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Relationships between Dietary Intake and Cognitive Function in Healthy Korean Children and Adolescents

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Background: It has long been theorized that a relatively robust dietary intake impacts cognitive function. The aim of the study was to explore dietary intake and cognitive function in healthy Korean children and adolescents.
Methods: Three hundred and seventeen healthy children with no previous diagnosis of neurologic or psychiatric disorders were evaluated (167 girls and 150 boys with a mean age of 11.8 ± 3.3 years). Analysis indicators including food frequency questionnaires (FFQs) consisting of 76 items and neurocognitive tests including symbol digit modalities (SDMT), verbal memory, visual memory, shift attention, reasoning, and digit span (forward and backward) tests were observed and recorded.
Results: The standard deviation in reaction time was significantly shorter in girls than in boys ($p < 0.05$). Verbal memory and SDMT percentile results were significantly higher in girls than in boys ($p < 0.05$). Vitamin C and potassium intake showed positive correlation with SDMT results ($p < 0.05$). Vitamin B1 intake showed positive correlation with the results of digit span forward tasks and SDMT ($p < 0.01$). Vitamin B6 intake showed positive correlation with the results of digit span forward tasks ($p < 0.01$). The consumption of noodles showed negative correlation with verbal memory, SDMT, shift attention, and reasoning test results ($p < 0.05$). The consumption of fast food showed negative correlation with SDMT and reasoning test results ($p < 0.05$). The consumption of Coca-Cola showed negative correlation with the results of verbal memory tests ($p < 0.05$). The consumption of mushrooms showed positive correlation with visual memory and reasoning test results ($p < 0.05$). The consumption of nuts showed positive correlation with SDMT results ($p < 0.01$). Omission errors were negatively correlated with the intake of protein, vitamin B1, vitamin B2, niacin, and vitamin B6 ($p < 0.05$), as well as with vitamin D and zinc intake ($p < 0.01$). Reaction time showed positive correlation with caffeine intake ($p < 0.05$). Omission errors were positively correlated with the consumption of rice and ramyeon ($p < 0.01$). Reaction time showed positive correlation with the consumption of snacks ($p < 0.05$). Standard deviations in reaction times showed positive correlation with the consumption of rice ($p < 0.01$), snacks, and chocolate ($p < 0.05$). Omission errors were negatively correlated with the consumption of rice with mixed grains ($p < 0.01$) and eggs ($p < 0.05$).
Conclusion: The relationship between dietary intake and cognitive function is generally better observed in girls than in boys. The consumption of healthy foods is correlated with good cognitive function. These results suggest that diet is closely related to cognitive function, even in healthy children and adolescents.

Key Words: Nutrition, Dietary intake, Cognitive function

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INTRODUCTION

Adequate brain function is a prerequisite for efficient cognition and the performance of organized behavior. Indeed, the uninterrupted activity of the brain is vitally important to the survival of an organism because it ensures the continuous performance of many essential voluntary and involuntary functions [1].

Balanced nutrition is very important in school-age children, which is a period of vigorous growth, increased activity, and the development of physical and cognitive functions. Food quality and good nutrition are related to brain development and cognitive function, which are important in childhood for health and well-being [2,3]. From the perspective of neuropsychology, adequate nutrition is essential for healthy brain functioning, optimal learning, and academic performance [4].

Numerous studies have been conducted about the beneficial and detrimental effects of specific nutrients and ingredients on cognition and behavior [5-8]. An existing review study focuses on four key dietary components in relation to neurocognitive functioning: 1) dietary fatty acids (including fish oil) and the Mediterranean diet, 2) antioxidants (including vitamins E and C), as well as fruits and vegetables, 3) vitamins B6 and B12 (cobalamin) and folate, and 4) caloric restriction [9]. Another study by Wolraich et al. finds that diets high in sucrose have no significant effects on behavior and cognitive performance in children [10]. Whether or not a child eats breakfast may impact nutrient intake and nutritional status, which, in turn, potentially impact cognition [11-13].

Recent years have seen a move away from analyzing the associations between isolated nutrients and brain health to an overall consideration of the effects of dietary behavior or patterns, such as the consumption of junk food or a Mediterranean diet (which is heavily loaded with fruits, vegetables, and fish) [14-17].

Looking at the potential effects of diet on learning in young people is of special importance. However, few studies have investigated the association between cognitive function and diet in Korean youth. The aim of this study is to explore the relationship between dietary intake and cognitive function in healthy Korean children and adolescents.

