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The association between dairy product consumption and cognitive function in the National Health and Nutrition Examination Survey

Keigan M. Park[1]* and Victor L. Fulgoni III[2]

[1]*Dairy Research Institute, 10255 W Higgins Road, Suite 900, Rosemont, IL, 60622, USA*
[2]*Nutrition Impact, LLC, 9725 D Drive North, Battle Creek, MI 49014, USA*

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Abstract

The present cross-sectional study sought to determine the potential relationships between the intake of dairy foods (total dairy products, milk and cheese) and cognitive function through information garnered in the National Health and Nutrition Examination Surveys (1988–94 and 1999–2002). Cognitive measures of vasomotor speed, coding speed and immediate memory recall were assessed from a simple reaction time task (SRTT), symbol–digit substitution test (SDST) and serial digit learning task, respectively, in adults 20–59 years of age. A summation of the percentile rank scores on each of the three tests provided a measure of overall cognitive function. In adults 60 years of age and above, a story recall test and a digit–symbol substitution test (DSST) were utilised to determine cognitive function in an elderly population. The results indicated that cognitive scores for the SRTT were not different between consumers and non-consumers of dairy foods. However, there were associations observed between 20- and 59-year-old consumers of total dairy foods and a higher SDST percentile score (53·2 (SE 1·3) to 49·4 (SE 2·0)) and a calculated global cognitive percentile score (53·3 (SE 1·1) to 50·2 (SE 1·4)) compared with non-consumers. A similar significant association was observed with cheese consumers. In adults over 60 years of age, an association between total dairy product consumption and higher DSST percentile scores (51·5 (SE 1·9) to 46·2 (SE 3·0)) was also observed. These findings highlight the need for additional research on how dairy products may affect cognition and by what mechanisms, through its nutrients or other components.

Key words: **Dairy foods: Cheese: Cognition: National Health and Nutrition Examination Surveys**

There are many environmental factors that may affect the progression of cognitive decline, including inflammatory stress, ecological toxins and a nutritionally poor diet[1]. Dietary-mediated effects on neurological function and cognition early in life might lead to the development of frank dementia later in life[2]. So far, many hypotheses exist in which the diet may affect neurological functioning; however, there is a current lack of clinical evidence to confirm them. One possible scenario is that alterations in blood flow to the central nervous system (CNS) may result in reduced delivery of vital nutrients or decrease the removal of toxic side products of metabolism[3]. In fact, the American Heart Association has indicated the need for additional work on how traditional cardiovascular risk factors, such as hypertension and hypercholesterolaemia, may have an impact on the vascular system and lead to cognitive impairment since these risk factors have been linked to cognitive diseases such as Alzheimer's through epidemiological findings[4]. It is likely that the enhanced intake of industrially produced *trans*-fatty acids, given that consumption has been linked to increases in serum cholesterol, may combine with genetics to negatively affect the CNS. In contrast, the consumption of healthy fats may help to provide the necessary substrates for optimal neuronal health by limiting cholesterol deposition and may work to limit inflammation, both possible causes of cognitive decline[5]. Some epidemiological work has already been undertaken with regard to this question, with some results indicating a higher risk of dementia with high-fat diets that include more saturated fat and cholesterol and lower intakes of polyunsaturated fats[6]. Still, this evidence is far from conclusive as other studies have shown no effect of dietary fat intakes in the same study cohort[7].

In contrast to the deficits hypothesised by the intake of certain nutrients, it is also likely that optimal neuronal function requires the availability of numerous amino acids, minerals and vitamins[1]. For example, an antioxidant-rich diet including higher intakes of vitamins C and E has been associated with a lower risk for Alzheimer's disease development[8].

Abbreviations: CNS, central nervous system; DSST, digit–symbol substitution test; NHANES, National Health and Nutrition Examination Survey; SDLT, serial digit learning task; SDST, symbol–digit substitution test.

