BMI, self-reported diabetes, SBP, DBP, antihypertensive medication, physical activity and education level),²¹ the dietary intake factors (fibre, sodium, potassium, carbohydrate, protein and fat) associated with cognitive function^{22–24} and the baseline global cognitive score. Possible modifications of the association between thiamine intake and the 5-year decline rate in global or composite cognitive scores were evaluated by stratified analyses and interaction testing.

Several sensitivity analyses were performed to assess the robustness of the key findings. First, to exclude the confounding effects of total energy intake, the association between energy-adjusted thiamine intake, calculated using the nutrient residual model, and cognitive decline was further examined. Second, to exclude the influence of food consumption, the intake of whole grains, legumes, unprocessed red meat and processed red meat was further included in the adjustments. Third, considering the potential confounding effect of other dietary B vitamins due to similar food sources, we further adjusted the dietary intakes of riboflavin and niacin in the regression models. Lastly, considering that some participants had more than two cognitive measurements, a mixed linear regression model was applied to capture the information from the multiple measurements to

assess the relationship between dietary thiamine and cognitive decline. To eliminate false positives caused by multiple tests, the Benjamini-Hochberg method was used to further calculate the multiple testing corrected *p* values (P-BH) in regression and subgroup analysis.

All analyses were performed using R software (V.3.6.3), and a two-sided *p*<0.05 was considered statistically significant.

RESULTS

Characteristics of the study participants

A total of 3106 participants were included in this study (figure 1). The mean age was 63.1 (7.0) years, and the average intake of thiamine was 0.93 (0.32) mg/day.

The characteristics of the study population are presented in online supplemental table 1. Participants with a higher dietary thiamine intake were younger, more likely to be male, smokers, alcohol drinkers and farmers. Moreover, those with a higher dietary thiamine intake had higher BMI, physical activity, education, better cognitive function, lower SBP and higher

intakes of fibre, sodium, potassium, carbohydrates, protein and fat.

The relationship between dietary thiamine intake and cognitive decline

The median follow-up time was 5.9 years (25th–75th percentiles: 2.0, 8.8). The distribution of decline rates in the global and composite cognitive scores approximates a normal distribution (online supplemental figure 1). There was a J-shaped relationship between dietary thiamine intake and the 5-year decline rate in both global and composite cognitive scores (online supplemental figure 2A,B), with an inflection point at 0.68 (95% CI: 0.56 to 0.80) mg/day (table 1). Before the inflection point, thiamine intake was not significantly associated with cognitive decline. Beyond the inflection point, each unit increase in thiamine intake (mg/day) was associated with a significant decrease of 4.24 (95% CI: 2.22 to 6.27) points in global score and 0.49 (95% CI: 0.23 to 0.76) standard units in the composite score within 5 years.

To further explore the optimal intake range of dietary thiamine for maintaining cognitive function, the value of thiamine intake was further categorised

Table 1 The relationship between dietary thiamine intake and cognitive decline using two-piecewise linear regression*

Inflection point, mg/day					
Estimate (95% CI)	n	Mean (SD)	β (95% CI)	P value	R ²
Decline rate in global cognitive scores, points/5 years					
Model 1					
0.67 (0.51 to 0.82)					0.270
<0.67	570	2.89 (11.13)	−7.43 (−18.79 to 3.93)	0.200	
≥0.67	2536	2.09 (11.12)	3.10 (1.35 to 4.85)	<0.001	
Model 2					
0.68 (0.56 to 0.80)					0.312
<0.68	617	2.80 (10.95)	−7.13 (−18.77 to 4.50)	0.230	
≥0.68	2489	2.09 (11.16)	4.24 (2.22 to 6.27)	<0.001	
Decline rate in composite cognitive scores, SU/5 years					
Model 1					
0.66 (0.52 to 0.81)					0.256
<0.66	527	0.43 (1.47)	−0.90 (−2.50 to 0.70)	0.271	
≥0.66	2579	0.29 (1.43)	0.33 (0.10 to 0.55)	0.005	
Model 2					
0.68 (0.56 to 0.80)					0.297
<0.68	617	0.40 (1.46)	−1.00 (−2.56 to 0.56)	0.208	
≥0.68	2489	0.29 (1.44)	0.49 (0.23 to 0.76)	<0.001	

p values less than 0.05 are shown in bold.

*Model 1 was adjusted for age, sex, global score, as well as the intakes of carbohydrate, protein and fat. Model 2 was further adjusted for smoking, alcohol consumption, BMI, SBP, DBP, education level, occupation, region, urban or rural residency, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fibre, sodium and potassium.

BMI, body mass index; CI, confidence interval; DBP, diastolic blood pressure; SBP, systolic blood pressure; SD, standard deviation; SU, standard units by averaging *z* scores.

Table 2 The relationship between dietary thiamine intake and cognitive decline*

Thiamine intake, mg/day	n	Mean (SD)	Model 1			Model 2		
			β (95% CI)	P value	P-BH	β (95% CI)	P value	P-BH
Decline rate in global cognitive scores, points/5 years								
Group 1								
<0.40	30	2.63 (13.14)	0.61 (−2.95 to 4.18)	0.736	0.736	0.98 (−2.95 to 4.92)	0.625	0.625
[0.40, 0.60)	284	3.26 (11.10)	0.69 (−0.64 to 2.03)	0.310	0.466	1.08 (−0.37 to 2.53)	0.144	0.216
[0.60, 0.80)	843	2.32 (10.76)	Ref			Ref		
[0.80, 1.00)	905	1.84 (10.52)	0.17 (−0.77 to 1.11)	0.727	0.736	0.45 (−0.57 to 1.48)	0.386	0.463
[1.00, 1.20)	547	2.15 (11.95)	1.17 (0.00 to 2.34)	0.049	0.099	1.58 (0.30 to 2.86)	0.015	0.031
[1.20, 1.40)	269	2.99 (10.98)	2.19 (0.66 to 3.73)	0.005	0.031	3.51 (1.82 to 5.21)	<0.001	<0.001
≥1.40	228	1.48 (12.55)	2.08 (0.22 to 3.93)	0.028	0.085	3.25 (1.18 to 5.33)	0.002	0.006
R ²			0.269			0.312		
Group 2								
<0.60	314	3.20 (11.29)	0.62 (−0.64 to 1.88)	0.334	0.334	0.91 (−0.46 to 2.28)	0.194	0.194
[0.60, 1.00)	1748	2.07 (10.63)	Ref			Ref		
[1.00, 1.20)	547	2.15 (11.95)	1.07 (0.08 to 2.06)	0.034	0.051	1.29 (0.22 to 2.36)	0.018	0.027
≥1.20	497	2.30 (11.74)	2.02 (0.79 to 3.24)	0.001	0.004	3.05 (1.70 to 4.41)	<0.001	<0.001
R ²			0.269			0.312		
Decline rate in composite cognitive scores, SU/5 years								
Group 1								
<0.40	30	0.39 (1.72)	0.11 (−0.36 to 0.58)	0.640	0.685	0.14 (−0.37 to 0.66)	0.586	0.586
[0.40, 0.60)	284	0.47 (1.50)	0.11 (−0.06 to 0.29)	0.203	0.304	0.15 (−0.04 to 0.34)	0.113	0.170
[0.60, 0.80)	843	0.33 (1.40)	Ref			Ref		
[0.80, 1.00)	905	0.27 (1.37)	0.03 (−0.10 to 0.15)	0.685	0.685	0.06 (−0.07 to 0.19)	0.382	0.459
[1.00, 1.20)	547	0.30 (1.53)	0.13 (−0.02 to 0.29)	0.089	0.194	0.19 (0.02 to 0.36)	0.026	0.051
[1.20, 1.40)	269	0.38 (1.38)	0.23 (0.03 to 0.43)	0.026	0.157	0.39 (0.17 to 0.62)	<0.001	0.003
≥1.40	228	0.19 (1.62)	0.21 (−0.04 to 0.45)	0.097	0.194	0.36 (0.09 to 0.63)	0.010	0.030
R ²			0.255			0.296		
Group 2								
<0.60	314	0.46 (1.52)	0.10 (−0.06 to 0.27)	0.219	0.219	0.13 (−0.05 to 0.31)	0.153	0.153
[0.60, 1.00)	1748	0.30 (1.38)	Ref			Ref		
[1.00, 1.20)	547	0.30 (1.53)	0.12 (−0.01 to 0.25)	0.076	0.113	0.15 (0.01 to 0.29)	0.033	0.049
≥1.20	497	0.29 (1.50)	0.20 (0.04 to 0.36)	0.014	0.043	0.33 (0.15 to 0.51)	<0.001	<0.001
R ²			0.255			0.296		

p values less than 0.05 are shown in bold.

*Model 1 was adjusted for age, sex, global score, as well as the intakes of carbohydrate, protein and fat. Model 2 was further adjusted for smoking, alcohol consumption, BMI, SBP, DBP, education level, occupation, region, urban or rural residency, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fibre, sodium and potassium.

