Research Article

The association of dietary protein intake in three meals and cognitive performance among people over sixty years old

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Abstract

Background: Cognitive dysfunction caused by aging is becoming increasingly significant, and despite increasing global attention to the prevention and treatment of cognitive impairment, effective treatment methods remain elusive, so changing lifestyle and dietary interventions are particularly important.

Objective: The aim of this study was to explore the effects of dietary protein intake on cognitive ability in the people aged over 60 years, and to provide new insights for the prevention and improvement of cognitive dysfunction in the elderly.

Methods: We conducted a cross-cutting study of 2649 older adults in the National Health and Nutrition Examination Survey database between 2011 and 2014, employing weighted logistic regression analysis to investigate the relationship between protein intake at three meals and cognitive capacity.

Results: In the fully adjusted model, compared to those in the lowest quantile, participants in the highest quintile of dinner protein intake had a lower risk of low cognitive performance (OR = 0.66, 95% CI 0.44–0.98 for Consortium to Establish a Registry for Alzheimer's Disease; OR = 0.64, 95% CI 0.39–0.95 for Digit Symbol Substitution Test; OR = 0.56, 95% CI 0.36–0.88 for Composite z-score).

Conclusions: Our study suggests that cognitive performance may be related to dinner protein intake but not breakfast protein intake.

Keywords

Alzheimer's disease, cognitive performance, time of protein intake

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Introduction

Nowadays, with the increasing life expectancy of people, the global population aging is intensifying, and cognitive decline of the elderly is gradually becoming one of the major issues in human society.[1] The disabilities and substantial lifelong costs associated with cognitive decline not only[2] affect the individuals with the condition but also impose a significant burden on their families and society.[3] The process of cognitive decline leading to dementia is persistent and irreversible. There are currently no effective treatments available and the medications that can be used are also very limited.[4] Therefore, exploring modifiable lifestyle factors and dietary habits is of great significance for the prevention of low cognition. Diet is a variable that can be changed, and current research suggests that dietary interventions play an important part in the prevention or alleviation of cognitive performance.[5,6]

Protein is an essential macronutrient that is vital for maintaining normal human function. It plays a crucial role in maintaining muscles and organs, tissue/cell repair, and the production of neurotransmitters, among other

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physiological functions.[7] It is well known that protein intake can help stay healthy in older adults, particularly in promoting body function.[8,9] The elderly who consume more protein than the Recommended Dietary Allowance tend to have better physical function and greater muscle strength.9 The intake of animal protein is inversely associated with all-cause mortality and cardiovascular mortality in the elderly.[10] Older adults consuming adequate protein is also positively associated with memory function and reduces the risk of cognitive impairment. Although extensive research has explored various dietary strategies to prevent the onset of dementia in the elderly, conclusive results remain limited.[11]

The human body's metabolism and circadian systems have a complex interrelationship, where disturbances in one system can affect the other. Studying the impact of meal timing by aligning elements of nutritional research with chronobiology (chrono-nutrition), may have significant implications for reducing the prevalence of chronic diseases.[12] At present, there is a lack of research on the relationship between protein intake timing and cognitive function. Therefore, our study selected two cycles of National Health and Nutrition Examination Survey (NHANES), namely NHANES 2011-2012 and 2013–2014. Because these two NHANES cycles included specific cognitive function tests. Our research was limited to 2649 adults aged 60 and above to assess the relationship between protein intake at three meals and low cognitive performance.

Methods

Data sources and study population

In this cross-sectional study, all participant data was sourced from the NHANES database. The NHANES is a research program designed to assess the health and nutritional status of adults and children in the United States. It combines interviews with physical examinations, employing a sophisticated, stratified, multistage sampling design to select a representative sample of the non-institutionalized U.S. population.[13] The NHANES protocol was approved by the National Center for Health Statistics (NCHS) Research Ethics Review Board. All the NHANES participants were provided with informed consent.

In this study, we selected two cycles of the NHANES dataset, specifically 2011–2012 and 2013–2014, as cognitive function tests were only conducted during these periods. A total of 19,931 individuals participated in NHANES from 2011 to 2014. Our analysis was restricted to 2934 individuals aged 60 and above who completed the cognitive tests. After further excluding those with missing dietary data or abnormal energy intake (less than 500 or more than 5000 kcal/day for women, and less than 500 or more than 8000 kcal/day for men), a total of 2649 participants were included in the final analysis (Figure 1).

Protein intake at three meals

In each NHANES cycle, participants provided detailed dietary intake information through two 24-h dietary recall interviews. The first dietary recall interview was collected in person at the Mobile Examination Center, and the second interview was conducted by telephone between 3 to 10 days later. Protein intake at breakfast, lunch, and dinner was calculated using the variable "Name of eating occasion," where "Breakfast" and "Desayuno" were defined as breakfast; "Lunch" and "Almuerzo" as lunch; and "Dinner," "Supper," and "Cena" as dinner. The protein intake per meal (g) for each participant was based on the average of the two 24-h dietary recalls, and for those who only participated in a single dietary interview, the protein intake was taken from that single instance.

Cognitive assessment

Between 2011 and 2014, a series of cognitive function tests were conducted on adults aged 60 and above in NHANES. These included the Consortium to Establish a Registry for Alzheimer's Disease (CERAD) Word Learning subtest, the Animal Fluency Test (AFT), and the Digit Symbol Substitution Test (DSST). These tests were utilized to examine the association between cognitive function and numerous medical conditions and risk factors measured during the NHANES examination.

The CERAD Word Learning subtest (CERAD W-L) assesses immediate and delayed learning ability for new verbal information (memory sub-domain).[14] The test consists of three consecutive learning trials and a delayed recall. During the learning trials, participants were asked to read 10 unrelated words aloud and then recall them to the best of their ability, with a maximum score of 10 possible on each trial. The delayed word recall occurred after the other two cognitive exercises (AFT and DSST), approximately 8–10 min after the word learning experiment began. The final score is the sum of the three consecutive learning trials and the delayed recall trial.