* **Corresponding author:** Dr K. M. Park, fax +1 847 803 2077, email keigan.park@rosedmi.com

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In addition, the intakes of folate and vitamin D have also been associated with a reduced risk for Alzheimer's disease and cognitive decline[9–11]. Furthermore, some research has been accomplished on the ability of certain dietary patterns to affect cognitive function. In a study by Barberger-Gateau *et al.*[12], a diet rich in fruit, vegetables and fish was associated with a decreased risk of dementia and Alzheimer's disease, while others have shown that a Mediterranean diet may reduce the risk for mild cognitive impairment and the development of Alzheimer's disease[13,14]. However, these studies fall short of linking specific foods to cognitive function and, in fact, very few studies have examined the ability of individual foods to affect cognitive functioning.

Our current focus has been on examining the ability of dairy foods to affect cognitive health. Possible mechanisms by which dairy products may affect cognitive function were outlined in a recent review by Camfield *et al.*[15]. The authors discussed the potential importance of dairy foods in cognitive health through their hypothesised ability to decrease the risk of the metabolic syndrome, a collection of risk factors that signify an increased risk of CVD and diabetes, and their possible role in stabilising glucose levels. Furthermore, the presence of bioactive peptides, vitamin B_{12}, Ca and end products of fermentation in dairy foods may play a role in their ability to affect cognitive health. However, even with these hypotheses, there is actually very little evidence to suggest an association between dairy product consumption and cognitive health. A recent review outlined the limited findings of several published studies examining the ability of dairy food intake to affect cognitive function[16]. The review concluded that a lower consumption of dairy products was generally found to increase the risk for vascular dementia[16]. This was more pronounced for low-fat dairy products, as some evidence indicated that the consumption of full-fat dairy products may be linked with cognitive deficits in the elderly. However, the data were specific to several individual population groups and therefore not very informative with regard to the population as a whole. In addition, since early defects can lead to long-term shortfalls in cognition, we felt it was important to study not only the effects of dietary factors on cognition in the elderly but also in a younger population. We hypothesised that the relationship with dairy products would be conserved for both milk and cheese, as both dairy products contribute similar nutrients to the diet. In order to confirm or refute our hypothesis, we sought a nationally representative database that afforded a large enough dataset to examine possible associations in adults and in the elderly with different facets of cognitive health. In the present study, the National Health and Nutrition Examination Survey (NHANES) was utilised to cross-sectionally assess the potential relationship between dairy product consumption and cognitive measures.

Experimental methods

The present study utilised data from the NHANES database, compiled by the Centers for Disease Control and Prevention. Ethical approval of the interviews and physical examinations was obtained from the NHANES Institutional Review Board and documented consent was obtained from each participant. The 1988–94 NHANES dataset included three cognitive tests for individuals 20–59 years of age as a single, computerised test battery called the Neuropsychological Evaluation System[17,18]. The battery included the simple reaction time task, which measures visuomotor speed, by assessing an individual's response time to a random presentation of specific visual symbols over a number of trials. It also included the symbol–digit substitution test (SDST), which measures information-processing speed, concentration and motor control by having the subject memorise nine symbols matched to integers 1 to 9. The symbols are then shown in a random order and the subject is responsible for providing the corresponding digit as quickly as possible from memory. The last test in this battery was the serial digit learning task (SDLT), which measures learning and recall by having the subject memorise a predefined sequence of numbers, and subsequently testing their ability to repeat the sequence consecutively with as few errors as possible. To maintain consistency, scores were converted to a percentile score for each subject, with a higher percentile score representing a better score on the cognitive assessments. By combining the results from each of the three primary tests included in NHANES III, a measure of global cognitive function was obtained. This was accomplished, as previously demonstrated by Zhang *et al.*[19], by summing the percentile rank scores achieved on each of the three tests. In this same NHANES survey, a story recall was utilised as the only test of cognitive endpoints (attention and delayed verbal memory) in adults 60 years of age and older (60 +). In this test, subjects are assessed on their ability to remember details from a story presented to them by the interviewer. Again, scores were converted to a percentile, with a higher percentile indicating a better cognitive score. In order to provide additional data for the 60 + age group, we also utilised a later dataset (NHANES 1999–2002) which contained the digit–symbol substitution test (DSST) of response speed, sustained attention, visual spatial skills, and associative learning and memory in adults over 60 years. The DSST requires that the subject correctly codes a series of symbols in 2 min. This exercise is thought to be a sensitive measure of dementia, and has been administered in the National Institute on Aging's Health ABC study[20–22].