BMI, body mass index; CI, confidence interval; DBP, diastolic blood pressure; P-BH, multiple testing corrected p values by Benjamini-Hochberg method; SBP, systolic blood pressure; SD, standard deviation; SU, standard units by averaging z scores.

by the cut-off points of 0.40, 0.60, 0.80, 1.00, 1.20 and 1.40 mg/day. For the 5-year decline rate in the composite cognitive score, compared with participants with thiamine intake of 0.60–<1.00 mg/day, β (95% CI) was 0.13 (−0.05 to 0.31), 0.15 (0.01 to 0.29) and 0.33 (0.15 to 0.51) in those with thiamine intake of <0.60, 1.00–<1.20 and ≥1.20 mg/day, respectively (table 2). Similar patterns were observed for the global cognitive scores. Moreover, multiple test correction had no significant effect on the results.

A series of sensitivity analyses were performed to test the robustness of the association. First, results from

the threshold analysis did not substantially change when thiamine intakes were tested in the energy-adjusted form (online supplemental table 2). Second, similar patterns were found with further adjustments for other B vitamins (riboflavin and niacin) (online supplemental table 3) or food consumptions (whole grain, legume, unprocessed red meat and processed red meat) (online supplemental table 4). Lastly, the mixed linear regression analysis for participants who underwent more than two cognitive assessments also found that participants with a dietary thiamine intake

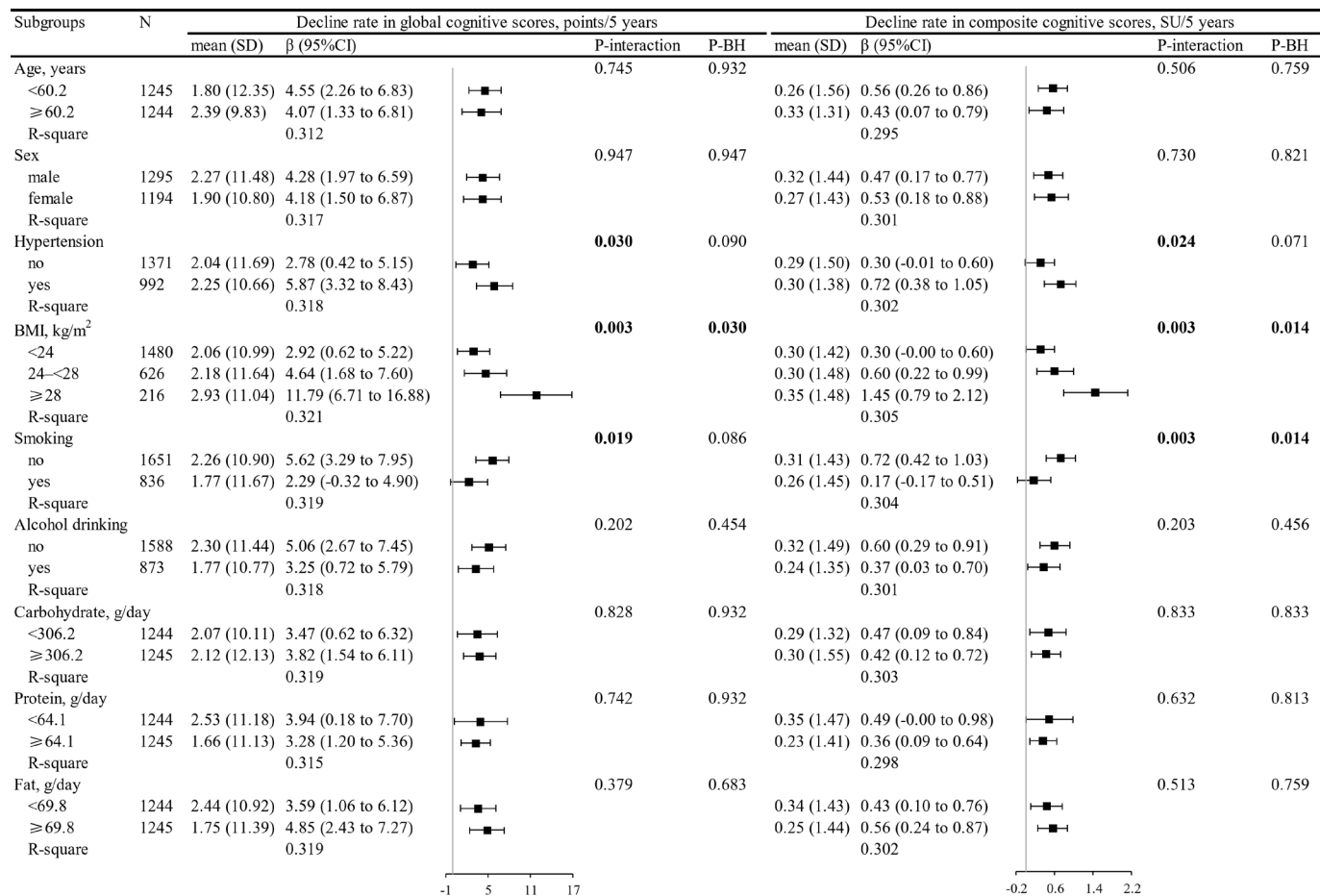


Figure 2 Subgroup analyses for the association between dietary thiamine intake and the 5-year decline rate in cognitive scores in participants with dietary thiamine intake higher than the inflection point (0.68 mg/day). (Adjusted, if not stratified, for age, sex, global score, smoking, alcohol consumption, BMI, SBP, DBP, education level, occupation, region, urban or rural residency, self-reported diabetes, antihypertensive medication, physical activity, as well as the intakes of fibre, sodium, potassium, carbohydrate, protein and fat. Hypertension was defined as SBP \geq 140 mm Hg or DBP \geq 90 mm Hg, or diagnosed by a physician, or currently under antihypertensive treatment.) BMI, body mass index; CI, confidence interval; DBP, diastolic blood pressure; P-BH, multiple testing corrected p values by Benjamini-Hochberg method; SBP, systolic blood pressure; SD, standard deviation; SU, standard units by averaging z scores.

of 0.71–<1.02 mg/day had the lowest cognitive decline rate (online supplemental table 5).

Stratified analyses

Stratified analyses were performed in those with thiamine intake higher than the inflection point (0.68 mg/day) (figure 2). The positive association between thiamine intake and cognitive decline was stronger in those with hypertension (vs non-hypertension), obesity (BMI \geq 28, vs 24–<28 vs <24 kg/m²) and non-smokers (vs smokers) (all p interaction <0.05). However, after multiple test correction, the modifying effect of hypertension (P-BH=0.090) and smoking on the decline rate in global cognitive scores became non-significant (P-BH=0.086), and the modifying effect of hypertension on the decline rate in composite cognitive scores became non-significant (P-BH=0.071).

None of the other variables, including age, sex, alcohol consumption and the intake of fat, protein and

carbohydrate, significantly modified the linear positive association between dietary thiamine intake and cognitive decline.

DISCUSSION

Main findings

In this study, we found a J-shaped association between dietary thiamine intake and cognitive decline in cognitively healthy, older Chinese individuals, with an inflection point at 0.68 mg/day and a minimal risk at 0.60–1.00 mg/day of dietary thiamine intake. Dietary thiamine intake was not significantly associated with cognitive decline before the inflection point. However, a significant and positive association with cognitive decline emerged after the inflection point, especially in individuals with obesity, hypertension and those who were non-smokers.

Several previous clinical trials with small sample sizes reported that thiamine treatment (5–600 mg/

day) can improve cognitive function in patients with cognitive impairment or mild dementia ($n=70$),³ in hemodialysis patients with cognitive impairment ($n=50$)⁴ and in patients with alcohol dependence ($n=107$).⁵ However, due to the small sample sizes and high-risk participants included, the conclusions of these clinical trials cannot be used to infer the effect of dietary thiamine intake on cognitive function in the general population. In addition, only a few previous cross-sectional and case-control studies with limited sample sizes have investigated the relationship between dietary thiamine intake and cognition in older adults, and these have reported inconsistent results.⁶⁻⁹ As such, the association of dietary thiamine intake with the risk of cognitive function in the general older population remains unknown. Our current study, with a perspective study design, a relatively larger sample size and adjustments for a series of important confounding factors, provided an opportunity to examine the dose-response association of dietary thiamine intake with cognitive function in the general older population.

Our study provides several novel insights. First, we established a J-shaped relationship between dietary thiamine intake and cognitive decline, with an inflection point at 0.68 mg/day of dietary thiamine intake. Before the inflection point, the cognitive decline rate showed a decreasing trend with increased dietary thiamine intake, although the results were not significant, probably due to the small sample size. Thiamine deficiency may lead to an insufficient supply of energy to the neurons of the brain and decreased acetylcholine signalling in the brain, which may impair cognitive function.^{25 26} As such, maintaining optimal thiamine intake is necessary for cognitive function in older adults. However, beyond the inflection point of dietary thiamine intake, thiamine intake was significantly positively associated with cognitive decline. This finding is consistent with our recent studies, which found that long-term excessive intake of thiamine was associated with an increased risk of new-onset diabetes¹⁴ and new-onset hypertension²⁷ in the general population. This series of studies consistently shows that excessive intake of thiamine may have adverse health effects on Chinese adults. Of note, both diabetes and hypertension are risk factors for cognitive decline or dementia.²¹ Moreover, thiamine can regulate acetylcholine levels by inhibiting the activity of cholinesterase.²⁵ High levels of acetylcholine in the brain can adversely affect cognition.²⁶ Therefore, we speculate that high levels of dietary thiamine intake may lead to cognitive decline by inducing elevated levels of acetylcholine in the brain. More research is needed to confirm our results and further explore the underlying mechanisms.

