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Association between the consumption of tree nut and peanut and cognitive performance among middle-aged and older adults: Evidence from the Chinese Square Dancer Cohort

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ABSTRACT: Background: The inclusion of nuts in the diet has been explored as a dietary approach for supporting cognition health across the lifespan. However, research on the types of nuts and their effects on various cognitive domains remains limited, especially in Chinese populations.

Methods: This cross-sectional study investigated the associations of tree nut and peanut consumption with cognitive function and mild cognitive impairment (MCI) risk among middle-aged and older adults from the Chinese Square Dancer Cohort. Data on nut consumption were collected using a semi-quantitative food frequency questionnaire. Cognitive function was assessed by the neuropsychological tests, such as the Verbal Fluency Test (VFT), Auditory Verbal Learning Test (AVLT), Trail Making Test-B (TMT-B), and the Digit Symbol Substitution Test (DSST), and the diagnosis of MCI was conducted following Petersen's criteria. Multiple linear and logistic regression models were utilized to examine the relationship between the consumption of tree nut and peanut and cognitive performance, as well as the likelihood of MCI.

Results: This study included 4,275 adults aged 55 and above. After controlling demographic characteristics, lifestyle factors, other dietary factors, and history of chronic disease, tree nut consumption was positively associated with global cognition scores (P for trend < 0.001). Compared with non-consumers of tree nuts (0 g/day), the β values (95% confidence intervals, 95% CIs) were 0.10 (0.06, 0.15) for 0.01–4.99 g/day, 0.12 (0.06, 0.18) for 5.00–9.99 g/day, and 0.15 (0.10, 0.20) for ≥ 10.00 g/day. Participants consuming ≥ 10.00 g/day of tree nuts also had lower odds of MCI than non-consumers (odds ratio [OR] = 0.69, 95% CI: 0.55, 0.87). As for peanuts, no significant association with MCI was observed after full adjustment. Peanut consumption showed weaker and non-linear associations with global cognition; compared with non-consumers, the β values (95% CIs) were 0.07 (0.03, 0.12) for 0.01–4.99 g/day.

Conclusions: Higher tree nut consumption was associated with better overall cognitive performance and lower odds of MCI. Peanut consumption showed weaker and non-linear associations with global cognition, but was not significantly associated with MCI after full adjustment.

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1. Introduction

In 2021, China was reported the world's highest age-standardized dementia prevalence rate at 900.8 per 100,000^[1]. The rapidly aging population has contributed to the escalation of the dementia crisis, imposing substantial health and economic burdens^[2]. Mild cognitive impairment (MCI), a transitional stage between normal age-related cognitive decline and the onset of dementia, represents a critical window for intervention^[3]. Due to the absence of effective dementia treatments, it is essential to identify modifiable factors in the early stages of disease progression.

Diet is an important modifiable factor influencing cognitive performance^[4–6], and accumulating evidence suggests that nut-rich dietary patterns and higher nut consumption are associated with better cognitive function^[7,8]. For instance, an observational study among middle-aged and older adults in China showed that eating nuts once a week or more was linked to a 43% lower risk of MCI compared with rarely eating nuts^[9]. Another cross-sectional study among older Italians showed that nut consumption was associated with a lower risk of cognitive impairment^[10]. Recent systematic and narrative reviews also suggest that nut consumption may contribute to the maintenance of cognitive health, although the evidence remains heterogeneous across populations, nut types, and cognitive outcomes^[8,11].

Tree nuts and peanuts are often analyzed together in previous studies, but the available evidence is not evenly distributed across nut types. Existing cognitive evidence has more often focused on total nut consumption or tree nuts, particularly walnuts, whereas evidence specific to peanuts remains relatively limited^[12,13]. This distinction is biologically and nutritionally relevant because tree nuts and peanuts differ in botanical classification, nutrient and bioactive profiles, and typical preparation methods. Tree nuts include walnuts, almonds, hazelnuts, pistachios, cashews, pecans, macadamias, chestnuts, and pine nuts, whereas peanuts are botanically legumes and may be consumed in different dietary contexts. Therefore, examining tree nuts and peanuts separately may help clarify type-specific associations with cognitive outcomes.

According to the Chinese Dietary Guidelines, the recommended consumption is 50–70g of nuts per week (approximately 10g per day)^[14]. However, the *Report on the Nutrition and Chronic Diseases Status of Chinese Residents 2020* reported that, the average daily intake of nuts from 2015 to 2017 was only 3.6g/d^[15], less than half of the recommendation, and significantly lower than the levels seen in developed countries (e.g. United States, Europe, and Japan). Based on the disease burden and current status of nut consumption in the Chinese population, these patterns highlight the need to examine the association between nut consumption and cognitive performance in Chinese populations.

Therefore, the objective of this research is to investigate the associations between the consumption of tree nut and peanut and multiple cognitive domains as well as MCI among middle-aged and older adults in China.

2. Methods

2.1 Study design and population

The participants of this study were middle-aged and older adults who participated in the Chinese Square Dancer Cohort (ChiCTR2200056477). The cohort's survey methodology has been described previously^[16]. This cross-sectional analysis employed baseline information collected from August 2020 to December 2024, which involved a total of 6197 participants. For each participant, dietary assessment via food frequency questionnaire (FFQ), neuropsychological evaluation, and physical examination were completed during a single, comprehensive face-to-face visit.

Given that associations between nut consumption and cognitive health are particularly relevant for older adults^[11], participants below 55 years of age were excluded ($n = 698$). We further excluded participants with incomplete neuropsychological test data ($n = 412$), missing information on the food-frequency questionnaire ($n = 319$), implausible daily energy intakes based on sex-specific cutoffs (<600 or >3500 kcal/day for women and <800 or >4200 kcal/day for men; $n = 159$)^[17], and missing information on covariates ($n = 334$). The final analytic sample included 4275 participants (**Figure 1**). The data collection protocols were approved by the Ethics Committee of Wuhan University of Science and Technology (ethics number: 201925), and Wuhan University (WHU-LFMD-2023084). All respondents provided informed consent.