MATERIALS AND METHODS

1. Participants and ethics

This study was conducted at the Data Center for Korean EEG in Seoul from November 2012 to February 2014. Three hundred and sixty-one Korean children and adolescents applied spontaneously for this study. Following neurocognitive evaluation by experts and emotion evaluation via a survey, 44 applicants were excluded and 317 healthy children and adolescents were ultimately selected. The inclusion criteria for healthy subjects were the absence of pathology in the perinatal period, the absence of a history of neurological or mental diseases, head injuries, or convulsive/paroxysmal activity, and normal mental and physical development. We excluded subjects receiving abnormal scores of neurocognitive evaluation according to the symbol digit modalities test (SDMT) (Z score < -1), verbal memory tests, visual memory tests, shift attention tests, reasoning tests, and digit span forward/backward (F/B) tasks (Z score < -2 under one parameter or < -1.5 under three parameters). We also excluded subjects with abnormal scores of emotional evaluation according to the Children's Depression Inventory (CDI) and the State Trait Anxiety Inventory-Trait/State (STAI-T/S) scale (Z score < -2 under one parameter or < -1.5 under two parameters), as well as subjects with poor school achievement records, serious behavioral problems, and a history of abuse. Approval for this study was obtained from the Institutional Review Board of Seoul National University (SNUCM/SNUH), and informed consent was obtained from each participant and his/her parents prior to commencement of the study.

2. Anthropometric measurements

Anthropometric data were gathered using standard methods. Body weight (kg) and height (cm) were measured to the nearest 0.1 kg and 0.1 cm, respectively. A percent value of ideal body weight (PIBW) was calculated for each subject using data from the Korean National Growth Chart (Korea Centers for Disease Control and Prevention, 2007) for a standard body weight for height [18].

3. Food frequency questionnaire (FFQ)

Typical dietary intake was assessed by a modified version of a semi-quantitative food frequency questionnaire (FFQ), which was designed by the Korea Centers for Disease Control and Prevention (Cheongwon-gun, Republic of Korea) developed for children and adolescents regarding the consumption of food additives (caffeine, sodium saccharin, aspartame, and acesulfame K) [19-21]. This FFQ investigates the frequency of consumption and portion size of 76 food items commonly consumed by children and adolescents. Using the Computer Aided Nutritional (CAN) PRO 4.0 analysis software program developed by The Korean Nutrition Society (Seoul, Republic of Korea), an amount of each food item included on the FFQ was converted into grams, from which the daily intake was calculated in terms of nutrients.

4. Cognitive function tests

1) Neurocognitive tests

A computerized cognitive assessment battery termed CNS Vital Signs (CNSVS) is used in clinical research in psychiatric settings. The CNSVS battery comprises six common neuropsychological measures, including verbal and visual memory tests, a symbol digit modalities test (SDMT), shift attention tests, reasoning tests, and digit span forward and backward tasks.

2) Visual continuous performance test (vCPT)

A modification of the visual two-stimulus GO/NOGO paradigm was used. The task consisted of 400 trials presented to a subject every three seconds. In the task, we selected four categories of stimuli including (1) 20 different images of animals—subsequently referred to as A, (2) 20 different images of plants—P, and (3) 20 different images of humans presented together with an artificial, novel sound —Hs. Trials consisted of the presentation of a pair of stimuli with an inter-stimulus interval of 1,100 ms. The four categories of trials were A-A, A-P, P-P, and P-Hs. The trials were grouped into four sessions with 100 trials each. In each session, a unique set of five A stimuli, five P, and five Hs stimuli was selected. Each session consisted of a pseudo-random presentation of 100 pairs of stimuli with equal probability for the presentation of each category and each stimulus. The task required subjects to press a button with their right hand to indicate all AA pairs as rapidly and as accurately as possible. Subsequently, AA pairs will be referred to as GO (+) trials, and AP pairs will be referred to as NOGO (−) trials. The subjects were instructed only to press the button in (+) trials, whereas they were told they must not press the button in (−) trials.

5. Statistical analyses

All data analyses were performed using Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM, New York, NY, USA). Data are expressed as the mean value ± standard deviation for continuous variables. Comparisons of males and females were analyzed with independent *t-tests*. Partial correlation analysis (adjusted for age and total calorie intake) was conducted so that correlation between FFQ data on the consumption of foods (grams) and nutrition and cognitive function could be determined. All tests were two-tailed, and p-values of < 0.05 were considered to represent statistically significant differences.