An in-person 24 h dietary recall was obtained from participants in the NHANES 1988–94 and 1999–2002 datasets[23,24]. Dairy consumption from all sources (including both low fat and full fat) was defined as (1) total dairy products (including milk, cheese and yogurt), (2) dairy servings from milk and (3) dairy servings from cheese (yogurt intake was too low to be analysed separately). Dairy product consumers were defined as those consuming at least one serving of dairy products (one cup equivalent) per recall, whereas non-consumers were defined as indicating no servings of dairy products consumed. Analyses were conducted for two separate age groups in NHANES 1988–94, namely adults 20–59 years (*n* 4355) and 60 + (*n* 4282), while only adults 60 + (*n* 2189) were analysed in NHANES 1999–2002. All analyses were adjusted for major covariates that have been previously shown to affect public health. These included sex, ethnicity, age, smoking

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status, energy intake (kJ), BMI (kg/m^2), poverty income ratio, intakes of saturated fat (g), monounsaturated fat (g), polyunsaturated fat (g), cholesterol (mg), carbohydrate (g) and protein (g). Unreliable records (e.g. energy intake that was unreasonable), pregnant or lactating females, any person not taking one of the cognitive tests and any person with missing values for any of the covariates were excluded from the analysis. Additionally, all analyses were conducted with appropriate sample weighting for analysing the NHANES data.

ANOVA, adjusting for the complex sample design of the NHANES, were used to determine whether there was an association between dairy product intake variables and cognitive parameters. ANOVA was used to ascertain whether cognitive measures were different among consumers and non-consumers of dairy product intake variables. Additionally, subjects were separated into quintiles of dairy product intake variables (by age group) and ANOVA was used to assess a *P*-for-trend of the relationship of dairy product intake with cognitive measures. The first quintile included non-consumers and consumers were split into four additional quartiles of dairy product consumption based on cup equivalents of dairy foods consumed. Cut-offs for total dairy product consumption in 20–59-year-olds in NHANES 1988–94 were 0, 0·1–0·62, 0·63–1·32, 1·33–2·38 and >2·38 cup equivalents, comparable data for milk were 0, 0·1–0·23, 0·24–0·76, 0·77–1·7 and >1·7 cup equivalents and for cheese were 0, 0·1–0·37, 0·38–0·74, 0·75–1·34 and >1·34 cup equivalents. Cut-offs for total dairy product consumption in 60+ in NHANES 1988–94 were 0, 0·1–0·50, 0·51–1·09, 1·10–2·00 and >2·01 cup equivalents, for milk were 0, 0·1–0·39, 0·40–0·93, 0·94–1·71 and >1·72 cup equivalents and for cheese were 0, 0·1–0·21, 0·22–0·42, 0·43–0·81 and >0·82 cup equivalents. Cut-offs for total dairy product consumption in 60+ in NHANES 1999–2002 were 0, 0·1–0·52, 0·53–1·13, 1·14–1·99 and >2·00 cup equivalents, for milk were 0, 0·1–0·31, 0·32–0·82, 0·83–1·50 and >1·51 cup equivalents and for cheese were 0, 0·1–0·18, 0·19–0·47, 0·48–0·87 and >0·88 cup equivalents.

Results

Percentile scores for the simple reaction time task, SDLT and SDST in adults 20–59 years of age were not different for consumers and non-consumers of total dairy products (Table 1). In contrast, in the 60+ age group, consumers of total dairy products were associated with higher percentile scores on the short-term memory measure (story recall) when compared with non-consumers (49·6 (SE 0·7) *v.* 43·7 (SE 1·3) for a combined score of two stories, $P<0·0001$). Comparing consumers and non-consumers, milk consumption was not related to any cognitive measures in either age group (Table 2). In the 60+ age group, consumers of cheese (Table 3) had higher story recall percentile scores when compared with non-consumers (51·9 (SE 0·9) *v.* 47·3 (SE 0·7) for a combined score of two stories, $P<0·0001$). Additionally, there was some support that cheese consumers had higher DSST percentile scores when examining individuals 60+ in the NHANES 1999–2002 dataset (52·0 (SE 0·8) *v.* 48·4 (SE 1·2), $P=0·0221$).