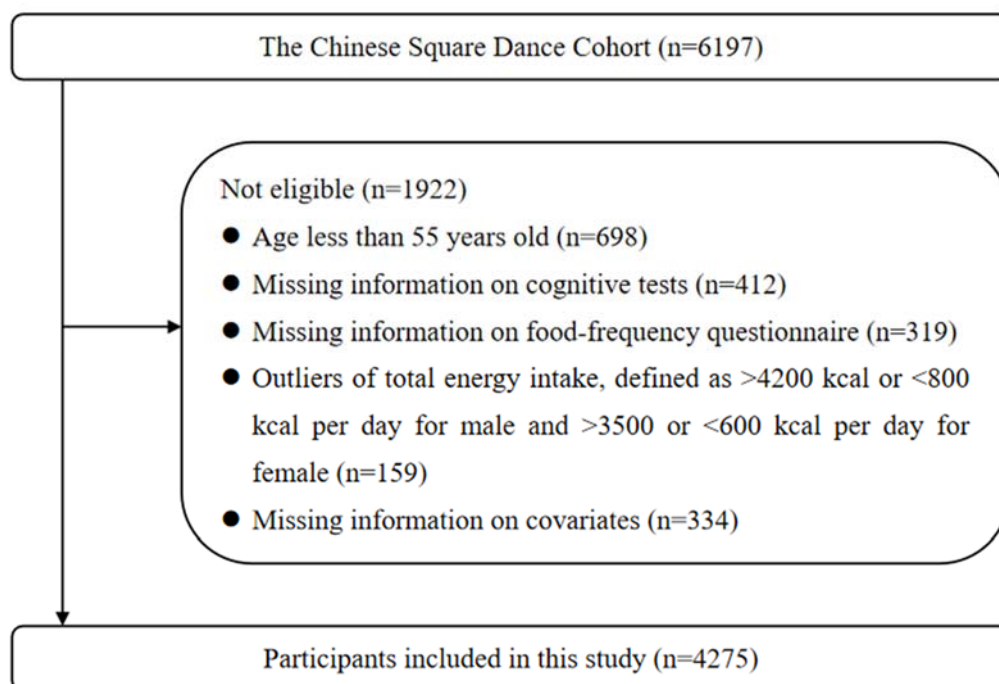


Figure 1. Flowchart of included population in this study.

Participants flow chart for a cross-sectional analysis of the consumption of tree nut and peanut and cognitive performance in older adults in the Chinese Square Dancer Cohort

2.2 Assessment of Nut Consumption

The dietary intake was evaluated through a 64-item semi-quantitative food frequency questionnaire (FFQ), which contained foods commonly consumed by Chinese residents^[18, 19]. Participants were queried their average consumption per eating occasion for individual tree nuts (walnuts, almonds, hazelnuts, pistachios, cashews, pecans, macadamias, chestnuts, and pine nuts) and peanuts (excluding peanut butter) over the past year. Participants reported their average amount of nuts consumed per eating occasion in grams.

The consumption frequency included nine categories: never or rarely, 1 time per month, 2–3 times per month, 1–2 times per week, 3–4 times per week, 5–6 times per week, 1 time per day, 2 times per day, and ≥ 3 times per day. Monthly and weekly consumption frequencies reported by participants were transformed into daily equivalents. Daily tree nut and peanut consumption were subsequently calculated by multiplying the daily frequency by the average amount consumed per eating occasion.

2.3 Measurements of cognitive function and diagnosis of MCI

A battery of neuropsychological tests was conducted to assess cognitive performance, including the Auditory Verbal Learning Test (AVLT), Verbal Fluency Test (VFT), Digit Symbol Substitution Test (DSST), and the Trail Making Test-B (TMT-B). The AVLT^[20] evaluates memory abilities, including immediate and delayed recall, cued recall, and recognition ability on a 60-point scale, with higher scores representing better memory. The VFT^[21] was utilized to assess the language domain by asking the participants to name as many animal names as possible in one minute. Each unrepeated animal name counts as one point. The DSST^[22] was performed to assess attention domain, with participants matching symbols to numbers within a 90-second timeframe, and scores are based on the number of accurately drawn symbols. The TMT-B^[23] assessed executive function by requiring the participants to connect numbers in an alternating sequence of black and white, with shorter completion times indicating better cognitive function.

These tests collectively evaluate memory, executive function, attention, and language, providing a comprehensive assessment of cognitive abilities. Composite scores for global cognition were computed as the average of z-scores from the four cognitive tests (with TMT-B reverse scored)^[24]. The means and standard deviations used for

z-score standardization were derived from the current analytic sample. The four standardized test scores were equally weighted because no prior evidence supported assigning different weights to these cognitive domains in the present cohort, and equal weighting avoids data-driven weighting of individual tests. Elevated composite scores suggest superior cognitive performance.

$$Z_AVLT = (AVLT_{scores} - Mean_{AVLT}) / SD_{AVLT}$$

$$Z_VFT = (VFT_{scores} - Mean_{VFT}) / SD_{VFT}$$

$$Z_DSST = (DSST_{scores} - Mean_{DSST}) / SD_{DSST}$$

$$Z_TMT-B = (TMT-B_{scores} - Mean_{TMT-B}) / SD_{TMT-B}$$

$$Composite\ Z-scores\ of\ global\ cognition = (Z_AVLT + Z_VFT + Z_DSST - Z_TMT-B) / 4$$

MCI was defined based on Petersen's criteria^[25, 26], requiring simultaneous fulfillment of all four conditions: (1) subjective cognitive complaints reported by the participant, family members, or close contacts; (2) objective cognitive impairment in at least one domain, defined using cohort-derived age- and education-specific reference values among dementia-free participants, with performance below the age- and education-specific mean minus 1.5 SD for AVLT, VFT, and DSST, or above the age- and education-specific mean plus 1.5 SD for TMT-B because longer completion time indicates poorer performance; (3) essentially preserved ability to perform activities of daily living; (4) absence of dementia.