RESULTS

Ages of subjects ranged from 6-18 years at the time of the cognitive function tests. The mean ages of girls and boys were 11.6 ± 0.3 and 12.0 ± 0.3, respectively. The standard deviation of reaction time in the GO/NOGO test was significantly smaller in girls than in boys. Girls scored significantly higher than boys on the SDMT and verbal memory tests (Table 1).

In exploring the relationships between discrete nutrients or food additives and various domains of cognitive function, vitamin B1 was shown to significantly correlate with digit span forward and shift attention test scores. In addition, vitamin B6 significantly correlated with digit span forward scores, and SDMT scores significantly correlated with vitamin C and potassium intake (Table 2). Table 3 shows significant correlations between cognitive function tests and the consumption of specific foods in greater detail. With increased consumption of noodles, verbal memory, SDMT, shift attention capacity, and reasoning scores worsened significantly in all subjects. Coca-Cola negatively correlated with verbal memory function. Overall fast food intake negatively correlated with SDMT and reasoning capacity. On the other hand, mushroom consumption positively correlated with visual memory and reasoning capacity. Meat and poultry also positively correlated with both forward and backward digit span test scores in subjects.

There were many more significant correlations between the results of the GO/NOGO visual continuous performance

Table 1. Anthropometric measurements and cognitive function test data, stratified by gender

	Total (N = 317)	Boys (n = 150)	Girls (n = 167)	p-value
Age (year)	11.8 ± 3.3[1)]	11.6 ± 3.3	12.0 ± 3.3	0.316[2)]
Height (cm)	147.9 ± 16.0	149.3 ± 18.5	146.7 ± 13.3	0.152
Weight (kg)	43.8 ± 16.0	45.4 ± 18.3	42.3 ± 13.6	0.094
PIBW (%)[3)]	102.4 ± 16.6	102.7 ± 17.6	102.0 ± 15.7	0.714
Omission errors	7.3 ± 9.6	8.0 ± 10.7	6.7 ± 8.5	0.244
Commission errors	2.6 ± 4.9	3.1 ± 5.3	2.1 ± 4.4	0.071
RT	422.5 ± 107.3	428.8 ± 106.3	417.0 ± 108.2	0.337
STD_RT	11.5 ± 4.4	12.1 ± 4.5	11.0 ± 4.3	0.034
DS_F	7.1 ± 1.8	7.1 ± 1.8	7.2 ± 1.9	0.650
DS_B	5.1 ± 1.9	5.2 ± 2.0	5.1 ± 1.9	0.554
Verbal M	70.0 ± 28.1	66.5 ± 28.9	73.1 ± 27.2	0.040
Visual M	65.8 ± 26.6	62.7 ± 27.0	68.5 ± 26.1	0.057
SDMT	80.7 ± 24.8	76.1 ± 28.2	84.8 ± 20.7	0.003
Shift attention tests	71.2 ± 24.3	71.0 ± 23.1	71.3 ± 25.4	0.928
Reasoning tests	56.6 ± 28.6	56.3 ± 29.3	56.9 ± 28.0	0.848

1) Mean ± SD.
2) Significant difference between groups as determined by independent t-tests, $p < 0.05$.
3) Percentage of ideal body weight (PIBW) calculated using the ideal body weight estimated by the Korea Centers for Disease Control and Prevention (2007).
RT: Reaction time, STD_RT: standard deviation of reaction time, DS_F, DS_B: digit span forward and backward, verbal M, visual M: verbal and visual memory tests, SDMT: symbol digit modalities test.

Table 2. Partial correlation between intake of nutrition and neurocognitive tests, adjusted for age

	DS_F	DS_B	Verbal M	Visual M	SDMT	Shift attention test	Reasoning test
Total calorie (kcal)	−.044	−.063	−.073	−.066	−.041	−.059	−.061
Carbohydrate (g)	.075	.056	.029	−.057	.058	.029	.025
Lipid (g)	−.051	−.057	−.018	.037	−.018	−.007	−.059
Protein (g)	.017	−.039	−.023	.046	−.012	−.010	.012
Vit C (mg)	.088	−.022	.089	−.113	.143*	.037	−.032
Vit B1 (mg)	.233**	.101	.106	−.076	.202**	.100	−.019
Vit B6 (mg)	.176**	.087	.082	−.011	.110	.060	−.021
Folate (ug)	.035	−.069	.062	−.062	.105	.043	.009
Potassium (mg)	.103	−.036	.044	−.034	.137*	.059	−.024
Caffeine (mg)	−.074	−.024	−.070	.087	−.055	−.041	.051
Artificial sweeteners (mg)	.061	.055	−.025	.017	.017	−.052	−.030