The AFT measures absolute verbal fluency, which is a component of executive function.15 Scores were used to distinguish between people with normal cognitive function, those with mild cognitive impairment, and those with more severe cognitive impairment, such as Alzheimer's disease. Participants were asked to name as many animals as possible within one minute, with each correctly named animal earning one point, and the final AFT score is the total number of correctly named animals.

The DSST is a performance module in the Wechsler Adult Intelligence Scale (WAIS III). It assesses processing speed, sustained attention and working memory. It assesses processing speed, sustained attention and working memory. This exercise is done with a piece of paper with a key on it

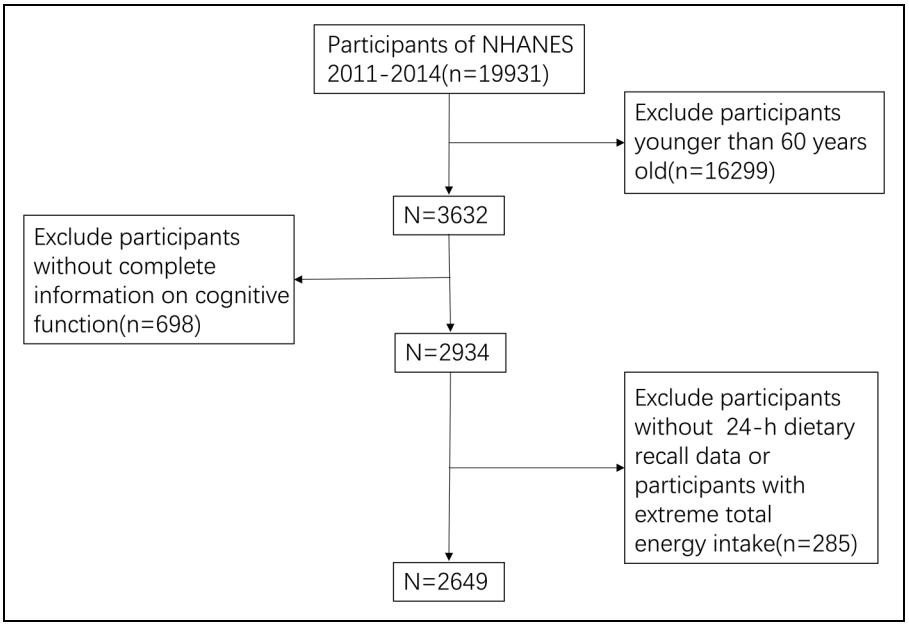

Figure 1. Flow chart of the selection of eligible participants.

with 9 numbers and symbols paired inside. Participants had 2 min to copy the corresponding symbol in one of 133 boxes next to the number. The final score is the total number of correct matches.

Currently, there are no standard cutoff points for identifying low cognitive performance in the CERAD, Animal Fluency, and DSST tests. Therefore, we used the 25th percentile (the lowest quartile) of the scores as the cutoff point, which is consistent with methods used in published literature.[16–18] In addition, we standardized scores on the three tests and then averaged them to obtain a composite cognitive Z score that more fully reflects cognitive function.19 The cutoff values for low cognitive performance in the four levels are 20, 13, 33, and −0.5626059, respectively. The participants were divided into two groups: those with scores above the threshold defined as normal cognitive performance, and those below the threshold defined as low cognitive performance.

Covariates

In addition to the protein intake at three meals, we also studied some other confounding factors including age (60–69 years and ≥70 years), gender (male and female), race (Mexican American, other Hispanic, Non-Hispanic White, Non-Hispanic Black and other races), educational level (below high school, high school and above), marital status (Married, living with partner and others), poverty–income ratio (≤0.99 and ≥1), body mass index (BMI) (underweight: <18.5 kg/m2, normal: 18.5 to 25 kg/m2, overweight: 25 to <30 kg/m2, obesity: ≥ 30 kg/m^2), drinking (having at least 12 alcohol drinks per year or not) and smoking status (never smoked or smoked <100 cigarettes in life, smoked ≥100 cigarettes in life),[20] fruit intake (low/high) and vegetable intake (low/high) were determined by the median of the total intake of the participants, exercise (having engaged in recreational moderate and vigorous physical activity in the past 30 days or not), diabetes (yes/no), cardiovascular disease (yes/no), depression (yes/no). Participants were considered to have diabetes when they met any of the following criteria: (a) hemoglobin A1C level ≥6.5%; (b) self-reported physician diagnosis. Participants were identified as having a history of cardiovascular disease if they self-reported being told by a doctor that they had congestive heart failure, coronary artery disease, angina, a heart attack, stroke, hypertension, or high cholesterol levels.[21] Depression is determined through the Patient Health Questionnaire, which is a nine-item screening tool used to assess the frequency of depressive symptoms over the past two weeks. Each question has four response categories: “Not at all”, “Several days”, “More than half the days”, and “Nearly every day”. Responses are scored on a scale of 0 to 3, and the final result corresponds to the sum of the scores (ranging from 0 to 27). A score of 10 or above is defined as indicative of depression.[21]

Statistical analyses

In this study, all participants were categorized into two groups: low cognitive performance and normal cognitive performance. We conducted a descriptive analysis between the two groups, with categorical variables presented as numbers and percentages. “n” represents the

unweighted count, and "(%)" indicates the weighted percentage. The comparison between the low cognitive performance and normal cognitive performance groups was performed using the chi-squared (χ^2) test. Continuous variables, which were non-normally distributed, are expressed as medians and interquartile ranges. The Mann-Whitney U test was selected to compare the low cognitive performance group with the normal cognitive performance group. Missing values of the data are interpolated using the "missForest" package.