Second, the positive association between thiamine intake and cognitive decline was stronger in individuals with hypertension, obesity and non-smokers.

Hypertension and obesity are established risk factors for cognitive decline,²¹ which could impair cognitive function by affecting cerebrovascular structure and central inflammation, respectively. Our findings suggest that hypertension and obesity have a synergistic effect with high thiamine intake on the risk of cognitive decline, emphasising the importance of avoiding excessive thiamine intake for those with hypertension and obesity. We also found that the positive association between thiamine intake and cognitive decline was significantly weaker in smokers. Nicotine has been reported to have certain cognitive enhancement effects.²⁸ Nicotine may enhance the signal-to-noise ratio or facilitate synaptic plasticity in specific neural circuits by binding to the nicotinic acetylcholine receptor.²⁸ As such, we speculate that nicotine may partly attenuate the detrimental effects of high dietary thiamine intake. However, after multiple test correction, the modifying effect of hypertension and smoking became non-significant, suggesting that our findings are hypothetical and need to be further evaluated by more studies.

Third, our results suggest the optimal dietary thiamine intake range for the lowest risk of cognitive decline in older adults to be 0.60–1.00 mg/day, which is slightly lower than the optimal dietary thiamine intake ranges for new-onset diabetes (0.75–1.10 mg/day)¹⁴ and new-onset hypertension (0.76–1.13 mg/day)²⁷ in our previous studies. This is likely due to the older age of the current study population than in the previous two studies (mean age, 41.2–43.1 years), resulting in a lower basal metabolic rate and, consequently, a lower thiamine requirement. In addition, the recommended nutrient intake (RNI) of dietary thiamine for older Chinese (≥ 50 years) is 1.2–1.4 mg/day,²⁹ which is higher than our findings. However, it is important to note that the RNI was established based on those with energy intakes of 2600 kcal/day,²⁹ which is much higher than our study population (mean, 2076 kcal/day). People with higher energy intake also have higher thiamine requirements, which may explain the discrepancy between dietary thiamine RNI and our findings. After adjusting for energy intake, the RNI of dietary thiamine in the older population in China is 0.46 mg/1000 kcal, and the optimal dietary thiamine intake range in our current study is 0.3–0.5 mg/1000 kcal, covering the dietary thiamine RNI.

Limitations

Our study has several limitations. First, being an observational analysis, despite adjustments for important risk factors for cognitive decline, the possibility of residual confounding due to unmeasured or unknown factors could not be completely eliminated. Second, CHNS did not provide information on the use of thiamine supplements. However, the 2010–2012 China Nutrition and Health Surveillance, a nationally representative cross-sectional study, showed that

the proportions of people using nutrient supplements, multivitamins and vitamin B supplements were 0.71%, 0.03% and 0.21% in the Chinese population, respectively.³⁰ Considering these low proportions, we believe that dietary supplement use is unlikely to significantly alter the findings of our study. Third, while 24-hour dietary recall is one of the most widely used approaches for assessing dietary intake, it only captures dietary information on specific days and may be subject to recall bias. Lastly, this study focused on the older population in China, and further research is needed to determine whether the observed results can be extrapolated to other populations. Overall, further research is needed to validate our findings.

Implications

In conclusion, we first found a J-shaped association between dietary thiamine intake and cognitive decline in cognitively healthy, older Chinese individuals, with an inflection point at 0.68 mg/day and a minimal risk at 0.60–1.00 mg/day of dietary thiamine intake. If substantiated by further research, our study highlights the importance of maintaining optimal dietary thiamine intake levels in the general older population to prevent cognitive decline.

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Ethics approval This study involves human participants and was approved by the institutional review boards (IRB) of the University of North Carolina at Chapel Hill, the National Institute of Nutrition and Food Safety and the Chinese Center for Disease Control and Prevention. We are unable to provide the IRB reference number because it could not be obtained from the official website of CHNS (<http://www.cpc.unc.edu/projects/china>). Participants gave informed consent to participate in the study before taking part.

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Data availability statement Data are available in a public, open access repository. Data analysed in this study are from CHNS. Data are publicly available and can be downloaded from CHNS website: <https://www.cpc.unc.edu/projects/china>.

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Supplementary Table 1. Population characteristics by categories of dietary thiamine intake *

	Dietary thiamine intake, mg/day							Statistic	P value
	<0.4	0.4-0.6	0.6-0.8	0.8-1.0	1.0-1.2	1.2-1.4	≥1.4		
N	30	284	843	905	547	269	228		
Age, years	70.6 (61.6, 77.2)	67.7 (59.8, 74.1)	63.0 (58.3, 68.9)	60.8 (57.2, 66.9)	59.4 (57.1, 65.2)	58.5 (56.6, 63.4)	58.4 (56.8, 63.3)	KWT	<0.001
Female	25 (83.3)	214 (75.4)	511 (60.6)	476 (52.6)	232 (42.4)	107 (39.8)	70 (30.7)	χ^2 , 176.43	<0.001
Body mass index, kg/m ²	21.4 (3.6)	22.4 (3.9)	22.9 (3.5)	23.0 (3.6)	23.3 (3.5)	23.2 (3.9)	23.1 (3.3)	F, 3.05	0.006
Smoking	7 (23.3)	66 (23.2)	234 (27.8)	282 (31.2)	190 (34.7)	107 (39.8)	101 (44.3)	χ^2 , 43.44	<0.001
Alcohol drinking	4 (13.3)	47 (16.5)	222 (26.6)	284 (32.1)	214 (39.3)	114 (42.5)	105 (46.5)	χ^2 , 95.61	<0.001
Systolic blood pressure, mmHg	134.6 (22.7)	131.8 (24.3)	131.1 (20.9)	130.0 (21.0)	129.9 (20.2)	128.6 (17.9)	126.8 (20.3)	F, 1.96	0.068
Diastolic blood pressure, mmHg	82.3 (14.2)	81.2 (14.5)	81.3 (11.5)	81.8 (12.3)	82.1 (11.9)	80.7 (11.3)	79.3 (12.5)	F, 1.69	0.120
Antihypertensive medicine	4 (13.3)	38 (13.4)	93 (11.1)	96 (10.7)	66 (12.1)	31 (11.6)	16 (7.0)	χ^2 , 6.22	0.399
Self-report hypertension	5 (16.7)	52 (18.4)	114 (13.6)	132 (14.8)	84 (15.5)	41 (15.4)	21 (9.3)	χ^2 , 9.67	0.139
Self-report diabetes	0 (0.0)	13 (4.6)	28 (3.4)	32 (3.6)	22 (4.1)	7 (2.7)	4 (1.8)	χ^2 , 5.3	0.506
Urban residents	11 (36.7)	120 (42.3)	322 (38.2)	338 (37.3)	202 (36.9)	100 (37.2)	63 (27.6)	χ^2 , 12.43	0.053
Region								χ^2 , 164.2	<0.001
north	11 (36.7)	66 (23.2)	169 (20.0)	128 (14.1)	70 (12.8)	28 (10.4)	27 (11.8)		
central	9 (30.0)	106 (37.3)	327 (38.8)	421 (46.5)	284 (51.9)	162 (60.2)	175 (76.8)		
south	10 (33.3)	112 (39.4)	347 (41.2)	356 (39.3)	193 (35.3)	79 (29.4)	26 (11.4)		
Occupation								χ^2 , 108.35	<0.001
farmer	1 (3.4)	56 (19.9)	245 (29.8)	291 (32.8)	182 (34.0)	108 (40.9)	108 (48.9)		
worker	0 (0.0)	6 (2.1)	19 (2.3)	31 (3.5)	18 (3.4)	9 (3.4)	8 (3.6)		
inoccupation	26 (89.7)	200 (70.9)	472 (57.4)	452 (51.0)	264 (49.3)	114 (43.2)	78 (35.3)		
other	2 (6.9)	20 (7.1)	87 (10.6)	113 (12.7)	72 (13.4)	33 (12.5)	27 (12.2)		
Education								χ^2 , 100.01	<0.001
illiteracy	18 (66.7)	177 (65.3)	433 (53.0)	435 (50.1)	226 (42.4)	93 (36.3)	98 (44.1)		
primary school	5 (18.5)	55 (20.3)	210 (25.7)	204 (23.5)	156 (29.3)	87 (34.0)	44 (19.8)		