When looking at quintiles of consumption (non-consumers and quartiles of dairy product consumption) in NHANES 1988–94 (ages 20–59 years), there was a *P*-for-trend for SDST percentiles as total dairy product intake increased (49·4 (SE 2·0) to 53·2 (SE 1·3) in non-consumers and the highest quartile of dairy product intake, respectively, $P<0·002$; Table 4). This led to a significant association of total dairy product intake with the calculated global score for cognitive performance in the 20–59-year-olds (50·2 (SE 1·4) to 53·3 (SE 1·1) in non-consumers and the highest quartile of dairy product intake, respectively, $P<0·0207$). Additionally, there was a significant *P*-for-trend with DSST percentile scores in individuals 60+ in NHANES 1999–02 (46·2 (SE 3·0) to 51·5 (SE 1·9) in non-consumers and the highest quartile of dairy intake, respectively, $P<0·009$). In agreement with the previous analysis, milk consumption was not related to any cognitive measure when looking at quintile analyses for either age group (Table 5). In contrast, cheese consumption was related to SDST percentiles in the 20–59-year-olds (49·0 (SE 0·9) to 55·2 (SE 1·2) in non-consumers and the highest quintiles of

Table 1. Impact of total dairy product servings (some *v.* none) on cognitive measures in the National Health and Nutrition Examination Survey (NHANES) 1988–94 (NHIII) and NHANES 1999–2002 (NH 99–02)*

(Least square mean (LSM) values with their standard errors; number of participants)

			Non-consumers			Consumers			
Dataset	Age (years)	Test	*n*	LSM	SE	*n*	LSM	SE	*P*
NHIII	20–59	SDLT	526	49·51	2·05	3829	50·42	0·69	0·6498
NHIII	20–59	SDST	526	49·36	2·00	3829	50·56	0·68	0·5164
NHIII	20–59	SRTT	526	51·80	1·87	3829	49·97	0·86	0·3064
NHIII	20–59	20–59 All	526	50·22	1·41	3829	50·32	0·56	0·9474
NHIII	60+	SR-1	478	44·50	1·41	3804	49·87	0·75	0·0003
NHIII	60 +	SR-2	478	42·80	1·42	3804	49·41	0·70	0·0000
NHIII	60 +	SR-All	478	43·65	1·33	3804	49·64	0·71	0·0000
NH 99–02	60 +	DSST	208	46·16	2·95	1981	50·63	0·65	0·1149

SDLT, serial digit learning task; SDST, symbol–digit substitution test; SRTT, simple reaction time task; SR-1, story recall one; SR-2, story recall two; DSST, digit–symbol substitution test.

* Data were adjusted for sex, ethnicity, age, smoking status, energy intake (kJ), BMI (kg/m^2), poverty:income ratio, intakes of saturated fat (g), monounsaturated fat (g), polyunsaturated fat (g), cholesterol (mg), carbohydrate (g) and protein (g).

Table 2. Impact of milk servings (some *v.* none) on cognitive measures in the National Health and Nutrition Examination Survey (NHANES) 1988–94 (NHIII) and NHANES 1999–2002 (NH 99–02)*

(Least square mean (LSM) values with their standard errors; number of participants)

			Non-consumers			Consumers			
Dataset	Age (years)	Test	*n*	LSM	SE	*n*	LSM	SE	*P*
NHIII	20–59	SDLT	1072	50·28	1·43	3283	50·36	0·70	0·9524
NHIII	20–59	SDST	1072	50·74	1·46	3283	50·39	0·67	0·7996
NHIII	20–59	SRTT	1072	51·35	1·56	3283	49·80	0·97	0·3811
NHIII	20–59	20–59 All	1072	50·79	1·11	3283	50·19	0·59	0·6114
NHIII	60+	SR-1	674	47·67	1·48	3608	49·67	0·76	0·1813
NHIII	60 +	SR-2	674	47·23	1·55	3608	49·08	0·69	0·2407
NHIII	60 +	SR-All	674	47·45	1·44	3608	49·37	0·70	0·1841
NH 99–02	60 +	DSST	386	47·87	1·81	1803	50·74	0·75	0·1402

SDLT, serial digit learning task; SDST, symbol–digit substitution test; SRTT, simple reaction time task; SR-1, story recall one; SR-2, story recall two; DSST, digit–symbol substitution test.