We categorized the protein intake from three meals into tertiles (Q) (Q1: below the 33rd percentile, Q2: from the 33rd to the 66th percentile, Q3: above the 66th percentile), with Q1 serving as the reference group. We treated cognitive performance as a binary variable and conducted a weighted logistic regression analysis to explore the relationship between protein intake from three meals and cognitive performance. Model 1 was unadjusted for any confounding factors; Model 2 was adjusted for age and gender; Model 3 further adjusted for race, education level, marital status, poverty income ratio, body mass index, alcohol consumption, smoking status, diabetes, cardiovascular disease, and depression. Then we used a restricted cubic spline with three knots located at the 5th, 50th, and 95th percentiles of the exposure distribution to assess the dose-response relationship between protein intake and cognition. Subsequently, we conducted stratified analyses by age, gender, and BMI to draw more targeted conclusions. Additionally, we performed sensitivity analyses before and after removing missing values to assess the robustness of our results. All statistical analyses in this study were performed with R 4.4.1. A two-sided $p < 0.05$ was considered statistically significant.

Results

Baseline characteristics

Among all participants, individuals with low cognitive performance and normal cognitive performance in the CERAD test, AFT, and DSST showed significant differences in age, race, education level, marital status, poverty income ratio, alcohol use, vegetable intake, exercise and the distribution of protein intake at lunch and dinner ($p < 0.05$) (Table 1). It can be observed from the table that those who reported low cognitive performance were more likely to be older, have lower education levels, lower poverty income ratio, lower vegetable intake, lack of physical activity and lower protein intake at lunch or dinner. In contrast, non-Hispanic whites, married individuals, and alcohol users had lower rates of low cognitive performance. For the AFT and DSST, the prevalence of diabetes, cardiovascular diseases, and depression was higher among individuals with low cognitive performance compared to those with normal cognitive performance.

The association between protein intake at three meals and cognitive performance

Table 2 demonstrates the correlation between protein intake at breakfast, lunch, and dinner and cognitive performance. This study used three models. After adjusting for age, gender, race, educational level, marital status, poverty–income ratio, body mass index (BMI), history of alcohol use, history of smoking, fruit intake, vegetable intake, exercise, diabetes, cardiovascular disease, and depression (Model 3), the multivariable logistic regression analysis (Model 3) showed that for the AFT, compared to the lowest quantile of lunch protein intake, those in the highest quantile had a lower risk (OR = 0.63, 95% CI 0.43–0.93) of low cognitive performance; for the CERAD Test and Digit Symbol Test, participants in the highest quantile of dinner protein intake had a lower risk (OR = 0.66, 95% CI 0.44–0.98 for CERAD; OR = 0.64, 95% CI 0.39–0.95 for DSST) of low cognitive performance. For the comprehensive evaluation of cognition, participants in the highest quantile of dinner protein intake had a lower risk (OR = 0.56, 95% CI 0.36–0.88 for dinner) of low cognitive performance. These results indicate that protein intake at lunch is associated with AFT performance. Protein intake at dinner is correlated with scores on the CERAD test and the Digit Symbol Test. In contrast, protein intake at breakfast shows no association with low cognitive performance. The association between dinner protein intake and cognitive performance was displayed in Figure 2. In sensitivity analyses, the composite z-score and lunch, dinner protein intake were still relevant, and the correlation between dinner protein intake and scores on the CERAD and DSST remained significant, while the association between lunch protein intake and the CERAD was not (Supplemental Table 1). Additionally, the trends of the Restricted Cubic Splines (RCS) curve suggest that dinner protein intake may be negatively associated with lower cognitive performance (Figure 3).

Stratified analyses by age, gender, and BMI

In this study, we also conducted stratified analyses by age, gender, and BMI. The results are shown in Supplemental Table 2. We found that the relationship between dinner protein intake and CERAD, DSST test, and Composite z-score still holds when stratified by age, gender, and BMI levels. The results indicate that for individuals over the age of 70, males, and those with a BMI in the range of 25–30 kg/m^2, there is a significant association between dinner protein intake and cognitive ability. The association between dinner protein intake and cognitive performance may be more robust for these individuals.

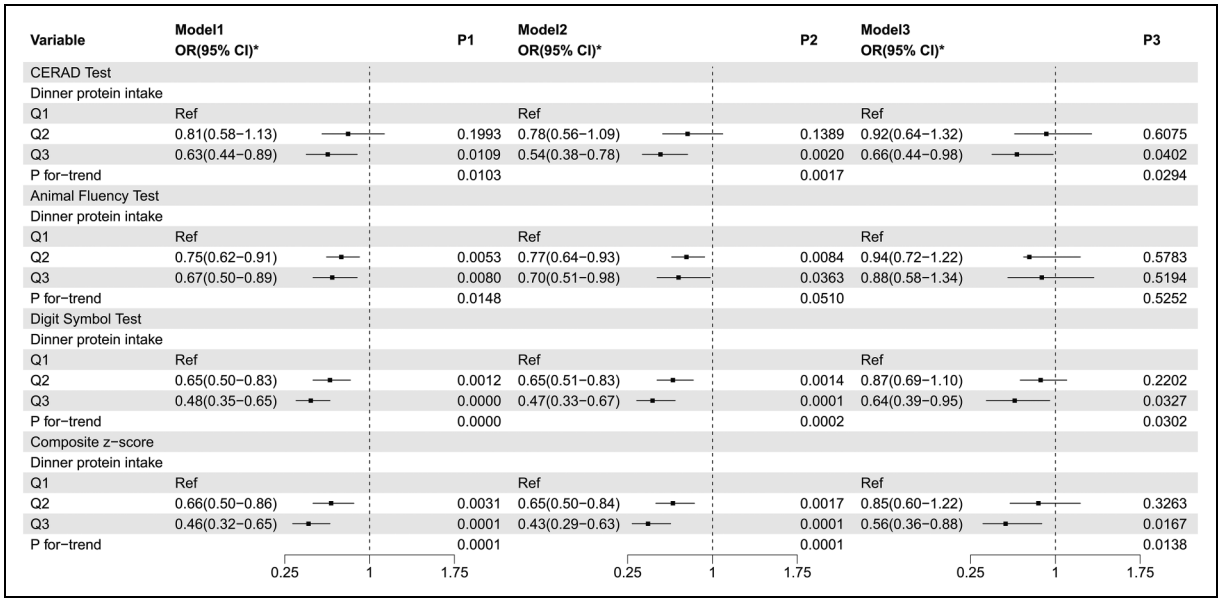

Figure 2. Ors and 95% CI for the association of dinner protein intake with cognitive performance.