2.4 Covariates

Based on previous studies and dementia guidelines^[27-29], the following factors were adjusted as covariates in this study: age, sex (female or male), education level (categorized as 0–6 years, 7–12 years and >12 years), marital status (married and non-married, including single, divorced, or widowed), per capita income (low, middle, or high), smoking status (currently smoking or non-smoking), alcohol intake (currently drinking or non-drinking), physical activity (below or meeting/exceeding the established guidelines), total energy intake, dietary quality score excluding nuts, sleep quality, body mass index (BMI), hypertension (yes or no), diabetes (yes or no), cardiovascular disease (CVD) (yes or no) and depressive symptoms (yes or no).

Per capita income was categorized as low (<20,000 CNY/year), middle (20,000–39,999 CNY/year), and high ($\geq$ 40,000 CNY/year). Physical activity levels were assessed using the Physical Activity Scale for the Elderly (PASE)^[30], and classified based on guideline recommendations. Those engaging in less than 150 minutes of moderate-intensity activity per week were considered below the recommendation, while those meeting or exceeding this threshold were classified as meeting/exceeding the guideline^[31]. The dietary intake data were collected through the FFQ and cross-referenced with the China Food Composition Tables^[18, 19, 32]. The dietary quality score excluding nuts was constructed based on major food-group recommendations in the Chinese Dietary Guidelines, with the nut component excluded to avoid overlap with the exposure of interest. Higher scores indicated better overall dietary quality. BMI was calculated by dividing weight (in kilograms) by height (in meters) squared, and categorized as <18.5, 18.5–23.9, 24.0–27.9, and $\geq$ 28.0 kg/m²^[33]. Hypertension was defined by the presence of any of the following conditions: systolic blood pressure $\geq$ 140 mmHg, diastolic blood pressure $\geq$ 90 mmHg, a self-reported history of hypertension, or current use of antihypertensive medications^[34]. Diabetes was considered present if there was a self-reported history or current use of glucose-lowering medications^[35]. The definition of CVD included self-reported cases of heart disease or stroke. Depressive symptoms were assessed using the Patient Health Questionnaire-9 (PHQ-9), with a score of $\geq$ 5 indicating the presence of depressive symptoms^[36].

2.5 Statistical analysis

In this study, we separately analyzed the relationships between two types of nut consumption (tree nut and peanut) and cognition. Participants were categorized by tree nut consumption into four recommendation-relevant intake groups: 0, 0.01–4.99, 5.00–9.99, and $\geq$ 10.00 g/day. The same classification was applied to peanuts. These cutoffs were selected based on the Chinese Dietary Guidelines, which recommend 50–70 g of nuts per week, approximately 10 g/day^[14]. Participant characteristics based on nut consumption were compared using Pearson's χ^2 test (for categorical variables) and one-way ANOVA test (for continuous variables). Multiple linear regression models were employed to assess the association between nut consumption and various cognitive domains, represented by β coefficients and 95% confidence intervals (CI). Logistic regression models were used to explore the associations between tree nut or peanut consumption and the risk of MCI, presented as odds ratio (OR) and 95% CI.

This study sequentially adjusted for confounders across three models: Model 1 was adjusted for age, sex, and mutually adjusted other nut types. Specifically, tree nut models were additionally adjusted for peanut intake, whereas peanut models were additionally adjusted for tree nut intake. Model 2 was further adjusted for education level, marital status, per capita income, smoking status, alcohol intake, physical activity, sleep quality, dietary quality score excluding the nut component, and total daily energy intake. Model 3 was additionally adjusted for BMI, hypertension, CVD, diabetes, and depressive symptoms. To assess the robustness of the main findings, two stratified subgroup analyses were performed. First, considering that the study population was predominantly female, we conducted a sex-stratified analysis. Second, to examine the association between nut consumption and cognitive function across different age groups, we performed stratified analyses based on the age of 65 years^[27]. Statistical significance was set at a two-sided *P*-value of less than 0.05. All statistical analyses were conducted using SAS software version 9.4^[37].

3 Results

3.1 Participants characteristics

This study enrolled a total of 4275 participants aged between 55 and 82 years (**Table 1**). Participants with higher tree nut consumption were more likely to be female, have higher education levels and per capita income, engage in active physical activity, have better sleep quality, higher dietary quality scores and total daily energy intake, and were less likely to smoke or have diabetes ($P < 0.05$). Significant differences across peanut consumption categories were observed for education level, marital status, per capita income, alcohol intake, poor sleep quality, dietary quality scores and total daily energy intake ($P < 0.05$).

Table 1. Demographic characteristics, lifestyles, physical health, and cognitive function of study participants (n=4275) according to tree nut and peanut consumption.