middle school	3 (11.1)	16 (5.9)	81 (9.9)	108 (12.4)	83 (15.6)	50 (19.5)	35 (15.8)		
high school or above	1 (3.7)	23 (8.5)	93 (11.4)	122 (14.0)	68 (12.8)	26 (10.2)	45 (20.3)		
Physical activity, MET-hours/week	19.7 (1.3, 59.3)	38.9 (11.6, 112.0)	64.3 (18.7, 153.2)	77.5 (24.0, 164.8)	68.8 (24.7, 170.0)	89.5 (28.4, 184.5)	94.0 (32.5, 198.2)	KWT	<0.001
Dietary									
Fiber, g/day	4.3 (3.3, 6.0)	6.3 (5.1, 7.9)	7.8 (6.2, 10.0)	9.4 (7.6, 11.9)	11.2 (9.1, 14.0)	12.7 (10.2, 15.6)	17.0 (13.7, 21.9)	KWT	<0.001
Sodium, g/day	3.8 (2.9, 5.3)	3.9 (3.0, 5.4)	4.3 (3.3, 5.8)	4.7 (3.7, 6.1)	5.1 (3.8, 6.8)	5.0 (4.1, 6.7)	5.3 (4.0, 7.4)	KWT	<0.001
Potassium, g/day	0.6 (0.6, 1.0)	1.0 (0.9, 1.2)	1.3 (1.1, 1.5)	1.5 (1.3, 1.7)	1.7 (1.5, 1.9)	1.8 (1.6, 2.1)	2.1 (1.8, 2.6)	KWT	<0.001
Carbohydrate, g/day	152.9 (43.6)	210.5 (45.5)	261.0 (54.0)	296.8 (61.7)	330.6 (70.2)	366.2 (81.2)	433.0 (108.4)	F, 375.94	<0.001
Protein, g/day	27.7 (10.6)	42.4 (10.2)	52.4 (10.2)	62.2 (12.6)	70.4 (13.8)	77.5 (15.3)	88.8 (19.0)	F, 495.65	<0.001
Fat, g/day	47.4 (29.5)	50.7 (19.0)	63.1 (22.6)	71.2 (25.5)	78.2 (29.8)	81.3 (32.3)	81.8 (39.0)	F, 60.79	<0.001
Cognitive assessment									
Global score at baseline, points	9.5 (6.1)	11.9 (5.9)	13.9 (6.1)	14.8 (6.0)	15.3 (6.0)	16.0 (6.0)	15.5 (6.3)	F, 18.91	<0.001
Global score at last survey, points	7.6 (5.0)	9.2 (6.2)	11.3 (6.4)	12.4 (6.5)	13.0 (6.5)	13.5 (6.2)	13.9 (6.2)	F, 22.01	<0.001
Composite score at baseline, SU	-0.53 (0.85)	-0.18 (0.82)	0.08 (0.83)	0.20 (0.81)	0.27 (0.80)	0.35 (0.80)	0.29 (0.83)	F, 18.97	<0.001
Composite score at last survey, SU	-0.80 (0.71)	-0.56 (0.86)	-0.27 (0.88)	-0.12 (0.88)	-0.03 (0.89)	0.04 (0.83)	0.09 (0.84)	F, 22.86	<0.001

*For continuous variables, values are presented as mean (SD) or median (25 percentile, 75 percentile), for categorical variables, values are present as N (%). **KWT**: Kruskal Wallis test, **SU** = Standard units by averaging z scores

Supplementary Table 2. The association of energy-adjusted thiamine intake with cognitive decline using two piecewise linear regression*

Changing point, mg/day	N	mean (SD)	β (95%CI)	P value	R-square
estimate (95%CI)					
<i>Decline rate in global cognitive scores, points/5 years</i>					
Model 1					
0.62 (0.43, 0.81)					0.269
<0.62	142	0.8 (12.6)	-8.37 (-35.17, 18.43)	0.542	
\geq 0.62	2964	2.3 (11.0)	2.90 (1.18, 4.63)	<0.001	
Model 2					
0.62 (0.27, 0.97)					0.310
<0.62	142	0.8 (12.6)	-7.99 (-40.89, 24.91)	0.635	
\geq 0.62	2964	2.3 (11.0)	4.10 (2.14, 6.07)	<0.001	
<i>Decline rate in composite cognitive scores, SU/5 years</i>					
Model 1					
0.62 (0.44, 0.80)					0.255
<0.62	142	0.15 (1.63)	-1.41 (-4.92, 2.10)	0.433	
\geq 0.62	2964	0.32 (1.43)	0.31 (0.09, 0.54)	0.007	
Model 2					
0.62 (0.32, 0.91)					0.294
<0.62	142	0.15 (1.63)	-1.00 (-5.38, 3.38)	0.656	
\geq 0.62	2964	0.32 (1.43)	0.47 (0.22, 0.73)	<0.001	

*Model 1 was adjusted for age, sex, global score, as well as the intakes of carbohydrate, protein and fat;

Model 2 was further adjusted for smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation, region, urban or rural residents, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fiber, sodium and potassium.

SU = Standard units by averaging z scores

Supplementary Table 3. The association between thiamine intake and cognitive decline by further adjustment for the intakes of riboflavin and niacin*

Thiamine intake, mg/day	N	Mean (SD)	Model 1			Model 2		
			β (95%CI)	P value	P-BH	β (95%CI)	P value	P-BH
<i>Decline rate in global cognitive scores, points/5 years</i>								
Group 1								
<0.4	30	2.6 (13.1)	0.98 (-2.95, 4.92)	0.625	0.625	0.96 (-2.98, 4.90)	0.633	0.633
0.4-0.6	284	3.3 (11.1)	1.08 (-0.37, 2.53)	0.144	0.216	1.08 (-0.38, 2.53)	0.147	0.220
0.6-0.8	843	2.3 (10.8)	ref			ref		
0.8-1.0	905	1.8 (10.5)	0.45 (-0.57, 1.48)	0.386	0.463	0.46 (-0.57, 1.49)	0.382	0.458
1.0-1.2	547	2.2 (12.0)	1.58 (0.30, 2.86)	0.015	0.031	1.60 (0.31, 2.89)	0.015	0.030
1.2-1.4	269	3.0 (11.0)	3.51 (1.82, 5.21)	<0.001	<0.001	3.53 (1.83, 5.23)	<0.001	<0.001
≥ 1.4	228	1.5 (12.6)	3.25 (1.18, 5.33)	0.002	0.006	3.29 (1.19, 5.39)	0.002	0.006
R-square			0.312			0.312		
Group 2								
<0.6	314	3.2 (11.3)	0.91 (-0.46, 2.28)	0.194	0.194	0.90 (-0.47, 2.28)	0.198	0.198
0.6-1.0	1748	2.1 (10.6)	ref			ref		
1.0-1.2	547	2.2 (12.0)	1.29 (0.22, 2.36)	0.018	0.027	1.31 (0.23, 2.38)	0.017	0.026
≥ 1.2	497	2.3 (11.7)	3.05 (1.70, 4.41)	<0.001	<0.001	3.08 (1.71, 4.45)	<0.001	<0.001
R-square			0.312			0.312		
<i>Decline rate in composite cognitive scores, SU/5 years</i>								
Group 1								
<0.4	30	0.39 (1.72)	0.14 (-0.37, 0.66)	0.586	0.586	0.14 (-0.38, 0.66)	0.591	0.591
0.4-0.6	284	0.47 (1.50)	0.15 (-0.04, 0.34)	0.113	0.170	0.15 (-0.04, 0.34)	0.114	0.171
0.6-0.8	843	0.33 (1.40)	ref			ref		
0.8-1.0	905	0.27 (1.37)	0.06 (-0.07, 0.19)	0.382	0.459	0.06 (-0.07, 0.20)	0.380	0.456
1.0-1.2	547	0.30 (1.53)	0.19 (0.02, 0.36)	0.026	0.051	0.19 (0.02, 0.36)	0.025	0.050
1.2-1.4	269	0.38 (1.38)	0.39 (0.17, 0.62)	<0.001	0.003	0.40 (0.17, 0.62)	<0.001	0.003
≥ 1.4	228	0.19 (1.62)	0.36 (0.09, 0.63)	0.010	0.030	0.36 (0.09, 0.64)	0.010	0.028
R-square			0.296			0.296		
Group 2								
<0.6	314	0.46 (1.52)	0.13 (-0.05, 0.31)	0.153	0.153	0.13 (-0.05, 0.31)	0.154	0.154
0.6-1.0	1748	0.30 (1.38)	ref			ref		
1.0-1.2	547	0.30 (1.53)	0.15 (0.01, 0.29)	0.033	0.049	0.16 (0.01, 0.30)	0.032	0.047
≥ 1.2	497	0.29 (1.50)	0.33 (0.15, 0.51)	<0.001	<0.001	0.34 (0.16, 0.52)	<0.001	<0.001
R-square			0.296			0.296		

*Model 1 was adjusted for age, sex, global score, smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation, region, urban or rural residents, self-reported diabetes, antihypertensive

medicine, physical activity, as well as the intakes of fiber, sodium, potassium, carbohydrate, protein and fat;

Model 2 was further adjusted for riboflavin and niacin.