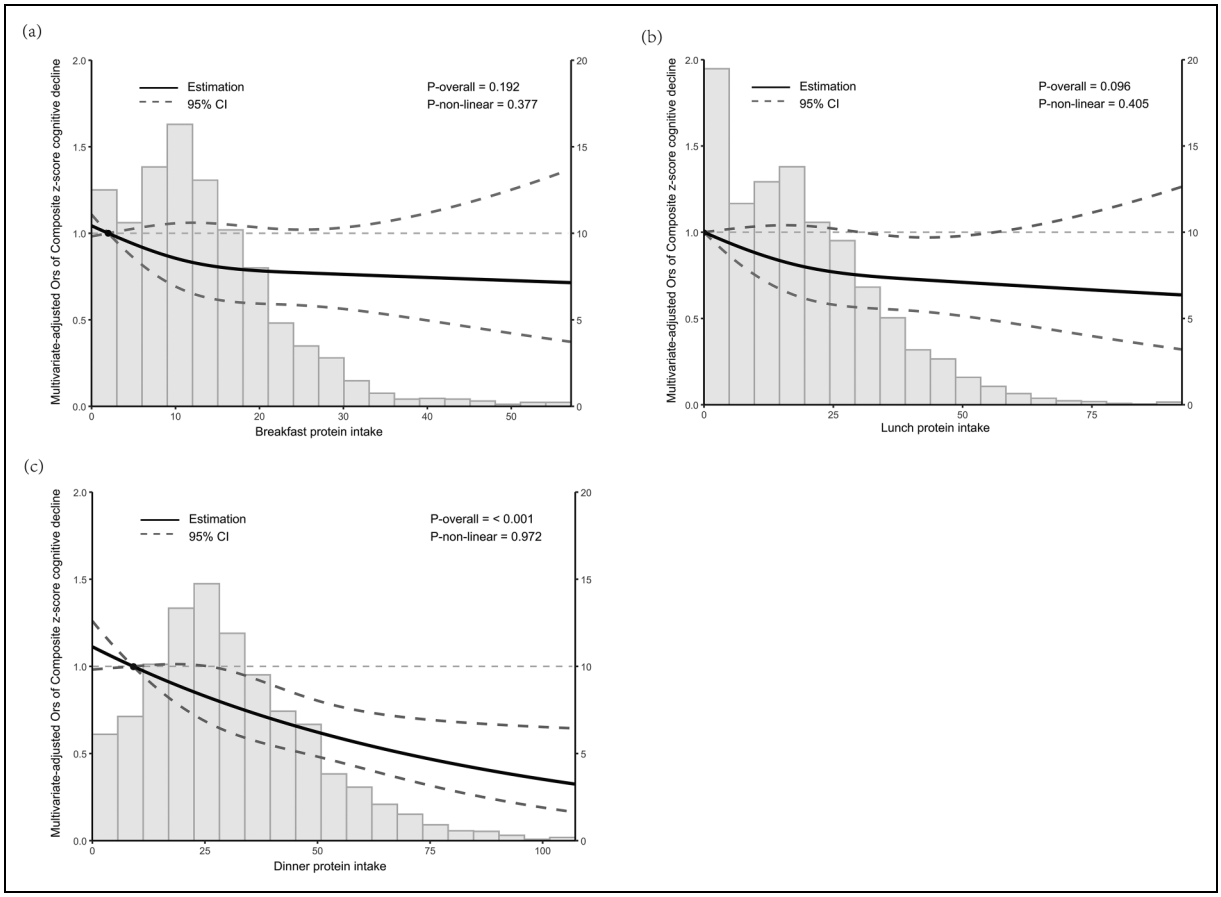

Figure 3. (a) The dose–response relationship between breakfast protein intake and composite z-score; (b) the dose–response relationship between lunch protein intake and composite z-score; (c) the dose–response relationship between dinner protein intake and composite z-score. The solid line represents the odds ratios, and the dotted line represents the 95% confidence interval.

Table 1. Characteristics of the study population, National Health and Nutrition Examination Survey (NHANES) 2011–2014 (N = 2649).