* Data were adjusted for sex, ethnicity, age, smoking status, energy intake (kJ), BMI (kg/m^2), poverty:income ratio, intakes of saturated fat (g), monounsaturated fat (g), polyunsaturated fat (g), cholesterol (mg), carbohydrate (g) and protein (g).

dairy product intake, respectively, $P<0·001$; Table 6) and short-term memory in the 60 + age group via the average of story recalls (47·3 (SE 0·7) to 50·5 (SE 1·8) in non-consumers and the highest quartile of dairy product intake, respectively, $P<0·0003$). With an additional modest effect on the SDLT, cheese consumption was also related to a global score for cognitive performance in the 20–59-year-olds (49·9 (SE 0·7) to 52·9 (SE 0·9) in non-consumers and the highest quartile of dairy product intake, respectively, $P<0·006$).

Discussion

The results of the present cross-sectional analysis indicated that there are some associations between dairy product consumption and cognitive function that deserve further research. In particular, total dairy product consumption in consumers *v.* non-consumers was associated with a higher story recall percentile scores in adults 60 + , which was also significant for cheese intake but not for milk consumption. In addition, when looking across dairy product consumption quintiles in 20–59-year-olds, there was an association with the SDST for both total dairy product and cheese consumption, which drove an association for the calculated global cognitive percentile score. However, again, there was no association with milk consumption. To the extent possible, the data were adjusted for numerous covariates that may have had an effect on cognitive performance (see the Methods section). These adjustments, plus the size of the NHANES dataset and its applicability to the national population, provide some confidence that the associations presented may be the real effects of dairy product intake. Nonetheless, NHANES data are cross-sectional, resulting from observational information and, as such, cause and effect cannot be concluded. In addition, some dietary factors which may have a significant impact on cognition, such as total fruit and vegetable intake, *n*-3 fatty acids, and alcohol consumption were not specifically addressed in the present analysis. Further research with a database containing more cognitive assessments and a greater dietary assessment accuracy is required before the association can be completely confirmed and clinical research is needed before causality can be assigned.

Similar trends were observed with the SDST and DSST, which are similar but not identical tests of coding speed, in both the 20–59 and 60 + age groups, indicating that more research on the ability of dairy food to affect this facet of cognitive function is needed. However, the absence of the other

Table 3. Impact of cheese servings (some *v.* none) on cognitive measures in the National Health and Nutrition Examination Survey (NHANES) 1988–94 (NHIII) and NHANES 1999–2002 (NH 99–02)*

(Least square mean (LSM) values with their standard errors; number of participants)

			Non-consumers			Consumers			
Dataset	Age (years)	Test	*n*	LSM	SE	*n*	LSM	SE	*P*
NHIII	20–59	SDLT	1914	49·69	1·00	2441	50·75	0·82	0·3716
NHIII	20–59	SDST	1914	49·01	0·94	2441	51·35	0·89	0·0538
NHIII	20–59	SRTT	1914	50·91	1·15	2441	49·63	0·92	0·2517
NHIII	20–59	20–59 All	1914	49·87	0·72	2441	50·57	0·68	0·4201
NHIII	60+	SR-1	2774	47·61	0·85	1508	52·10	1·02	0·0004
NHIII	60 +	SR-2	2774	47·01	0·70	1508	51·57	0·90	0·0000
NHIII	20–59	SR-All	2774	47·31	0·74	1508	51·84	0·94	0·0000
NH 99–02	60 +	DSST	1127	48·39	1·22	1062	51·98	0·80	0·0221

SDLT, serial digit learning task; SDST, symbol–digit substitution test; SRTT, simple reaction time task; SR-1, story recall one; SR-2, story recall two; DSST, digit–symbol substitution test.