P-BH = Multiple testing corrected *P*-value by Benjamini-Hochberg method; **SU** = Standard units by averaging z scores

Supplementary Table 4. The association between thiamine intake and cognitive decline by further adjustment for food consumption of whole grains, legumes, unprocessed red meat and processed red meat *

Thiamine intake, mg/day	N	Mean (SD)	Model 1			Model 2		
			β (95%CI)	P value	P-BH	β (95%CI)	P value	P-BH
<i>Decline rate in global cognitive scores, points/5 years</i>								
Group 1								
<0.4	30	2.6 (13.1)	0.98 (-2.95, 4.92)	0.625	0.625	0.90 (-3.05, 4.85)	0.656	0.656
0.4-0.6	284	3.3 (11.1)	1.08 (-0.37, 2.53)	0.144	0.216	1.07 (-0.39, 2.52)	0.150	0.226
0.6-0.8	843	2.3 (10.8)	ref			ref		
0.8-1.0	905	1.8 (10.5)	0.45 (-0.57, 1.48)	0.386	0.463	0.43 (-0.60, 1.47)	0.413	0.495
1.0-1.2	547	2.2 (12.0)	1.58 (0.30, 2.86)	0.015	0.031	1.57 (0.27, 2.87)	0.018	0.037
1.2-1.4	269	3.0 (11.0)	3.51 (1.82, 5.21)	<0.001	<0.001	3.49 (1.76, 5.22)	<0.001	<0.001
≥ 1.4	228	1.5 (12.6)	3.25 (1.18, 5.33)	0.002	0.006	3.05 (0.87, 5.23)	0.006	0.018
R-square			0.312			0.313		
Group 2								
<0.6	314	3.2 (11.3)	0.91 (-0.46, 2.28)	0.194	0.194	0.89 (-0.49, 2.27)	0.207	0.207
0.6-1.0	1748	2.1 (10.6)	ref			ref		
1.0-1.2	547	2.2 (12.0)	1.29 (0.22, 2.36)	0.018	0.027	1.30 (0.22, 2.38)	0.018	0.027
≥ 1.2	497	2.3 (11.7)	3.05 (1.70, 4.41)	<0.001	<0.001	2.98 (1.59, 4.38)	<0.001	<0.001
R-square			0.312			0.313		
<i>Decline rate in composite cognitive scores, SU/5 years</i>								
Group 1								
<0.4	30	0.39 (1.72)	0.14 (-0.37, 0.66)	0.586	0.586	0.13 (-0.39, 0.65)	0.621	0.621
0.4-0.6	284	0.47 (1.50)	0.15 (-0.04, 0.34)	0.113	0.170	0.15 (-0.04, 0.34)	0.123	0.185
0.6-0.8	843	0.33 (1.40)	ref			ref		
0.8-1.0	905	0.27 (1.37)	0.06 (-0.07, 0.19)	0.382	0.459	0.06 (-0.08, 0.19)	0.399	0.479
1.0-1.2	547	0.30 (1.53)	0.19 (0.02, 0.36)	0.026	0.051	0.19 (0.02, 0.36)	0.028	0.056
1.2-1.4	269	0.38 (1.38)	0.39 (0.17, 0.62)	<0.001	0.003	0.39 (0.17, 0.62)	<0.001	0.004
≥ 1.4	228	0.19 (1.62)	0.36 (0.09, 0.63)	0.010	0.030	0.34 (0.06, 0.63)	0.019	0.056
R-square			0.296			0.287		
Group 2								
<0.6	314	0.46 (1.52)	0.13 (-0.05, 0.31)	0.153	0.153	0.13 (-0.05, 0.31)	0.170	0.170
0.6-1.0	1748	0.30 (1.38)	ref			ref		
1.0-1.2	547	0.30 (1.53)	0.15 (0.01, 0.29)	0.033	0.049	0.16 (0.01, 0.30)	0.032	0.047
≥ 1.2	497	0.29 (1.50)	0.33 (0.15, 0.51)	<0.001	<0.001	0.33 (0.14, 0.51)	<0.001	0.001
R-square			0.296			0.297		

*Model 1 adjusted for age, sex, global score, smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation,

region, urban or rural residents, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fiber, sodium, potassium, carbohydrate, protein and fat;

Model 2 further adjusted for the food consumptions of whole grain, legume, unprocessed red meat and processed red meat.

P-BH = Multiple testing corrected *P*-value by Benjamini-Hochberg method; ***SU*** = Standard units by averaging *z* scores

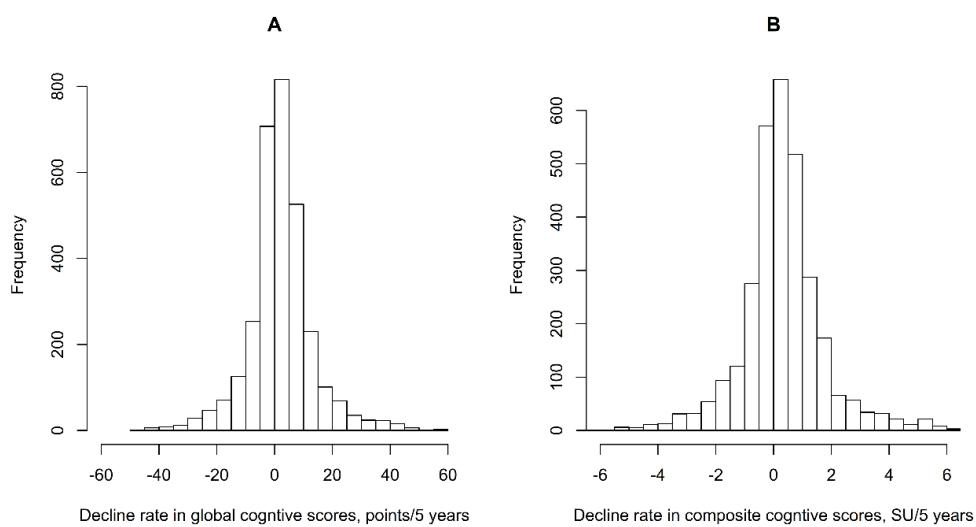
Supplementary Table 5. The association between dietary thiamine (tertiles) intake and cognitive decline using mixed linear regression*

Tertiles of dietary thiamine intake, mg/day	Change rate in global cognitive scores, points/5 years		Change rate in composite cognitive scores, SU/5 years	
	β (95%CI)	<i>P</i> value	β (95%CI)	<i>P</i> value
<0.71	-0.51 (-0.84, -0.18)	0.002	-0.07 (-0.11, -0.03)	0.002
0.71-1.01	ref		ref	
≥ 1.01	-0.44 (-0.81, -0.08)	0.018	-0.06 (-0.11, -0.01)	0.023
R-square	0.289		0.311	

*Adjusted for age, sex, urban or rural residents, education levels, occupations and regions at baseline, as well as the repeat measured smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, self-reported diabetes, antihypertensive medicine, physical activity, and the dietary intakes of fiber, sodium, potassium, carbohydrate, protein and fat during the follow-up.

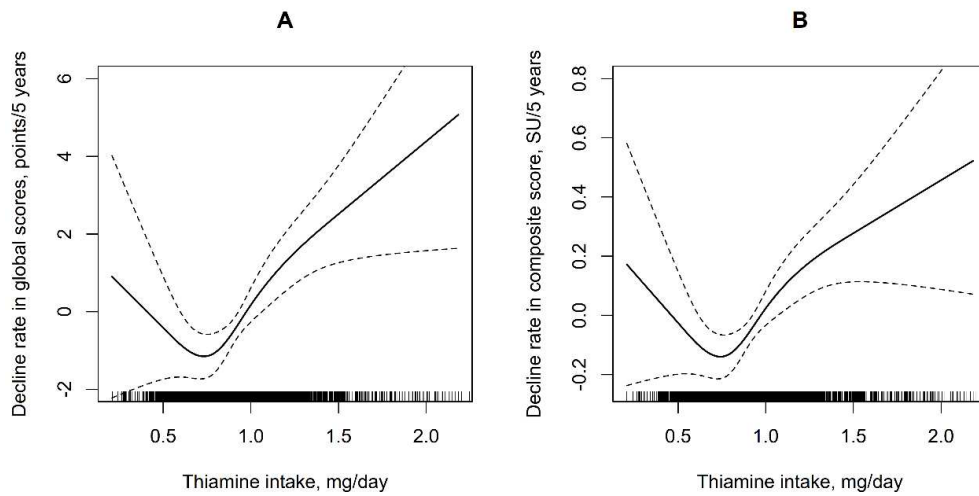
The intercept and slope were both fitted as random effects. Interaction terms of time (from baseline) and tertiles of thiamine intake were included in the model, and the regression coefficient can be interpreted as the change rate in global and composite cognitive scores. Negative β values represent how much cognitive score declines over 5 years, and positive β values represent how much cognitive score increases over 5 years.