		CERAD test			Animal Fluency Test			Digit Symbol Test		
Variables	Number of Subjects (N)	Normal Cognitive Performance	Low Cognitive Performance	p	Normal Cognitive Performance	Low Cognitive Performance	p	Normal Cognitive Performance	Low Cognitive Performance	p
Number of subjects (%)	2649	2008	641		1872	777		2009	640	
Age (%)	2649		<0.0001		<0.0001			<0.0001		
60–70 y		1191 (62.22)	255 (33.27)		1090 (61.77)	356 (37.86)		1169 (60.53)	277 (33.32)	
≥70 y		817 (37.78)	386 (66.73)		782 (38.23)	421 (62.14)		840 (39.47)	363 (66.68)	
Gender (%)	2649		0.0001			0.8205			0.4816	
Male		913 (43.92)	396 (56.62)		931 (46.47)	378 (45.74)		948 (46.04)	361 (48.07)	
Female		1095 (56.08)	245 (43.38)		941 (53.53)	399 (54.26)		1061 (53.96)	279 (51.93)	
Race (%)	2649		0.0029			<0.0001			<0.0001	
Mexican American		156 (3.01)	69 (5.32)		166 (3.17)	59 (4.47)		144 (2.58)	81 (8.82)	
Other Hispanic		185 (3.21)	82 (6.27)		172 (3.13)	95 (6.27)		148 (2.35)	119 (12.75)	
Non-Hispanic White		1012 (80.38)	292 (73.19)		1032 (83.18)	272 (63.34)		1115 (83.14)	189 (53.38)	
Non-Hispanic Black		470 (8.08)	153 (9.89)		366 (6.25)	257 (16.61)		401 (6.32)	222 (21.50)	
Other Race		185 (5.33)	45 (9.89)		136 (4.27)	94 (9.31)		201 (5.61)	29 (3.55)	
Educational level (%)	2647			<0.0001			<0.0001			<0.0001
Below high school		382 (12.41)	266 (29.42)		356 (12.11)	292 (28.86)		289 (10.36)	359 (48.34)	
High school and above		1625 (87.59)	374 (70.58)		1516 (87.79)	483 (71.14)		1720 (89.64)	279 (51.66)	
Material status (%)	2646		0.0782			<0.0001			<0.0001	
Married		1132 (64.22)	337 (57.41)		1062 (64.47)	407 (57.11)		1171 (65.54)	298 (46.76)	
Widowed/divorced/ separated/never married		822 (33.35)	280 (38.87)		749 (32.64)	353 (41.04)		779 (31.79)	323 (50.59)	
living with partner		51 (2.43)	24 (3.73)		59 (2.89)	16 (1.85)		56 (2.68)	19 (2.65)	
Poverty–income ratio (%)	2047		<0.0001			<0.0001			<0.0001	
≤0.99		271 (7.08)	131 (16.34)		232 (6.81)	170 (16.67)		221 (6.32)	181 (24.70)	
≥1		1587 (92.92)	460 (83.66)		1511 (93.19)	536 (83.33)		1646 (93.68)	401 (75.30)	
Body mass index (%)	2618		0.0136			0.2373			0.4969	
< 18.5 kg/m^2		20 (0.95)	16 (3.22)		19 (1.15)	17 (2.21)		23 (1.25)	13 (2.14)	
18.5–24.9 kg/m^2		505 (25.01)	165 (27.10)		456 (24.75)	214 (27.89)		511 (25.28)	159 (26.17)	
25.0–29.9 kg/m^2		680 (35.24)	241 (38.88)		661 (35.94)	260 (35.78)		705 (36.36)	216 (33.04)	
≥30 kg/m^2		784 (38.82)	207 (30.80)		722 (38.16)	269 (34.11)		758 (37.11)	233 (38.65)	
Smoking status (%)	2648	1023 (50.63)	331 (48.57)	0.3810	960 (50.26)	394 (50.18)	0.9750	1014 (50.02)	304 (51.63)	0.6148
Alcohol use (%)	2629	1397 (75.02)	420 (66.32)	0.0010	1330 (76.20)	487 (62.78)	<0.0001	1426 (75.71)	391 (58.84)	<0.0001
Fruit intake (%)	2462	886 (46.87)	270 (47.90)	0.7297	847 (47.32)	309 (46.02)	0.6028	914 (47.78)	242 (42.39)	0.0933
Vegetable intake (%)	2462	912 (51.82)	232 (41.46)	0.0390	864 (51.86)	280 (42.05)	0.0040	928 (51.05)	216 (42.34)	0.0081
Exercise (%)	2462	481 (30.97)	92 (20.39)	0.0043	477 (32.08)	69 (16.74)	0.0001	511 (31.86)	62 (10.32)	<0.0001

(continued)

Table 1. Continued.

Variables	Number of Subjects (N)	CERAD test			Animal Fluency Test			Digit Symbol Test		
		Normal Cognitive Performance	Low Cognitive Performance	p	Normal Cognitive Performance	Low Cognitive Performance	p	Normal Cognitive Performance	Low Cognitive Performance	p
Diabetes (%)	2501	529 (22.45)	195 (25.37)	0.2884	464 (20.74)	260 (31.54)	0.0012	484 (20.58)	240 (38.01)	<0.0001
Cardiovascular disease (%)	2644	1629 (78.91)	510 (82.39)	0.1128	1503 (78.64)	636 (83.06)	0.0298	1600 (78.44)	539 (86.52)	0.0007
Depression (%)	1689	187 (11.92)	74 (13.67)	0.5103	154 (11.04)	107 (16.67)	0.0307	161 (10.26)	100 (24.10)	<0.0001
Breakfast protein intake (g/day)	2649	11.510 (6.356,17.397)	10.735 (6.737,16.718)	0.6745	11.516 (6.520,17.603)	10.735 (6.198,16.625)	0.1644	11.420 (6.504,17.459)	11.204 (5.976,16.339)	0.2481
Lunch protein intake (g/day)	2649	18.732 (9.905,29.222)	15.146 (6.116,26.263)	0.0281	19.115 (9.901,29.632)	14.702 (6.152,24.560)	0.0002	18.712 (9.561,29.099)	14.707 (5.752,25.003)	<0.0001
Dinner protein intake (g/day)	2649	29.730 (20.604,42.203)	29.292 (16.833,37.931)	0.0161	30.075 (20.622,41.998)	27.604 (16.742,39.353)	0.0228	30.237 (20.835,42.201)	25.187 (13.852,35.694)	<0.0001

Continuous and categorical variables are presented as weighted means (SD) and weighted percentages (SD) respectively.
NHANES: National Health and Nutrition Examination Survey.

Discussion

This study primarily analyzed the relationship between protein intake at three meals and cognitive performance among individuals over 60 years old in the NHANES dataset. We found that protein intake at dinner had the most significant impact on cognitive performance, followed by lunch, while breakfast had essentially no effect. A possible "L-shaped" dose-response relationships between dinner protein intake and the CERAD test were also detected (Supplemental Figure 1). In the RCS curve, no harmful effects associated with protein intake were observed, which may also imply that the protein intake in the people of this age group is far from sufficient. After stratified analysis by age, gender, and BMI, these results were still present in individuals aged 60–70, women, and those with a BMI between 25 and 29.9.