* Data were adjusted for sex, ethnicity, age, smoking status, energy intake (kJ), BMI (kg/m^2), poverty:income ratio, intakes of saturated fat (g), monounsaturated fat (g), polyunsaturated fat (g), cholesterol (mg), carbohydrate (g) and protein (g).

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Table 4. Impact of total dairy servings (quartiles of intake) on cognitive measures in the National Health and Nutrition Examination Survey (NHANES) 1988–94 (NHIII) and NHANES 1999–2002 (NH 99–02)*

(Least square mean (LSM) values with their standard errors)

			Non-consumers		Quartiles of intake: Q1		Q2		Q3		Q4		*P*
Dataset	Age (years)	Test	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	Quartile trend
NHIII	20–59	SDLT	49·51	2·05	48·88	1·14	50·27	1·29	49·58	1·14	53·18	1·32	0·1259
NHIII	20–59	SDST	49·36	2·00	48·21	1·05	50·45	0·93	50·57	1·29	53·24	1·27	0·0020
NHIII	20–59	SRTT	51·80	1·87	49·02	1·72	50·51	1·90	46·98	1·22	53·56	1·71	0·5149
NHIII	20–59	20–59 All	50·22	1·41	48·70	0·96	50·41	0·93	49·04	0·79	53·33	1·11	0·0207
NHIII	60+	SR-1	44·50	1·41	50·19	1·45	48·03	1·03	52·42	1·30	48·98	1·33	0·1110
NHIII	60 +	SR-2	42·80	1·42	49·76	1·41	49·24	1·27	50·64	1·22	48·01	1·26	0·1673
NHIII	60 +	SR-All	43·65	1·33	49·98	1·38	48·64	1·09	51·53	1·20	48·49	1·24	0·1181
NH 99–02	60 +	DSST	46·16	2·95	48·27	1·11	50·26	1·04	52·65	0·96	51·48	1·88	0·0090

SDLT, serial digit learning task; SDST, symbol–digit substitution test; SRTT, simple reaction time task; SR-1, story recall one; SR-2, story recall two; DSST, digit–symbol substitution test.

* Data were adjusted for sex, ethnicity, age, smoking status, energy intake (kJ), BMI (kg/m^2), poverty:income ratio, intakes of saturated fat (g), monounsaturated fat (g), polyunsaturated fat (g), cholesterol (mg), carbohydrate (g) and protein (g).

cognitive tests (SDLT, story recall) in both age groups makes it difficult to understand whether these associations, or the absence of an association, would hold true throughout the lifespan. It is possible that dairy product consumption may be having acute effects on cognition or dairy product intake may be having long-term effects that are manifested in different cognitive examinations. In addition, due to the low number of non-dairy product consumers, it was not possible to separate the age groups into further population segments. It would be interesting to examine a dataset that allowed for these measures, as the effects of dairy products may be different depending on the consumer's age. Prospective analysis is needed to determine whether long-term exposure to dairy products may decrease the risk for cognitive impairment, and clinical assessments are necessary to determine whether acute exposures to dairy products are enough to elicit short-term cognitive changes.

It is an interesting finding that cheese consumption may be associated with better cognitive functioning, since previous studies have indicated that the consumption of full-fat dairy products may be associated with negative cognitive outcomes[16]. These findings have typically been explained by pointing to the saturated fat content of full-fat dairy products. However, in a study published by Rahman *et al.*[25], a link between cheese consumption and improved cognition scores was also found. The authors indicated that the nutrients found in dairy products, possibly vitamin A and/or individual dairy fats, may be playing a role in this association. These two divergent findings indicate the need for further research on this topic. These future studies should be designed in such a way that cheese consumption is controlled and the nutrients found in cheese are tracked from both cheese and non-cheese sources. This is very important with respect to foods containing saturated fat, since they are composed of many different types of fatty acids, both saturated and unsaturated, which may have significantly diverse health effects[26]. In addition, effects of individual nutrients being contributed from cheese such as vitamin A, may not have the same effect in individuals who are already consuming adequate levels of vitamin A from other sources. With careful control,