SU = Standard units by averaging z scores



Supplementary Figure 1. The distribution of the 5-year decline rate in global (A) and composite (B) cognitive score

SU = Standard units by averaging z scores



Supplementary Figure 2. The relationship between dietary thiamine intake and the 5-year decline rate in global (A) and composite (B) cognitive scores *

*Adjusted for age, sex, global score, smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation, region, urban or rural residents, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fiber, sodium, potassium, carbohydrate, protein and fat. **SU** = Standard units by averaging z scores

J-shaped curve apparent between dietary thiamine and worsening mental acuity

*Sweet spot seems to be 0.68 mg/day among healthy older people to ward off decline
Optimal maintenance dose seems to be 0.6 to less than 1 mg/day*

There seems to be a J-shaped curve between dietary thiamine (vitamin B1) and worsening mental acuity among cognitively healthy older people, suggests research published in the open access journal **General Psychiatry**.

The sweet spot seems to be a daily intake of 0.68 mg, below which there is relatively little impact. But higher daily intake was strongly associated with cognitive decline, with the optimal maintenance dose 0.6 to less than 1 mg/day, the findings show.

Thiamine is an essential water-soluble B vitamin involved in energy metabolism and brain neurotransmitter activity. Good dietary sources include whole grains, fortified breakfast cereals, legumes, liver, and salmon.

Small previously published studies suggest that high doses can improve cognitive function in people with mild cognitive impairment or early stage dementia. But it's not clear if usual dietary intake is associated with slowing, or speeding up, cognitive decline.

To explore this further, the researchers used publicly available data from the China Health and Nutrition Survey (CHNS), a long term multipurpose study which began in 1989, and which included nearly half the country's population by 2011.

In 1997, 2000, 2004 and 2006, mental acuity was repeatedly assessed for cognitively healthy participants aged 55 and above. The current study is based on 3106 participants, with an average age of 63, and at least two rounds of survey data.

Information on diet was collected in each survey round, supplemented by detailed data on personal dietary intake over 24 hours on 3 consecutive days of the week, and collected in person by trained investigators. Nutrient intake was calculated using the Chinese food composition tables.

Three tests of immediate and delayed recall of a 10-word list, counting backwards from 20, and serial subtraction of 7 five times from 100, taken from the Telephone Interview for Cognitive Status—modified (TICS-m), were used to evaluate verbal memory, attention, and numerical fluency, respectively.

A higher score for each item (including verbal memory [0-20 points], attention [0-2 points] and calculation [0-5 points]) indicates better cognitive function, with a global cognitive score ranging from 0 to 27 points and also a composite score ranging from -1.82 to 1.67 standard units.

The average monitoring period was nearly 6 years, during which time a J-shaped association emerged between dietary thiamine intake and the pace of decline in cognitive function over 5 years.

Average thiamine intake was 0.93 mg/day, but the threshold seemed to be a daily intake of 0.68 mg. There was no significant association with cognitive decline below this level.

But above 0.68 mg/day, each daily unit (1 mg/day) increase in thiamine intake was associated with a significant fall of 4.24 points in the global cognitive score and 0.49 units in the composite

score within 5 years. Since the global cognitive score ranges from 0 to 27 points, a decline of about 4 points means a decline in cognitive function of at least 15%

These associations were stronger among those who were obese, had high blood pressure or who were non-smokers, although after further in depth analysis, the modifying effect of high blood pressure and smoking became statistically insignificant,

To further explore the optimal range of dietary thiamine for maintaining cognitive function, intake was further divided into 0.4, 0.6, 0.8, 1, 1.2 and 1.4 mg/day.

This showed that the lowest risk was associated with a thiamine intake of 0.6 to less than 1 mg/day. Similar patterns were also observed after accounting for daily intake of other B vitamins (riboflavin and niacin) and other foods, such as red or processed meat.

None of the other variables, including age, sex, alcohol consumption and dietary intake of fat, protein or carbohydrate, significantly changed the findings.

This is an observational study, and as such, can't establish cause, acknowledge the researchers. And 24-hour dietary recall only captures information on specific days and may not be completely accurate. The study also focused on older people in China, so the findings may not be applicable to other nationalities and age groups, they add.

"Thiamine deficiency may lead to an insufficient supply of energy to the neurons of the brain and decreased acetylcholine signalling in the brain, which may impair cognitive function," suggest the researchers, by way of an explanation for their findings.

"If substantiated by further research, our study highlights the importance of maintaining optimal dietary thiamine intake levels in the general older population to prevent cognitive decline."

Supplementary Table 1. Population characteristics by categories of dietary thiamine intake *

	Dietary thiamine intake, mg/day							Statistic	P value
	<0.4	0.4-0.6	0.6-0.8	0.8-1.0	1.0-1.2	1.2-1.4	≥1.4		
N	30	284	843	905	547	269	228		
Age, years	70.6 (61.6, 77.2)	67.7 (59.8, 74.1)	63.0 (58.3, 68.9)	60.8 (57.2, 66.9)	59.4 (57.1, 65.2)	58.5 (56.6, 63.4)	58.4 (56.8, 63.3)	KWT	<0.001
Female	25 (83.3)	214 (75.4)	511 (60.6)	476 (52.6)	232 (42.4)	107 (39.8)	70 (30.7)	χ^2 , 176.43	<0.001
Body mass index, kg/m ²	21.4 (3.6)	22.4 (3.9)	22.9 (3.5)	23.0 (3.6)	23.3 (3.5)	23.2 (3.9)	23.1 (3.3)	F, 3.05	0.006
Smoking	7 (23.3)	66 (23.2)	234 (27.8)	282 (31.2)	190 (34.7)	107 (39.8)	101 (44.3)	χ^2 , 43.44	<0.001
Alcohol drinking	4 (13.3)	47 (16.5)	222 (26.6)	284 (32.1)	214 (39.3)	114 (42.5)	105 (46.5)	χ^2 , 95.61	<0.001
Systolic blood pressure, mmHg	134.6 (22.7)	131.8 (24.3)	131.1 (20.9)	130.0 (21.0)	129.9 (20.2)	128.6 (17.9)	126.8 (20.3)	F, 1.96	0.068
Diastolic blood pressure, mmHg	82.3 (14.2)	81.2 (14.5)	81.3 (11.5)	81.8 (12.3)	82.1 (11.9)	80.7 (11.3)	79.3 (12.5)	F, 1.69	0.120
Antihypertensive medicine	4 (13.3)	38 (13.4)	93 (11.1)	96 (10.7)	66 (12.1)	31 (11.6)	16 (7.0)	χ^2 , 6.22	0.399
Self-report hypertension	5 (16.7)	52 (18.4)	114 (13.6)	132 (14.8)	84 (15.5)	41 (15.4)	21 (9.3)	χ^2 , 9.67	0.139
Self-report diabetes	0 (0.0)	13 (4.6)	28 (3.4)	32 (3.6)	22 (4.1)	7 (2.7)	4 (1.8)	χ^2 , 5.3	0.506
Urban residents	11 (36.7)	120 (42.3)	322 (38.2)	338 (37.3)	202 (36.9)	100 (37.2)	63 (27.6)	χ^2 , 12.43	0.053
Region								χ^2 , 164.2	<0.001
north	11 (36.7)	66 (23.2)	169 (20.0)	128 (14.1)	70 (12.8)	28 (10.4)	27 (11.8)		
central	9 (30.0)	106 (37.3)	327 (38.8)	421 (46.5)	284 (51.9)	162 (60.2)	175 (76.8)		
south	10 (33.3)	112 (39.4)	347 (41.2)	356 (39.3)	193 (35.3)	79 (29.4)	26 (11.4)		
Occupation								χ^2 , 108.35	<0.001
farmer	1 (3.4)	56 (19.9)	245 (29.8)	291 (32.8)	182 (34.0)	108 (40.9)	108 (48.9)		
worker	0 (0.0)	6 (2.1)	19 (2.3)	31 (3.5)	18 (3.4)	9 (3.4)	8 (3.6)		
inoccupation	26 (89.7)	200 (70.9)	472 (57.4)	452 (51.0)	264 (49.3)	114 (43.2)	78 (35.3)		
other	2 (6.9)	20 (7.1)	87 (10.6)	113 (12.7)	72 (13.4)	33 (12.5)	27 (12.2)		
Education								χ^2 , 100.01	<0.001
illiteracy	18 (66.7)	177 (65.3)	433 (53.0)	435 (50.1)	226 (42.4)	93 (36.3)	98 (44.1)		
primary school	5 (18.5)	55 (20.3)	210 (25.7)	204 (23.5)	156 (29.3)	87 (34.0)	44 (19.8)		