An increasing number of preclinical and clinical studies on healthy individuals in the early stages of cognitive decline have demonstrated the beneficial effects of nutrition on cognitive function.[22] Current evidence suggests that nutrients can affect neuroinflammatory processes leading to neurodegeneration in animals and exert greater biological effects through synergistic actions. However, data from these studies are still lacking, and the mechanisms are not yet clear.[23] Most previous studies have reported a positive correlation between protein intake in the elderly and overall cognitive function, while others have reported null results.[24–27] A protein drink and placebo intervention for up to 24 weeks in frail or prefrail elderly subjects found that protein drinks improved the reaction time performance of these elderly subjects, although there was no difference in cognitive function improvement.[28] Of course, such results do not directly negate the efficacy of protein for cognitive improvement, as subtle effects of nutrients can accumulate over decades, and improvements in reaction time are already noteworthy.[22] In a 6-year cohort study of community-dwelling elderly, dietary protein intake was positively correlated with memory test scores, which is highly consistent with our findings.[29] Similar conclusions have been drawn in several large population studies, where higher protein intake compared to isocaloric carbohydrates was found to reduce the incidence of subjective cognitive decline.[30] Similar conclusions have been reached in several studies of macronutrients and energy intake about cognition and dementia.[1,31] These studies emphasize that dietary protein intake in the elderly has some improvement in cognitive function.

Circadian clocks play a key role in guiding and maintaining the endocrine and metabolic pathways required for homeostasis, and food or nutrient intake can reset circadian clocks through various signaling pathways, making the timing of food intake profoundly influential

Table 2. The association between protein intake at three meals and cognitive performance.

		Model 1		Model 2		Model 3	
Variables	Breakfast protein intake	OR (95%CI)	p	OR (95%CI)	p	OR (95%CI)	p
CERAD Test	Q1	Ref		Ref		Ref	
	Q2	1.24 (0.94–1.62)	0.1220	1.04 (0.81–1.33)	0.7710	1.08 (0.81–1.45)	0.5481
	Q3	0.98 (0.72–1.35)	0.9220	0.83 (0.61–1.12)	0.2140	0.86 (0.60–1.21)	0.3342
	p for-trend		0.8020		0.1840		0.2799
Animal Fluency Test	Q1	Ref		Ref		Ref	
	Q2	0.93 (0.66–1.31)	0.649	0.81 (0.59–1.12)	0.1885	0.83 (0.60–1.14)	0.2162
	Q3	0.77 (0.56–1.07)	0.112	0.74 (0.54–1.02)	0.0668	0.73 (0.50–1.07)	0.0934
	p for-trend		0.1010		0.0695		0.0922
Digit Symbol Test	Q1	Ref		Ref		Ref	
	Q2	0.93 (0.63–1.37)	0.7050	0.79 (0.56–1.13)	0.1887	0.89 (0.60–1.33)	0.5340
	Q3	0.78 (0.59–1.03)	0.0760	0.73 (0.54–0.98)	0.0364	0.77 (0.52–1.14)	0.1626
	p for-trend		0.0669		0.0393		0.1541
Composite z-score	Q1	Ref		Ref		Ref	
	Q2	1.13 (0.76–1.69)	0.5260	0.94 (0.67–1.32)	0.7164	1.04 (0.72–1.51)	0.8197
	Q3	0.84 (0.62–1.13)	0.2340	0.75 (0.54–1.03)	0.0748	0.78 (0.54–1.12)	0.1546
	p for-trend		0.1760		0.0660		0.1240
		Model 1		Model 2		Model 3	
Variables	Lunch protein intake	OR (95%CI)	p	OR (95%CI)	p	OR (95%CI)	p
CERAD Test	Q1	Ref		Ref		Ref	
	Q2	0.64 (0.46–0.90)	0.0108	0.65 (0.46–0.93)	0.0209	0.77 (0.52–1.14)	0.1601
	Q3	0.55 (0.35–0.88)	0.0152	0.54 (0.33–0.89)	0.0184	0.69 (0.44–1.07)	0.0882
	p for-trend		0.0196		0.0221		0.0940
Animal Fluency Test	Q1	Ref		Ref		Ref	
	Q2	0.75 (0.59–0.95)	0.0189	0.77 (0.61–0.98)	0.0312	0.96 (0.72–1.28)	0.7463
	Q3	0.48 (0.35–0.66)	0.0001	0.50 (0.37–0.67)	0.0001	0.63 (0.43–0.93)	0.0234
	p for-trend		0.0000		0.0001		0.0180
Digit Symbol Test	Q1	Ref		Ref		Ref	
	Q2	0.69 (0.54–0.88)	0.0043	0.72 (0.56–0.91)	0.0076	1.06 (0.80–1.39)	0.6616
	Q3	0.51 (0.39–0.67)	0.0000	0.54 (0.41–0.71)	0.0001	0.80 (0.49–1.32)	0.3373
	p for-trend		0.0000		0.0001		0.3215
Composite z-score	Q1	Ref		Ref		Ref	
	Q2	0.73 (0.55–0.98)	0.0391	0.76 (0.56–1.04)	0.0841	1.07 (0.66–1.72)	0.7659
	Q3	0.49 (0.38–0.65)	0.0000	0.51 (0.38–0.67)	0.0000	0.72 (0.49–1.06)	0.0904
	p for-trend		0.0001		0.0000		0.0777
		Model 1		Model 2		Model 3	
Variables	Dinner protein intake	OR (95%CI)	p	OR (95%CI)	p	OR (95%CI)	p
CERAD Test	Q1	Ref		Ref		Ref	
	Q2	0.81 (0.58–1.13)	0.1993	0.78 (0.56–1.09)	0.1389	0.92 (0.64–1.32)	0.6075
	Q3	0.63 (0.44–0.89)	0.0109	0.54 (0.38–0.78)	0.0020	0.66 (0.44–0.98)	0.0402
	p for-trend		0.0103		0.0017		0.0294
Animal Fluency Test	Q1	Ref		Ref		Ref	
	Q2	0.75 (0.62–0.91)	0.0053	0.77 (0.64–0.93)	0.0084	0.94 (0.72–1.22)	0.5783
	Q3	0.67 (0.50–0.89)	0.0080	0.70 (0.51–0.98)	0.0363	0.88 (0.58–1.34)	0.5194
	p for-trend		0.0148		0.0510		0.5252
Digit Symbol Test	Q1	Ref		Ref		Ref	
	Q2	0.65(0.50–0.83)	0.0012	0.65(0.51–0.83)	0.0014	0.87(0.69–1.10)	0.2202
	Q3	0.48 (0.35–0.65)	0.0000	0.47 (0.33–0.67)	0.0001	0.64 (0.39–0.95)	0.0327
	p for-trend		0.0000		0.0002		0.0302
Composite z-score	Q1	Ref		Ref		Ref	
	Q2	0.66 (0.50–0.86)	0.0031	0.65 (0.50–0.84)	0.0017	0.85 (0.60–1.22)	0.3263
	Q3	0.46 (0.32–0.65)	0.0001	0.43 (0.29–0.63)	0.0001	0.56 (0.36–0.88)	0.0167
	p for-trend		0.0001		0.0001		0.0138