Table 5. Impact of milk servings (quartiles of intake) on cognitive measures in the National Health and Nutrition Examination Survey (NHANES) 1988–94 (NHIII) and NHANES 1999–2002 (NH 99–02)*

(Least square mean (LSM) values with their standard errors)

			Non-consumers		Quartiles of intake: Q1		Q2		Q3		Q4		*P*
Dataset	Age (years)	Test	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	Quartile trend
NHIII	20–59	SDLT	50·28	1·43	47·96	1·23	51·23	1·41	50·86	1·19	51·55	1·26	0·2477
NHIII	20–59	SDST	50·74	1·46	50·24	1·10	50·66	1·23	49·93	1·27	50·76	1·38	0·9271
NHIII	20–59	SRTT	51·35	1·56	48·04	1·36	50·66	1·74	49·54	1·78	51·08	1·97	0·8511
NHIII	20–59	20–59 All	50·79	1·11	48·75	0·81	50·85	1·08	50·11	1·00	51·13	1·17	0·5061
NHIII	60+	SR-1	47·67	1·48	49·12	1·31	49·66	0·96	50·14	1·26	49·81	1·25	0·1534
NHIII	60 +	SR-2	47·23	1·55	48·65	1·29	49·41	1·18	49·80	1·36	48·43	1·05	0·3456
NHIII	60 +	SR-All	47·45	1·44	48·88	1·23	49·54	1·02	49·97	1·26	49·12	1·10	0·2018
NH 99–02	60 +	DSST	47·87	1·81	48·98	1·34	51·22	1·08	53·33	1·15	49·50	1·83	0·1576

SDLT, serial digit learning task; SDST, symbol–digit substitution test; SRTT, simple reaction time task; SR-1, story recall one; SR-2, story recall two; DSST, digit–symbol substitution test.

* Data were adjusted for sex, ethnicity, age, smoking status, energy intake (kJ), BMI (kg/m^2), poverty:income ratio, intakes of saturated fat (g), monounsaturated fat (g), polyunsaturated fat (g), cholesterol (mg), carbohydrate (g) and protein (g).

Table 6. Impact of cheese servings (quartiles of intake) on cognitive measures in the National Health and Nutrition Examination Survey (NHANES) 1988–94 (NHIII) and NHANES 1999–2002 (NH 99–02)*

(Least square mean (LSM) values with their standard errors)

			Non-consumers		Quartiles of intake								P
					Q1		Q2		Q3		Q4		
Dataset	Age (years)	Test	LSM	SE	LSM	SE	LSM	SE	LSM	SE	LSM	SE	Quartile trend
NHIII	20–59	SDLT	49·69	1·00	48·32	1·50	50·72	1·75	51·42	1·84	52·71	1·37	0·0391
NHIII	20–59	SDST	49·01	0·94	50·29	1·65	50·39	1·38	50·12	1·50	55·19	1·22	0·0014
NHIII	20–59	SRTT	50·91	1·15	47·25	2·31	49·23	1·97	51·34	1·64	50·85	1·68	0·7903
NHIII	20–59	20–59 All	49·87	0·72	48·62	1·05	50·11	1·40	50·96	1·27	52·92	0·90	0·0061
NHIII	60+	SR-1	47·61	0·85	54·44	2·55	48·17	1·28	54·52	2·11	51·22	2·01	0·0020
NHIII	60 +	SR-2	47·01	0·70	53·29	2·24	48·45	1·51	54·55	1·82	49·81	1·79	0·0001
NHIII	60 +	SR-All	47·31	0·74	53·87	2·32	48·31	1·32	54·53	1·89	50·51	1·80	0·0003
NH 99–02	60 +	DSST	48·39	1·22	51·08	1·25	53·32	1·47	50·27	1·60	53·28	1·93	0·0743

SDLT, serial digit learning task; SDST, symbol–digit substitution test; SRTT, simple reaction time task; SR-1, story recall one; SR-2, story recall two; DSST, digit–symbol substitution test.