	Tree nut consumption					Peanut consumption				
	0 g/day	(0.01–4.99) g/day	(5.00–9.99) g/day	≥10.00 g/day	P value ^a	0 g/day	(0.01–4.99) g/day	(5.00–9.99) g/day	≥10.00 g/day	P value
Participants, n (%)	1410 (32.98)	1164 (27.23)	411 (9.61)	1290 (30.18)		1686 (39.44)	1140 (26.67)	358 (8.37)	1091 (25.52)	
Age, years, mean ± SD	64.03 (5.14)	63.39 (5.09)	63.22 (5.03)	63.61 (5.07)	0.004	63.58 (5.14)	63.48 (5.13)	63.58 (5.02)	63.97 (5.03)	0.123
Sex, n (%)					< 0.001					0.233
Female	1151 (81.63)	995 (85.48)	363 (88.32)	1160 (89.92)		1464 (86.83)	981 (86.05)	307 (85.75)	917 (84.05)	
Male	259 (18.37)	169 (14.52)	48 (11.68)	130 (10.08)		222 (13.17)	159 (13.95)	51 (14.25)	174 (15.95)	
Education, n (%)					< 0.001					< 0.001
0–6 years	279 (19.79)	129 (11.08)	41 (9.98)	103 (7.98)		257 (15.24)	125 (10.96)	41 (11.45)	129 (11.82)	
7–12 years	1029 (72.98)	895 (76.89)	313 (76.16)	1008 (78.14)		1275 (75.62)	888 (77.89)	275 (76.82)	807 (73.97)	
>12 years	102 (7.23)	140 (12.03)	57 (13.87)	179 (13.88)		154 (9.13)	127 (11.14)	42 (11.73)	155 (14.21)	
Marital status, n (%)					0.881					0.019
Married	1224 (86.81)	1016 (87.29)	360 (87.59)	1114 (86.36)		1443 (85.59)	988 (86.67)	328 (91.62)	955 (87.53)	
Non-married	186 (13.19)	148 (12.71)	51 (12.41)	176 (13.64)		243 (14.41)	152 (13.33)	30 (8.38)	136 (12.47)	
Per capita income, n (%)					< 0.001					0.027
Low	416 (29.50)	324 (27.84)	107 (26.03)	280 (21.71)		484 (28.71)	306 (26.84)	89 (24.86)	248 (22.73)	
Middle	632 (44.82)	455 (39.09)	167 (40.63)	547 (42.40)		687 (40.75)	466 (40.88)	161 (44.97)	487 (44.64)	
High	362 (25.67)	385 (33.08)	137 (33.33)	463 (35.89)		515 (30.55)	368 (32.28)	108 (30.17)	356 (32.63)	
Smoking status, n (%)					< 0.001					0.303
Current smoking	153 (10.85)	87 (7.47)	21 (5.11)	61 (4.73)		140 (8.30)	82 (7.19)	20 (5.59)	80 (7.33)	
Non-smoking	1257 (89.15)	1077 (92.53)	390 (94.89)	1229 (95.27)		1546 (91.70)	1058 (92.81)	338 (94.41)	1011 (92.67)	
Alcohol intake, n (%)					0.275					< 0.001
Current alcohol drinking	240 (17.02)	176 (15.12)	59 (14.36)	188 (14.57)		231 (13.70)	162 (14.21)	59 (16.48)	211 (19.34)	
Non-drinking	1170 (82.98)	988 (84.88)	352 (85.64)	1102 (85.43)		1455 (86.30)	978 (85.79)	299 (83.52)	880 (80.66)	
Active physical activity, n (%)	840 (59.57)	722 (62.03)	276 (67.15)	937 (72.64)	< 0.001	1077 (63.88)	740 (64.91)	228 (63.69)	730 (66.91)	0.401
Poor sleep quality, n (%)	612 (43.40)	474 (40.72)	175 (42.58)	442 (34.26)	< 0.001	680 (40.33)	493 (43.25)	139 (38.83)	391 (35.84)	0.004
Dietary quality score excluding nuts, mean ± SD	22.76 (5.27)	24.38 (5.29)	24.8 (4.79)	25.99 (4.58)	< 0.001	23.9 (5.27)	24.22 (5.30)	25.04 (5.12)	25.04 (4.89)	< 0.001
Total daily energy intake, mean ± SD	1895.93 (569.32)	1936 (567.61)	1998.19 (564.62)	2341.34 (610.59)	< 0.001	1940.25 (567.59)	1940.32 (587.26)	2082.51 (581.68)	2327.76 (625.76)	< 0.001
BMI, kg/m², mean ± SD	24.32 (3.06)	24.16 (3.13)	23.83 (3.19)	24.2 (3.05)	0.045	24.24 (3.09)	24.1 (3.06)	24.09 (3.17)	24.26 (3.1)	0.494
Hypertension, n (%)	737 (52.27)	614 (52.75)	194 (47.20)	652 (50.54)	0.207	895 (53.08)	585 (51.32)	180 (50.28)	537 (49.22)	0.243
CVD, n (%)	72 (5.11)	71 (6.10)	13 (3.16)	71 (5.50)	0.143	96 (5.69)	66 (5.79)	16 (4.47)	49 (4.49)	0.396
Diabetes, n (%)	153 (10.85)	94 (8.08)	29 (7.06)	99 (7.67)	0.008	153 (9.07)	109 (9.56)	20 (5.59)	93 (8.52)	0.127
Depressive symptoms, n (%)	125 (8.87)	79 (6.79)	36 (8.76)	95 (7.36)	0.193	136 (8.07)	95 (8.33)	28 (7.82)	76 (6.97)	0.646