Protein intake and cognitive performance; Reference (Ref.); Model 1 did not adjust for any confounders; Model 2 adjusted for age and gender; Model 3 adjusted for age and gender, race, educational level, marital status, poverty–income ratio, body mass index (BMI), alcohol use, smoking status, fruit intake, vegetable intake exercise, diabetes, cardiovascular disease and depression.

on physiological functions.[32,33] Our study is the first to further discuss the impact of protein intake timing on cognition, emphasizing the importance of dinner protein intake to prevent adverse outcomes associated with low cognitive function, especially in the 60–70 age group, women, and individuals with a BMI of 25–29.9. This conclusion highlights the potential role of circadian rhythms in the relationship between diet and cognitive performance, as sleep affects digestion, which may be related to sleep duration and the interval between mealtime and bedtime. In the future, we can seek new models to integrate sleep status with various temporal dietary patterns to explore the relationship between chrono-nutrition and cognition. In addition, this conclusion also provides new ideas for related research, for instance, we can identify the optimal timing for taking dietary supplements and vitamins associated with cognitive performance. This could involve investigating how the efficacy of these supplements and vitamins might vary depending on the time of day they are consumed.

Of course, this study has certain limitations. First, although the CERAD test has high sensitivity and specificity in assessing mild cognitive impairment and early Alzheimer's disease, it is mainly used to evaluate individuals with Alzheimer's disease or cognitive impairment. In this study, however, our subjects were community-dwelling individuals aged 60 and above. Future studies may consider using other assessment tools more suitable for healthy older adults, such as the Montreal Cognitive Assessment. Second, although our results indicate that increased protein intake is beneficial for good cognitive outcomes, it is widely believed that a high-protein diet is harmful to individuals with renal insufficiency. However, there is no evidence to suggest that high protein intake is harmful to healthy individuals.[34] Therefore, individuals with kidney disease should be cautious when considering increasing their protein intake. Finally, measurement errors in diet and other information are inevitable, and participants' daily dietary habits may differ from the self-reported 24-h dietary recall data, which could lead to misestimation of the associations. Due to the cross-sectional design of this study, the inference of causal relationships is limited. Future research should include new pilot studies to enhance the stability of the conclusions.

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Ethical considerations

We used NHANES data for our research study and it was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Review Board of National Center for Health Statistics. No additional ethical approval was required to perform secondary analyses.

Consent to participate

All the NHANES participants were provided with informed consent.

Consent for publication

Consent for publication was provided by the participant(s) or a legally authorized representative.

Author contributions

Fengru Niu: Conceptualization; Data curation; Formal analysis; Methodology; Writing – original draft.
Yifan Ma: Methodology.
Xiaodi Yuan: Investigation.
Yuan Wang: Software; Visualization.
Shangying Li: Software.
Tianshu Han: Project administration; Supervision; Validation; Writing – review & editing.

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Data availability statement

All the data comes from National Health and Nutrition Examination Survey (https://www.cdc.gov/nchs/nhanes/?CDC_AAref_Val = https://www.cdc.gov/nchs/nhanes/index.htm).

Supplemental material

Supplemental material for this article is available online.

References

1. Wang H, Lv Y, Ti G, et al. Association of low-carbohydrate-diet score and cognitive performance in older adults: National Health and Nutrition Examination Survey (NHANES). *BMC Geriatr* 2022; 22: 983.
2. Yeh T-S, Wang J-D and Ku L-JE. Estimating life expectancy and lifetime healthcare costs for Alzheimer's disease in Taiwan: does the age of disease onset matter? *J Alzheimers Dis* 2020; 73: 307–315.
3. Ahmadi-Abhari S, Guzman-Castillo M, Bandosz P, et al. Temporal trend in dementia incidence since 2002 and