middle school	3 (11.1)	16 (5.9)	81 (9.9)	108 (12.4)	83 (15.6)	50 (19.5)	35 (15.8)		
high school or above	1 (3.7)	23 (8.5)	93 (11.4)	122 (14.0)	68 (12.8)	26 (10.2)	45 (20.3)		
Physical activity, MET-hours/week	19.7 (1.3, 59.3)	38.9 (11.6, 112.0)	64.3 (18.7, 153.2)	77.5 (24.0, 164.8)	68.8 (24.7, 170.0)	89.5 (28.4, 184.5)	94.0 (32.5, 198.2)	KWT	<0.001
Dietary									
Fiber, g/day	4.3 (3.3, 6.0)	6.3 (5.1, 7.9)	7.8 (6.2, 10.0)	9.4 (7.6, 11.9)	11.2 (9.1, 14.0)	12.7 (10.2, 15.6)	17.0 (13.7, 21.9)	KWT	<0.001
Sodium, g/day	3.8 (2.9, 5.3)	3.9 (3.0, 5.4)	4.3 (3.3, 5.8)	4.7 (3.7, 6.1)	5.1 (3.8, 6.8)	5.0 (4.1, 6.7)	5.3 (4.0, 7.4)	KWT	<0.001
Potassium, g/day	0.6 (0.6, 1.0)	1.0 (0.9, 1.2)	1.3 (1.1, 1.5)	1.5 (1.3, 1.7)	1.7 (1.5, 1.9)	1.8 (1.6, 2.1)	2.1 (1.8, 2.6)	KWT	<0.001
Carbohydrate, g/day	152.9 (43.6)	210.5 (45.5)	261.0 (54.0)	296.8 (61.7)	330.6 (70.2)	366.2 (81.2)	433.0 (108.4)	F, 375.94	<0.001
Protein, g/day	27.7 (10.6)	42.4 (10.2)	52.4 (10.2)	62.2 (12.6)	70.4 (13.8)	77.5 (15.3)	88.8 (19.0)	F, 495.65	<0.001
Fat, g/day	47.4 (29.5)	50.7 (19.0)	63.1 (22.6)	71.2 (25.5)	78.2 (29.8)	81.3 (32.3)	81.8 (39.0)	F, 60.79	<0.001
Cognitive assessment									
Global score at baseline, points	9.5 (6.1)	11.9 (5.9)	13.9 (6.1)	14.8 (6.0)	15.3 (6.0)	16.0 (6.0)	15.5 (6.3)	F, 18.91	<0.001
Global score at last survey, points	7.6 (5.0)	9.2 (6.2)	11.3 (6.4)	12.4 (6.5)	13.0 (6.5)	13.5 (6.2)	13.9 (6.2)	F, 22.01	<0.001
Composite score at baseline, SU	-0.53 (0.85)	-0.18 (0.82)	0.08 (0.83)	0.20 (0.81)	0.27 (0.80)	0.35 (0.80)	0.29 (0.83)	F, 18.97	<0.001
Composite score at last survey, SU	-0.80 (0.71)	-0.56 (0.86)	-0.27 (0.88)	-0.12 (0.88)	-0.03 (0.89)	0.04 (0.83)	0.09 (0.84)	F, 22.86	<0.001

*For continuous variables, values are presented as mean (SD) or median (25 percentile, 75 percentile), for categorical variables, values are present as N (%). **KWT**: Kruskal Wallis test, **SU** = Standard units by averaging z scores

Supplementary Table 2. The association of energy-adjusted thiamine intake with cognitive decline using two piecewise linear regression*

Changing point, mg/day	N	mean (SD)	β (95%CI)	P value	R-square
estimate (95%CI)					
<i>Decline rate in global cognitive scores, points/5 years</i>					
Model 1					
0.62 (0.43, 0.81)					0.269
<0.62	142	0.8 (12.6)	-8.37 (-35.17, 18.43)	0.542	
\geq 0.62	2964	2.3 (11.0)	2.90 (1.18, 4.63)	<0.001	
Model 2					
0.62 (0.27, 0.97)					0.310
<0.62	142	0.8 (12.6)	-7.99 (-40.89, 24.91)	0.635	
\geq 0.62	2964	2.3 (11.0)	4.10 (2.14, 6.07)	<0.001	
<i>Decline rate in composite cognitive scores, SU/5 years</i>					
Model 1					
0.62 (0.44, 0.80)					0.255
<0.62	142	0.15 (1.63)	-1.41 (-4.92, 2.10)	0.433	
\geq 0.62	2964	0.32 (1.43)	0.31 (0.09, 0.54)	0.007	
Model 2					
0.62 (0.32, 0.91)					0.294
<0.62	142	0.15 (1.63)	-1.00 (-5.38, 3.38)	0.656	
\geq 0.62	2964	0.32 (1.43)	0.47 (0.22, 0.73)	<0.001	

*Model 1 was adjusted for age, sex, global score, as well as the intakes of carbohydrate, protein and fat;

Model 2 was further adjusted for smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation, region, urban or rural residents, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fiber, sodium and potassium.

SU = Standard units by averaging z scores

Supplementary Table 3. The association between thiamine intake and cognitive decline by further adjustment for the intakes of riboflavin and niacin*

Thiamine intake, mg/day	N	Mean (SD)	Model 1			Model 2		
			β (95%CI)	P value	P-BH	β (95%CI)	P value	P-BH
<i>Decline rate in global cognitive scores, points/5 years</i>								
Group 1								
<0.4	30	2.6 (13.1)	0.98 (-2.95, 4.92)	0.625	0.625	0.96 (-2.98, 4.90)	0.633	0.633
0.4-0.6	284	3.3 (11.1)	1.08 (-0.37, 2.53)	0.144	0.216	1.08 (-0.38, 2.53)	0.147	0.220
0.6-0.8	843	2.3 (10.8)	ref			ref		
0.8-1.0	905	1.8 (10.5)	0.45 (-0.57, 1.48)	0.386	0.463	0.46 (-0.57, 1.49)	0.382	0.458
1.0-1.2	547	2.2 (12.0)	1.58 (0.30, 2.86)	0.015	0.031	1.60 (0.31, 2.89)	0.015	0.030
1.2-1.4	269	3.0 (11.0)	3.51 (1.82, 5.21)	<0.001	<0.001	3.53 (1.83, 5.23)	<0.001	<0.001
≥ 1.4	228	1.5 (12.6)	3.25 (1.18, 5.33)	0.002	0.006	3.29 (1.19, 5.39)	0.002	0.006
R-square			0.312			0.312		
Group 2								
<0.6	314	3.2 (11.3)	0.91 (-0.46, 2.28)	0.194	0.194	0.90 (-0.47, 2.28)	0.198	0.198
0.6-1.0	1748	2.1 (10.6)	ref			ref		
1.0-1.2	547	2.2 (12.0)	1.29 (0.22, 2.36)	0.018	0.027	1.31 (0.23, 2.38)	0.017	0.026
≥ 1.2	497	2.3 (11.7)	3.05 (1.70, 4.41)	<0.001	<0.001	3.08 (1.71, 4.45)	<0.001	<0.001
R-square			0.312			0.312		
<i>Decline rate in composite cognitive scores, SU/5 years</i>								
Group 1								
<0.4	30	0.39 (1.72)	0.14 (-0.37, 0.66)	0.586	0.586	0.14 (-0.38, 0.66)	0.591	0.591
0.4-0.6	284	0.47 (1.50)	0.15 (-0.04, 0.34)	0.113	0.170	0.15 (-0.04, 0.34)	0.114	0.171
0.6-0.8	843	0.33 (1.40)	ref			ref		
0.8-1.0	905	0.27 (1.37)	0.06 (-0.07, 0.19)	0.382	0.459	0.06 (-0.07, 0.20)	0.380	0.456
1.0-1.2	547	0.30 (1.53)	0.19 (0.02, 0.36)	0.026	0.051	0.19 (0.02, 0.36)	0.025	0.050
1.2-1.4	269	0.38 (1.38)	0.39 (0.17, 0.62)	<0.001	0.003	0.40 (0.17, 0.62)	<0.001	0.003
≥ 1.4	228	0.19 (1.62)	0.36 (0.09, 0.63)	0.010	0.030	0.36 (0.09, 0.64)	0.010	0.028
R-square			0.296			0.296		
Group 2								
<0.6	314	0.46 (1.52)	0.13 (-0.05, 0.31)	0.153	0.153	0.13 (-0.05, 0.31)	0.154	0.154
0.6-1.0	1748	0.30 (1.38)	ref			ref		
1.0-1.2	547	0.30 (1.53)	0.15 (0.01, 0.29)	0.033	0.049	0.16 (0.01, 0.30)	0.032	0.047
≥ 1.2	497	0.29 (1.50)	0.33 (0.15, 0.51)	<0.001	<0.001	0.34 (0.16, 0.52)	<0.001	<0.001
R-square			0.296			0.296		

*Model 1 was adjusted for age, sex, global score, smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation, region, urban or rural residents, self-reported diabetes, antihypertensive

medicine, physical activity, as well as the intakes of fiber, sodium, potassium, carbohydrate, protein and fat;

Model 2 was further adjusted for riboflavin and niacin.