Composite score, mean ± SD	-0.2 (0.71)	-0.06 (0.63)	-0.03 (0.66)	0.01 (0.67)	< 0.001	-0.13 (0.70)	-0.04 (0.66)	-0.05 (0.64)	-0.05 (0.67)	< 0.001
AVLT score, mean ± SD	23.45 (9.87)	25.79 (9.79)	26.05 (9.96)	27.44 (10.31)	< 0.001	24.88 (10.3)	25.81 (10.17)	25.66 (9.33)	26.23 (9.98)	0.005
VFT score, mean ± SD	15.58 (4.54)	16.51 (4.20)	16.59 (4.49)	16.6 (4.44)	< 0.001	15.87 (4.37)	16.48 (4.59)	16.47 (4.29)	16.48 (4.40)	< 0.001
DSST score, mean ± SD	26.88 (9.65)	29.44 (9.67)	30.39 (10.13)	30.86 (9.93)	< 0.001	28.68 (10.13)	29.64 (9.89)	29.27 (9.72)	29.19 (9.69)	0.088
TMT-B, seconds, mean ± SD	67.57 (40.48)	59.37 (33.26)	57.01 (28.84)	56.69 (30.71)	< 0.001	63.74 (39.17)	58.81 (32.51)	57.96 (28.37)	60.21 (32.45)	< 0.001

The values were presented as mean (SD) for continuous variables or number (percentage) for categorical variables. Abbreviations: SD = standard deviation; BMI = body mass index; CVD = cardiovascular disease; VFT = Verbal Fluency Test; AVLT = Auditory Verbal Learning Test; TMT-B = Trail Making Test-B; DSST = Digit Symbol Substitution Test;

^a *P* values indicated comparisons of characteristics among participants across categories of nut consumption, and were assessed using the ANOVA for continuous variables or chi-squared test for categorical variables.

3.2 Associations of nut consumption and cognitive function

A total of 673 (15.74%) participants were diagnosed with MCI. The association of nut consumption with MCI is presented in **Table 2**. In the fully adjusted model, compared with non-consumers of tree nuts (0 g/day), participants consuming ≥ 10.00 g/day of tree nuts had lower odds of MCI (OR = 0.69, 95% CI: 0.55, 0.87; P trend = 0.012). The associations for the 0.01–4.99 g/day and 5.00–9.99 g/day groups were not statistically significant. As for peanuts, no significant association with MCI was observed across the intake categories in the fully adjusted model.

Table 2. Association of tree nut and peanut consumption with mild cognitive impairment in logistic regression analysis

Classification of Nut	Categories of nut consumption				P for trend ^a
	Q1	Q2	Q3	Q4	
Tree nut consumption	0 g/day	0.01–4.99 g/day	5.00–9.99 g/day	≥ 10.00 g/day	
Cases/N	269/1410	172/1164	68/411	164/1290	
Model 1 ^c	1 (Ref ^b)	0.74 (0.60, 0.91)	0.84 (0.63, 1.13)	0.61 (0.49, 0.76)	< 0.001
Model 2 ^d	1 (Ref)	0.80 (0.64, 0.99)	0.92 (0.69, 1.25)	0.70 (0.56, 0.89)	0.014
Model 3 ^e	1 (Ref)	0.80 (0.64, 0.99)	0.93 (0.69, 1.25)	0.69 (0.55, 0.87)	0.012
Peanut consumption	0 g/day	0.01–4.99 g/day	5.00–9.99 g/day	≥ 10.00 g/day	
Cases/N	284/1686	165/1140	49/358	175/1091	
Model 1	1 (Ref ^b)	0.83 (0.67, 1.02)	0.80 (0.57, 1.10)	1.02 (0.82, 1.26)	0.257
Model 2	1 (Ref)	0.84 (0.68, 1.04)	0.82 (0.59, 1.14)	1.03 (0.83, 1.28)	0.283
Model 3	1 (Ref)	0.84 (0.68, 1.04)	0.83 (0.59, 1.15)	1.03 (0.83, 1.28)	0.274

Data are presented as odds ratios (95%CI) for mild cognitive impairment in logistic regression models.

^a P values for trend were obtained from the corresponding models using nut intake per 5 g/day as a continuous variable.

^b Ref = reference category.

^c Model 1 was adjusted for age, sex, and mutually adjusted other nut types (tree nut models: peanut intake; peanut models: tree nut intake).

^d Model 2 was Model 1 + education level, marital status, per capita income, smoking status, alcohol intake, physical activity, sleep quality, dietary quality score excluding nuts, and total daily energy intake.

^e Model 3 was Model 2 + body mass index, hypertension, cardiovascular disease, diabetes, and depressive symptoms.

Table 3 presents the relationship between tree nut consumption and global and multi-domain cognition. In comparison to individuals not consuming tree nut (Q1), those with daily higher consumption were related to higher composite z scores of global cognition ($\beta_{Q2} = 0.10$, 95% CI: 0.06, 0.15; $\beta_{Q3} = 0.12$, 95% CI: 0.06, 0.18; $\beta_{Q4} = 0.15$, 95% CI: 0.10, 0.20; P trend < 0.001). For different cognitive domains, the participants consumed higher amounts of tree nuts were related to better performance on AVLTT ($\beta_{Q4} = 0.19$, 95% CI: 0.12, 0.26; P trend < 0.001), VFT ($\beta_{Q4} = 0.13$, 95% CI: 0.05, 0.21; P trend = 0.068), DSST ($\beta_{Q4} = 0.14$; 95% CI: 0.08, 0.20; P trend < 0.001), and TMT-B ($\beta_{Q4} = -0.13$; 95% CI: -0.20, -0.05; P trend = 0.002) compared to non-consumers (Q1).