projections for prevalence in England and Wales to 2040: modelling study. *Br Med J* 2017; 358: j2856.
4. Dong X, Li S, Sun J, et al. Association of coffee, decaffeinated coffee and caffeine intake from coffee with cognitive performance in older adults: National Health and Nutrition Examination Survey (NHANES) 2011–2014. *Nutrients* 2020; 12: 840.
5. Solfrizzi V, Custodero C, Lozupone M, et al. Relationships of dietary patterns, foods, and micro- and macronutrients with Alzheimer's disease and late-life cognitive disorders: a systematic review. *J Alzheimers Dis* 2017; 59: 815–849.
6. Gauci S, Young LM, White DJ, et al. Diet may moderate the relationship between arterial stiffness and cognitive performance in older adults. *J Alzheimers Dis* 2022; 85: 815–828.
7. Wu G. Dietary protein intake and human health. *Food Funct* 2016; 7: 1251–1265.
8. Houston DK, Nicklas BJ, Ding J, et al. Dietary protein intake is associated with lean mass change in older, community-dwelling adults: the health, aging, and body composition (health ABC) study. *Am J Clin Nutr* 2008; 87: 150–155.
9. Hruby A, Sahni S, Bolster D, et al. Protein intake and functional integrity in aging: the Framingham heart study offspring. *J Gerontol A Biol Sci Med Sci* 2020; 75: 123–130.
10. Meroño T, Zamora-Ros R, Hidalgo-Liberona N, et al. Animal protein intake is inversely associated with mortality in older adults: the InCHIANTI study. *J Gerontol A Biol Sci Med Sci* 2022; 77: 1866–1872.
11. Polis B and Samson AO. Enhancing cognitive function in older adults: dietary approaches and implications. *Front Nutr* 2024; 11: 1286725.
12. Franzago M, Alessandrelli E, Notarangelo S, et al. Chrono-nutrition: circadian rhythm and personalized nutrition. *Int J Mol Sci* 2023; 24: 2571.
13. NHANES - National Health and Nutrition Examination Survey Homepage, https://www.cdc.gov/nchs/nhanes/index.htm (2024, accessed 18 November 2024).
14. Morris JC, Heyman A, Mohs RC, et al. The consortium to establish a registry for Alzheimer's disease (CERAD). part I. Clinical and neuropsychological assessment of Alzheimer's disease. *Neurology* 1989; 39: 1159–1165.
15. Strauss E, Sherman EMS and Spreen AO. *A compendium of neuropsychological tests*, http://www.oup.com/academic/product/a-compendium-of-neuropsychological-tests-9780195159578?cc=pk&lang=en& (2006, accessed 20 November 2024).
16. Chen SP, Bhattacharya J and Pershing S. Association of vision loss with cognition in older adults. *JAMA Ophthalmol* 2017; 135: 963–970.
17. Marruganti C, Baima G, Aimetti M, et al. Periodontitis and low cognitive performance: a population-based study. *J Clin Periodontol* 2023; 50: 418–429.
18. Wang X, Xiao P, Wang R, et al. Relationships between urinary metals concentrations and cognitive performance among U.S. older people in NHANES 2011–2014. *Front Public Health* 2022; 10: 985127.
19. Nooyens ACJ, Bueno-de-Mesquita HB, van Boxtel MPJ, et al. Fruit and vegetable intake and cognitive decline in middle-aged men and women: the Doetinchem Cohort Study. *Br J Nutr* 2011; 106: 752–761.
20. Li Y, Li S, Wang W, et al. Association between dietary protein intake and cognitive function in adults aged 60 years and older. *J Nutr Health Aging* 2020; 24: 223–229.
21. Cardoso BR, Machado P and Steele EM. Association between ultra-processed food consumption and cognitive performance in US older adults: a cross-sectional analysis of the NHANES 2011–2014. *Eur J Nutr* 2022; 61: 3975–3985.
22. Vauzour D, Camprubi-Robles M, Miquel-Kergoat S, et al. Nutrition for the ageing brain: towards evidence for an optimal diet. *Ageing Res Rev* 2017; 35: 222–240.
23. McGrattan AM, McGuinness B, McKinley MC, et al. Diet and inflammation in cognitive ageing and Alzheimer's disease. *Curr Nutr Rep* 2019; 8: 53–65.
24. Muth A-K and Park SQ. The impact of dietary macronutrient intake on cognitive function and the brain. *Clin Nutr* 2021; 40: 3999–4010.
25. Coelho-Júnior HJ, Calvani R, Landi F, et al. Protein intake and cognitive function in older adults: a systematic review and meta-analysis. *Nutr Metab Insights* 2021; 14: 1178638 8211022373.
26. Aparicio Vizuete A, Robles F, Rodríguez-Rodríguez E, et al. Association between food and nutrient intakes and cognitive capacity in a group of institutionalized elderly people. *Eur J Nutr* 2010; 49: 293–300.
27. Salerno-Kennedy R and and Cashman KD. The relationship between nutrient intake and cognitive performance in people at risk of dementia. *Ir J Med Sci* 2007; 176: 193–198.
28. van der Zwaluw NL, van de Rest O, Tieland M, et al. The impact of protein supplementation on cognitive performance in frail elderly. *Eur J Nutr* 2014; 53: 803–812.
29. La Rue A, Koehler KM, Wayne SJ, et al. Nutritional status and cognitive functioning in a normally aging sample: a 6-y reassessment. *Am J Clin Nutr* 1997; 65: 20–29.
30. Yeh T-S, Yuan C, Ascherio A, et al. Long-term dietary protein intake and subjective cognitive decline in US men and women. *Am J Clin Nutr* 2022; 115: 199–210.
31. Roberts RO, Roberts LA, Geda YE, et al. Relative intake of macronutrients impacts risk of mild cognitive impairment or dementia. *J Alzheimers Dis* 2012; 32: 329–339.
32. Tahara Y and Shibata S. Entrainment of the mouse circadian clock: effects of stress, exercise, and nutrition. *Free Radic Biol Med* 2018; 119: 129–138.
33. Asher G and Sassone-Corsi P. Time for food: the intimate interplay between nutrition, metabolism, and the circadian clock. *Cell* 2015; 161: 84–92.
34. Friedman AN. High-protein diets: potential effects on the kidney in renal health and disease. *Am J Kidney Dis* 2004; 44: 950–962.