* Data were adjusted for sex, ethnicity, age, smoking status, energy intake (kJ), BMI (kg/m²), poverty:income ratio, intakes of saturated fat (g), monounsaturated fat (g), polyunsaturated fat (g), cholesterol (mg), carbohydrate (g) and protein (g).

this information will probably result in a better understanding of not only dairy-specific associations but also of nutrient–cognition interactions.

The present data also indicated that there may be a threshold effect of dairy product consumption in the 60 + age group. Moving from a non-consumer or low-consumer to the level of an average consumer (approximately two servings per d) seemed to have a greater effect on the cognitive assessments than moving beyond two servings of dairy products. However, more information is needed before this finding can be verified. Very recently, a cross-sectional analysis of dairy product consumption and cognitive measures utilising data from the Maine–Syracuse Longitudinal Study was published[27]. In this analysis, consumption of dairy products at least once per d was associated with an improvement in several measures of cognitive function. However, a similar threshold effect was observed, albeit at a lower level, indicating that in order to see an effect of dairy product consumption, a strict accounting of baseline dairy product intake may be necessary.

The lack of an association with milk in the present analysis is also interesting since our hypothesis was that all dairy products should have a similar effect on cognition and some previous studies have indicated an association with milk[2,28]. This potential association seems to be even more logical since fortified milk contributes a significant amount of vitamin D to the diet, and several studies have highlighted the potential contribution of vitamin D to cognitive function[11,29–31]. However, the exact mechanism for the ability of vitamin D to regulate cognition is still unknown and no clinical interventions with dietary vitamin D have established causality. The association between milk and cognition may be related to the type of milk being consumed (e.g. full fat *v.* non-fat). The present study did not disassociate between full-fat and reduced-fat milk and therefore may have missed an association, since other studies have shown relationships with low-fat varieties[15]. Future studies should track not only dairy products, but also individual dairy products, when examining cognitive endpoints, in an effort to determine which products or components within those products may be having the greatest effect on learning and memory.

Since the present study indicated that milk consumption had no association with cognition while cheese consumption did, it is difficult to speculate on the potential mechanism of action. It is possible that during the process of cheese development, bioactive compounds are formed which could have effects on memory. These compounds would need to be small, since the blood–brain barrier could prevent the access of complex molecules to critical areas of action. It is also possible that by providing a higher amount of certain protein components, lipids, vitamins or minerals than milk in a single serving, cheese more aptly replenishes the CNS with critical nutrients. For example, cheese may provide specific amino acids such as cysteine that are critical for glutathione production in a higher amount than milk[32]. Having adequate amounts of cysteine available for glutathione production during periods of inflammatory stress could allow the CNS to regulate any inflammation that arises and maintain homeostasis. In addition, providing lipids to the CNS so that neuronal cells and their signalling matrices are functioning optimally could be a secondary mechanism of action. The phospholipid components of the milk fat globule membrane, which is found in all fat-containing dairy products, may be one source of these necessary nutrients. Prior research has indicated that sphingolipids, which are found in the milk fat globule membrane, can dramatically affect neuronal growth and development[33]. However, their role in the maintenance of cognition is still not known. It is also possible that the consumption of other foods associated with cheese consumption (e.g. red wine), not adjusted for in the present analysis, may have also influenced the results, since these foods may contain compounds that have been suggested to affect cognition[34]. In addition, cheese intake may be an indicator of socioeconomic status and although we attempted to normalise this effect by adjusting for the poverty:income ratio, it is possible that the observed association could be driven by better general health. Once a better understanding of the role that specific nutrients and foods have in cognition is obtained, greater adjustment for these covariates can be utilised.

As an intervention to avoid deficits in cognition as the population ages, subtle changes in dietary intake are an attractive proposition. These changes could have dramatic effects on the loss of social functioning and lessen the economic impact of cognitive diseases without requiring too dramatic a shift in behaviour. In addition, nutrients or other bioactive compounds that are determined to have even a small effect via consumption may be very important to the development of more potent nutraceuticals or pharmaceuticals. As more information on food and cognitive function becomes available, it may be possible to tailor dietary advice for individuals at a significant risk for CNS-centric health issues. The present data indicate that more research on the ability of certain foods, such as cheese, to affect cognition is certainly needed.

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