Table 3. Relationship between the tree nut consumption and cognitive domain in multiple linear regression analysis

Cognitive tests	Categories of tree nut consumption				P for trend ^a
	Q1 (0 g/day)	Q2 (0.01–4.99 g/day)	Q3 (5.00–9.99 g/day)	Q4 (≥ 10.00 g/day)	
Composite z scores					
Model 1 ^c	0 (Ref ^b)	0.20 (0.15, 0.25)	0.24 (0.17, 0.31)	0.30 (0.25, 0.35)	<0.001
Model 2 ^d	0 (Ref)	0.10 (0.06, 0.15)	0.12 (0.06, 0.19)	0.15 (0.10, 0.19)	<0.001
Model 3 ^e	0 (Ref)	0.10 (0.06, 0.15)	0.12 (0.06, 0.18)	0.15 (0.10, 0.20)	<0.001

Cognitive tests	Categories of tree nut consumption				P for trend ^a
	Q1 (0 g/day)	Q2 (0.01–4.99 g/day)	Q3 (5.00–9.99 g/day)	Q4 (≥10.00 g/day)	
AVLT z scores					
Model 1	0 (Ref)	0.19 (0.12, 0.27)	0.21 (0.10, 0.31)	0.35 (0.28, 0.42)	<0.001
Model 2	0 (Ref)	0.11 (0.04, 0.18)	0.10 (0.00, 0.20)	0.19 (0.11, 0.26)	<0.001
Model 3	0 (Ref)	0.11 (0.04, 0.18)	0.10 (0.00, 0.20)	0.19 (0.12, 0.26)	<0.001
VFT z scores					
Model 1	0 (Ref)	0.20 (0.13, 0.28)	0.22 (0.11, 0.33)	0.23 (0.15, 0.30)	<0.001
Model 2	0 (Ref)	0.13 (0.06, 0.21)	0.14 (0.03, 0.24)	0.13 (0.05, 0.21)	0.070
Model 3	0 (Ref)	0.13 (0.06, 0.21)	0.14 (0.03, 0.24)	0.13 (0.05, 0.21)	0.068
DSST z scores					
Model 1	0 (Ref)	0.19 (0.13, 0.26)	0.27 (0.18, 0.36)	0.34 (0.27, 0.40)	<0.001
Model 2	0 (Ref)	0.06 (0.00, 0.12)	0.11 (0.03, 0.20)	0.14 (0.08, 0.20)	<0.001
Model 3	0 (Ref)	0.06 (0.01, 0.12)	0.11 (0.02, 0.19)	0.14 (0.08, 0.20)	<0.001
TMT-B z scores					
Model 1	0 (Ref)	-0.20 (-0.28, -0.13)	-0.26 (-0.37, -0.16)	-0.29 (-0.36, -0.22)	<0.001
Model 2	0 (Ref)	-0.10 (-0.17, -0.03)	-0.14 (-0.24, -0.04)	-0.13 (-0.20, -0.06)	0.001
Model 3	0 (Ref)	-0.10 (-0.17, -0.03)	-0.14 (-0.24, -0.04)	-0.13 (-0.20, -0.05)	0.002

Data are presented as multivariate β (95%CI) for z scores in linear regression models. Abbreviations: VFT = Verbal Fluency Test; AVLT = Auditory Verbal Learning Test; TMT-B = Trail Making Test-B; DSST = Digit Symbol Substitution Test.

^a P values for trend were obtained from the corresponding models using nut intake per 5 g/day as a continuous variable.

^b Ref = reference category.

^c Model 1 was adjusted for age, sex, and mutually adjusted other nut types (tree nut models: peanut intake; peanut models: tree nut intake).

^d Model 2 was Model 1 + education level, marital status, per capita income, smoking status, alcohol intake, physical activity, sleep quality, dietary quality score excluding nuts, and total daily energy intake.

^e Model 3 was Model 2 + body mass index, hypertension, cardiovascular disease, diabetes, and depressive symptoms.

The associations between the peanut consumption and various cognitive domains are presented in **Table 4**. Compared to non-consumers of peanut (Q1), individuals in Q2 were associated with better global cognitive performance, with β values of 0.07 (95% CI: 0.03, 0.12), whereas the associations for Q3 and Q4 were not statistically significant. For domain-specific outcomes, peanut consumption was associated with better VFT performance in Q2 ($\beta_{Q2} = 0.11$, 95% CI: 0.03, 0.18) and Q4 ($\beta_{Q4} = 0.08$, 95% CI: 0.01, 0.16), and with shorter TMT-B completion time in Q2 ($\beta_{Q2} = -0.09$, 95% CI: -0.16, -0.03) and Q3 ($\beta_{Q3} = -0.11$, 95% CI: -0.21, -0.01).

Table 4. Relationship between the peanut consumption and cognitive tests scores in multiple linear regression analysis.

Cognitive tests	Categories of peanut consumption				P for trend ^a
	Q1 (0 g/day)	Q2 (0.01–4.99 g/day)	Q3 (5.00–9.99 g/day)	Q4 (≥10.00 g/day)	
Composite z scores					
Model 1 ^c	0 (Ref ^b)	0.11 (0.06, 0.16)	0.10 (0.02, 0.17)	0.08 (0.03, 0.13)	0.982
Model 2 ^d	0 (Ref)	0.07 (0.03, 0.12)	0.05 (-0.01, 0.12)	0.03 (-0.01, 0.08)	0.476
Model 3 ^e	0 (Ref)	0.07 (0.03, 0.12)	0.05 (-0.01, 0.12)	0.03 (-0.01, 0.08)	0.449
AVLT z scores					
Model 1	0 (Ref)	0.09 (0.02, 0.16)	0.07 (-0.04, 0.17)	0.09 (0.02, 0.17)	0.538
Model 2	0 (Ref)	0.06 (-0.01, 0.12)	0.02 (-0.08, 0.12)	0.04 (-0.03, 0.11)	0.783
Model 3	0 (Ref)	0.06 (-0.01, 0.12)	0.02 (-0.08, 0.12)	0.04 (-0.03, 0.11)	0.773
VFT z scores					
Model 1	0 (Ref)	0.14 (0.06, 0.21)	0.12 (0.01, 0.24)	0.11 (0.04, 0.19)	0.592
Model 2	0 (Ref)	0.11 (0.04, 0.18)	0.09 (-0.02, 0.20)	0.08 (0.01, 0.16)	0.722
Model 3	0 (Ref)	0.11 (0.03, 0.18)	0.09 (-0.02, 0.20)	0.08 (0.01, 0.16)	0.767
DSST z scores					
Model 1	0 (Ref)	0.09 (0.02, 0.15)	0.05 (-0.05, 0.14)	0.03 (-0.04, 0.09)	0.284
Model 2	0 (Ref)	0.03 (-0.02, 0.09)	-0.01 (-0.10, 0.07)	-0.03 (-0.09, 0.03)	0.063