P-BH = Multiple testing corrected *P*-value by Benjamini-Hochberg method; **SU** = Standard units by averaging z scores

Supplementary Table 4. The association between thiamine intake and cognitive decline by further adjustment for food consumption of whole grains, legumes, unprocessed red meat and processed red meat *

Thiamine intake, mg/day	N	Mean (SD)	Model 1			Model 2		
			β (95%CI)	P value	P-BH	β (95%CI)	P value	P-BH
<i>Decline rate in global cognitive scores, points/5 years</i>								
Group 1								
<0.4	30	2.6 (13.1)	0.98 (-2.95, 4.92)	0.625	0.625	0.90 (-3.05, 4.85)	0.656	0.656
0.4-0.6	284	3.3 (11.1)	1.08 (-0.37, 2.53)	0.144	0.216	1.07 (-0.39, 2.52)	0.150	0.226
0.6-0.8	843	2.3 (10.8)	ref			ref		
0.8-1.0	905	1.8 (10.5)	0.45 (-0.57, 1.48)	0.386	0.463	0.43 (-0.60, 1.47)	0.413	0.495
1.0-1.2	547	2.2 (12.0)	1.58 (0.30, 2.86)	0.015	0.031	1.57 (0.27, 2.87)	0.018	0.037
1.2-1.4	269	3.0 (11.0)	3.51 (1.82, 5.21)	<0.001	<0.001	3.49 (1.76, 5.22)	<0.001	<0.001
≥ 1.4	228	1.5 (12.6)	3.25 (1.18, 5.33)	0.002	0.006	3.05 (0.87, 5.23)	0.006	0.018
R-square			0.312			0.313		
Group 2								
<0.6	314	3.2 (11.3)	0.91 (-0.46, 2.28)	0.194	0.194	0.89 (-0.49, 2.27)	0.207	0.207
0.6-1.0	1748	2.1 (10.6)	ref			ref		
1.0-1.2	547	2.2 (12.0)	1.29 (0.22, 2.36)	0.018	0.027	1.30 (0.22, 2.38)	0.018	0.027
≥ 1.2	497	2.3 (11.7)	3.05 (1.70, 4.41)	<0.001	<0.001	2.98 (1.59, 4.38)	<0.001	<0.001
R-square			0.312			0.313		
<i>Decline rate in composite cognitive scores, SU/5 years</i>								
Group 1								
<0.4	30	0.39 (1.72)	0.14 (-0.37, 0.66)	0.586	0.586	0.13 (-0.39, 0.65)	0.621	0.621
0.4-0.6	284	0.47 (1.50)	0.15 (-0.04, 0.34)	0.113	0.170	0.15 (-0.04, 0.34)	0.123	0.185
0.6-0.8	843	0.33 (1.40)	ref			ref		
0.8-1.0	905	0.27 (1.37)	0.06 (-0.07, 0.19)	0.382	0.459	0.06 (-0.08, 0.19)	0.399	0.479
1.0-1.2	547	0.30 (1.53)	0.19 (0.02, 0.36)	0.026	0.051	0.19 (0.02, 0.36)	0.028	0.056
1.2-1.4	269	0.38 (1.38)	0.39 (0.17, 0.62)	<0.001	0.003	0.39 (0.17, 0.62)	<0.001	0.004
≥ 1.4	228	0.19 (1.62)	0.36 (0.09, 0.63)	0.010	0.030	0.34 (0.06, 0.63)	0.019	0.056
R-square			0.296			0.287		
Group 2								
<0.6	314	0.46 (1.52)	0.13 (-0.05, 0.31)	0.153	0.153	0.13 (-0.05, 0.31)	0.170	0.170
0.6-1.0	1748	0.30 (1.38)	ref			ref		
1.0-1.2	547	0.30 (1.53)	0.15 (0.01, 0.29)	0.033	0.049	0.16 (0.01, 0.30)	0.032	0.047
≥ 1.2	497	0.29 (1.50)	0.33 (0.15, 0.51)	<0.001	<0.001	0.33 (0.14, 0.51)	<0.001	0.001
R-square			0.296			0.297		

*Model 1 adjusted for age, sex, global score, smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation,

region, urban or rural residents, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fiber, sodium, potassium, carbohydrate, protein and fat;

Model 2 further adjusted for the food consumptions of whole grain, legume, unprocessed red meat and processed red meat.

P-BH = Multiple testing corrected *P*-value by Benjamini-Hochberg method; **SU** = Standard units by averaging z scores

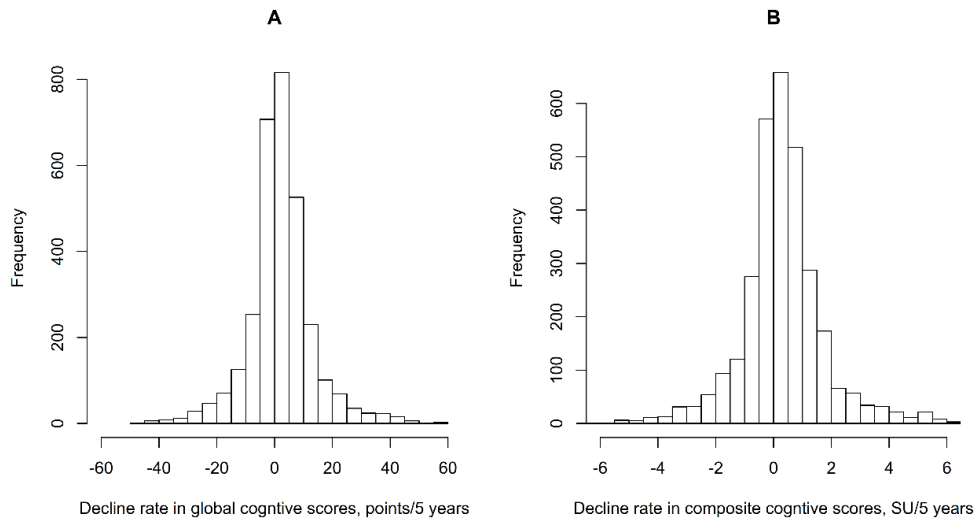
Supplementary Table 5. The association between dietary thiamine (tertiles) intake and cognitive decline using mixed linear regression*

Tertiles of dietary thiamine intake, mg/day	Change rate in global cognitive scores, points/5 years		Change rate in composite cognitive scores, SU/5 years	
	β (95%CI)	<i>P</i> value	β (95%CI)	<i>P</i> value
<0.71	-0.51 (-0.84, -0.18)	0.002	-0.07 (-0.11, -0.03)	0.002
0.71-1.01	ref		ref	
≥ 1.01	-0.44 (-0.81, -0.08)	0.018	-0.06 (-0.11, -0.01)	0.023
R-square	0.289		0.311	

*Adjusted for age, sex, urban or rural residents, education levels, occupations and regions at baseline, as well as the repeat measured smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, self-reported diabetes, antihypertensive medicine, physical activity, and the dietary intakes of fiber, sodium, potassium, carbohydrate, protein and fat during the follow-up.

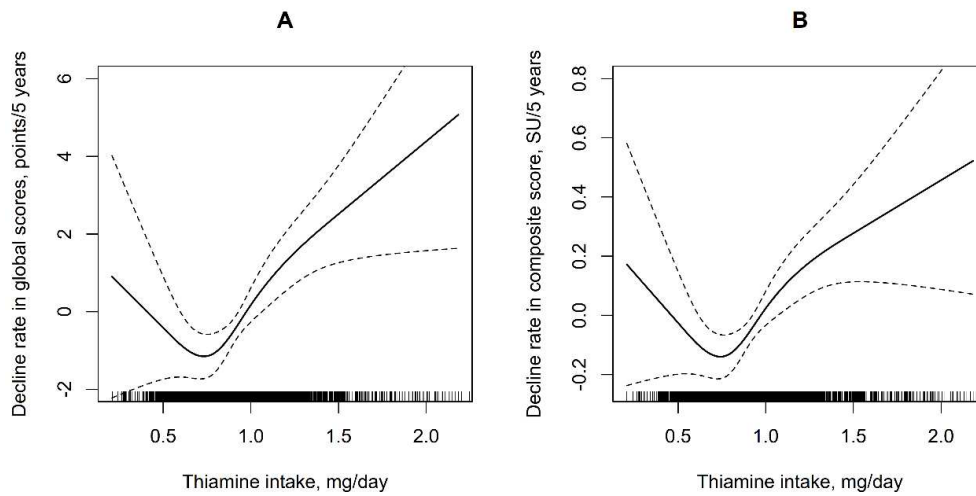
The intercept and slope were both fitted as random effects. Interaction terms of time (from baseline) and tertiles of thiamine intake were included in the model, and the regression coefficient can be interpreted as the change rate in global and composite cognitive scores. Negative β values represent how much cognitive score declines over 5 years, and positive β values represent how much cognitive score increases over 5 years.

SU = Standard units by averaging z scores



Supplementary Figure 1. The distribution of the 5-year decline rate in global (A) and composite (B) cognitive score

SU = Standard units by averaging z scores



Supplementary Figure 2. The relationship between dietary thiamine intake and the 5-year decline rate in global (A) and composite (B) cognitive scores *

*Adjusted for age, sex, global score, smoking, alcohol drinking, body mass index, systolic blood pressure, diastolic blood pressure, education levels, occupation, region, urban or rural residents, self-reported diabetes, antihypertensive medicine, physical activity, as well as the intakes of fiber, sodium, potassium, carbohydrate, protein and fat. **SU** = Standard units by averaging z scores