Cognitive tests	Categories of peanut consumption				P for trend ^a
	Q1 (0 g/day)	Q2 (0.01–4.99 g/day)	Q3 (5.00–9.99 g/day)	Q4 (≥10.00 g/day)	
Model 3	0 (Ref)	0.03 (-0.02, 0.09)	-0.02 (-0.10, 0.07)	-0.03 (-0.09, 0.03)	0.056
TMT-B z scores					
Model 1	0 (Ref)	-0.14 (-0.21, -0.07)	-0.15 (-0.26, -0.04)	-0.07 (-0.14, 0.00)	0.885
Model 2	0 (Ref)	-0.09 (-0.16, -0.03)	-0.11 (-0.21, -0.01)	-0.04 (-0.11, 0.03)	0.707
Model 3	0 (Ref)	-0.09 (-0.16, -0.03)	-0.11 (-0.21, -0.01)	-0.04 (-0.11, 0.03)	0.708

Data are presented as multivariate β (95%CI) for z scores in linear regression models. Abbreviations: VFT = Verbal Fluency Test; AVLT = Auditory Verbal Learning Test; TMT-B = Trail Making Test-B; DSST = Digit Symbol Substitution Test.

^a P values for trend were obtained from the corresponding models using nut intake per 5 g/day as a continuous variable.

^b Ref = reference category.

^c Model 1 was adjusted for age, sex, and mutually adjusted other nut types (tree nut models: peanut intake; peanut models: tree nut intake).

^d Model 2 was Model 1 + education level, marital status, per capita income, smoking status, alcohol intake, physical activity, sleep quality, dietary quality score excluding nuts, and total daily energy intake.

^e Model 3 was Model 2 + body mass index, hypertension, cardiovascular disease, diabetes, and depressive symptoms

Although some stratified estimates, particularly those for tree nut consumption, appeared more evident among women, formal interaction tests showed no significant effect modification by sex for tree nut or peanut consumption across cognitive outcomes (all *P* for interaction > 0.05; **Supplementary Table 1**). Similarly, stratified analyses by age group showed generally consistent associations across participants aged 55–64 years and ≥ 65 years, with no significant interactions by age group (all *P* for interaction > 0.05; **Supplementary Table 2**).

4. Discussion

In this cross-sectional study of middle-aged and older adults in China, we found that higher tree nut consumption was associated with better global and domain-specific cognitive performance and lower odds of MCI. In addition, peanut consumption showed weaker and non-linear associations with cognitive performance, particularly for global cognition, VFT, and TMT-B, but was not significantly associated with MCI after full adjustment.

Previous studies on nut consumption and cognition were consistent with the findings in this study. An analysis from the PREDIMED study, which investigated 447 participants with higher prevalence of cardiovascular disease, showed that a daily intake of 30 g of walnuts was independently related to better working memory^[38]. Another cross-sectional study using National Health and Nutrition Examination Survey (NHANES) data reported that higher nut consumption (including tree and ground nuts) was associated with better cognitive function compared with no nut consumption^[39]. In addition, compared to non-consumers, individuals with low (median: 3.4 g/d) and moderate (median: 19.9 g/d) nut consumption had better performance on CERAD total, animal fluency, and DSST. Despite substantially lower nut consumption than in Western populations, our study also investigated that higher tree nut consumption was associated with better cognitive function and lower odds of prevalent MCI.

Multiple large-scale cohort studies among Chinese populations have reported consistent findings regarding the cognitive benefits of nut consumption^[29, 40]. A prospective cohort study of 4,822 adults aged ≥55 years from the China Health and Nutrition Survey (CHNS, 1991-2006) indicated that long-term high nut consumption (≥10 g/d) was associated with higher global cognition scores and lower likelihood of cognitive

impairment, compared to non-consumers^[29]. Among the 16,737 middle-aged and elderly participants in the Singapore Chinese Health Study, those with higher baseline nut consumption (median: 11.87 g/d) had a significantly lower risk of cognitive impairment and better overall cognitive function after 20 years^[41]. In a cohort study from Zhejiang province following 9028 elderly for 6 years, participants consuming ≥ 70 g/week of nuts had a 17% lower risk of cognitive impairment^[40]. Although it is cross-sectional, this study provides evidence for an association between nut consumption and performance in specific cognitive domains. This approach enables a more comprehensive analysis of how nut consumption is linked to both global and domain-specific cognition in Chinese middle-aged and older adults.

Historically, peanuts have usually been subsumed under the broader category of “nuts” when examining their cognitive relevance. Given their cost-effectiveness and widespread consumption in China as an accessible nuts option, we analyzed peanuts separately from tree nuts. Our results suggested that peanut consumption had weaker and non-linear associations with cognitive performance. No significant association was observed between peanut consumption and MCI after full adjustment. A cross-sectional study from the National Health and Nutrition Examination (2011–2014) revealed that individuals who consumed neither peanuts/peanut butter or tree nuts performed worse on the CERAD Word Learning subtest, Animal Fluency test, and the DSST compared to those who included peanut butter or tree nuts in their diet^[13]. Unfortunately, the dichotomous categorization of exposure variables (consumers vs. non-consumers) without quantifying consumption amounts limited the exploration of the dose-response relationship. For the cognitive domains, a 16-week randomized crossover trial in 31 healthy Dutch adults aged ≥ 60 years reported that daily skin-roasted peanut intake (60 g) improved brain vascular function and verbal memory^[42]. Although, no significant association was observed between the highest consumption (≥ 10.00 g/d) and global cognitive function in this study. These findings underscore the need for future dose-response studies to determine the optimal amount and lifestyle contexts may influence cognitive health.

Notably, unlike the linear dose-response trend observed for tree nuts, our findings revealed an attenuated association between peanut consumption and cognitive function in the highest intake category (≥ 10.00 g/day). Several factors may explain this non-linear relationship. First, high peanut intake in the Chinese population is frequently associated with specific preparation methods, such as deep-frying or heavy salting, which introduce sodium and unhealthy fats that may counteract the neuroprotective components of peanuts. Furthermore, our study focused on whole peanuts and excluded peanut butter, which is increasingly consumed but often classified as a condiment or seasoning rather than a natural whole food. According to dietary guidelines and food processing standards, commercially available peanut butter may differ from whole peanuts in processing level, added sugar, added salt, and fat composition, depending on product formulation. These processing-related changes and the different dietary contexts in which peanut products are consumed could lead to health effects that differ substantially from those of whole, unprocessed peanuts. The exclusion of peanut butter and nuts used as ingredients in complex dishes in our FFQ might have led to an underestimation of total exposure or a misclassification of intake levels among the highest consumers. Future research with

more granular assessments of preparation methods and the degree of food processing is needed to determine the optimal threshold and healthiest forms of peanut consumption.

Nuts are a rich source of MUFA, PUFA, vitamin E, fiber, minerals (potassium, calcium, and magnesium), phenols, and polyphenol compounds^[43, 44]. These components possess antioxidant, neuroprotective, and anti-inflammatory properties^[45, 46], safeguarding neurons from free radicals and other reactive oxygen and nitrogen species, ultimately promoting better cognitive function^[47]. Moreover, other compounds, such as riboflavin and L-carnitine, may contribute to brain function by supporting the development of neural pathways^[48]. Compared to the recommendation^[14], approximately half of our participants failed to meet the guideline. This finding underscores the potential importance of promoting nut consumption as a modifiable lifestyle factor for cognitive health in middle-aged and older Chinese, if confirmed in future prospective studies or clinical trials.

Importantly, the interpretation of our findings should consider the selective nature of the Chinese Square Dancer Cohort. Participants recruited from square dancing communities may differ systematically from the general population of middle-aged and older adults in China, as they are likely to have higher social engagement, better physical functioning, greater health awareness, and more favorable lifestyle profiles. Consistent with this possibility, higher tree nut consumption in the present study was associated with higher education and income levels, greater physical activity, better sleep quality, and higher dietary quality scores. These patterns suggest that nut consumption may partly reflect a broader healthy lifestyle profile rather than an isolated dietary exposure. Compared with nationally representative aging studies in China, such as CHARLS and CLHLS, which were designed to capture broader social, economic, functional, and health circumstances of Chinese middle-aged and older adults, square dancing participants may represent a more socially active and health-conscious subgroup of older adults^[49, 50]. In addition, national studies have shown that cognitive impairment and MCI are strongly associated with education, rural residence, living arrangement, smoking, hypertension, diabetes, cardiovascular disease, and cerebrovascular disease, indicating that differences in these population characteristics may affect both cognitive outcomes and the observed exposure-outcome associations^[51]. Although we adjusted for socioeconomic status, physical activity, sleep quality, dietary quality, smoking, alcohol use, BMI, chronic diseases, and depressive symptoms, residual confounding from unmeasured or imperfectly measured health behaviors, social engagement, and health awareness cannot be excluded. Therefore, our findings should be generalized cautiously and may not apply to frail, home-bound, institutionalized, rural, or socially isolated older adults.

This study has several limitations to report. Firstly, its cross-sectional design prevented us from inferring causality between nut consumption and cognitive function or MCI. Secondly, information on nut consumption over the past year was gathered through the SFFQ, which is susceptible to recall bias, especially in participants with worse cognition. In addition, peanut butter and nuts consumed as ingredients in mixed dishes or recipes were not fully quantified, which may have led to underestimation of actual nut intake or exposure misclassification. Thirdly, objective cognitive impairment was defined using cohort-derived age- and

education-specific reference values among dementia-free participants, because external nationally representative Chinese normative data were not available for the full neuropsychological battery used in this study. This approach may limit comparability with studies using other normative criteria. Fourth, as discussed above, recruitment from square dancing communities may have introduced healthy-user selection bias and limited the external validity of our findings. Finally, despite considering numerous confounding variables, the possibility of residual confounding cannot be entirely ruled out. In particular, APOE ϵ 4 genotype, a major genetic risk factor for cognitive impairment, was not available in this study and therefore could not be adjusted for in the models.

5. Conclusions

In this cross-sectional study of a health-conscious cohort of Chinese middle-aged and older adults, higher tree nut consumption was associated with better global and domain-specific cognitive performance and lower odds of MCI. Peanut consumption showed weaker and non-linear associations with selected cognitive outcomes, but was not significantly associated with MCI after full adjustment. While these findings support further investigation, the cross-sectional design and selective nature of the cohort preclude causal inference and limit generalizability. Future longitudinal studies in broader populations are needed to confirm these associations.

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Conflicts of interest

There are no conflicts to declare.

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