Significant difference by partial correlation, adjusted for age $*p < 0.05$, $**p < 0.01$.
DS_F, DS_B: Digit span forward and backward, verbal M, visual M: verbal and visual memory tests.

test and nutrients or specific foods. The consumption of protein, vitamin D, vitamins B1, 2, 6, niacin and zinc was negatively correlated with omission errors, which indicate inattention. Prolongation of reaction time positively correlated with caffeine consumption, whereas, inconsistency in reaction time (expressed by its standard deviation) negatively correlated with the consumption of vitamin E (Table 4). Consumption of white rice and ramyeon significantly increased both omission and commission errors. On the other hand, the consumption of rice with mixed grains significantly decreased omission errors. The consumption of fast food increased commission errors, and the consumption of snacks prolonged reaction time. Consistency in reaction time was highly related to the intake of many kinds of foods. As the consumption of white rice, snacks, and chocolate increased, consistency in reaction time worsened. In

Table 3. Partial correlation between intake of food and neurocognitive tests, adjusted for age and total calorie intake

	DS_F	DS_B	Verbal M	Visual M	SDMT	Shift attention test	Reasoning test
Rice (raw) (g/day)	−.029	.008	.032	.020	−.063	−.062	.034
Rice with mixed grains (raw) (g/day)	.073	.073	−.018	−.043	.076	.027	.005
Noodles (g/day)	.033	−.025	−.127*	−.067	−.126*	−.146*	−.122*
Meat · poultry (g/day)	.129*	.140*	.075	.029	.013	.040	.055
Mushrooms (g/day)	.081	−.013	.014	.139*	.027	−.044	.116*
Dairy products (g/day)	−.012	−.100	−.088	−.072	−.011	−.165**	−.044
Nuts (g/day)	.046	−.012	.018	.106	.154**	.095	.069
Coca-Cola (g/day)	.085	.103	−.123*	.048	.048	.056	.024
Fast food (g/day)	−.079	−.074	.012	−.084	−.134*	−.016	−.119*

Significant difference by partial correlation, adjusted for age and total calorie intake, *p < 0.05, **p < 0.01.
DS_F, DS_B: Digit span forward and backward, verbal M, visual M: verbal and visual memory tests.

Table 4. Partial correlation between intake of nutrition and event-related potential data, adjusted for age

	Omission errors	Commission errors	RT	STD_RT
Total calorie (kcal)	.063	.067	.079	.040
Carbohydrate (g)	.035	−.023	.049	.041
Lipid (g)	−.022	−.002	−.021	−.030
Protein (g)	−.125*	.005	−.096	−.070
Vit D (ug)	−.167**	−.104	−.060	−.066
Vit E (mg)	−.067	−.002	−.059	−.123*
Vit B1 (mg)	−.131*	−.068	−.016	.005
Vit B2 (mg)	−.135*	−.080	−.001	−.015
Niacin (mg)	−.129*	−.008	−.111	−.110
Vit B6 (mg)	−.123*	−.068	−.026	−.063
Folate (ug)	−.064	−.043	−.024	−.046
Iron (mg)	−.018	−.040	−.074	−.113
Zinc (mg)	−.149**	−.034	−.082	−.084
Caffeine (mg)	.067	.014	.117*	.071
Artificial sweeteners (mg)	−.016	−.001	.052	.017

Significant difference by partial correlation, adjusted for age *p < 0.05, **p < 0.01.
RT: Reaction time, STD_RT: standard deviation of reaction time.

Table 5. Partial correlation between intake of foods and event-related potential data, adjusted for age and total calorie intake

	Omission errors	Commission errors	RT	STD_RT
Rice (raw) (g/day)	.221**	.133*	.099	.179**
Rice with mixed grains (raw) (g/day)	−.189**	−.089	−.047	−.078
Ramyeon (g/day)	.208**	.203**	−.021	.065
Meat · poultry (g/day)	−.071	.036	−.092	.008
Eggs (g/day)	−.145*	.027	−.022	−.079
Vegetables (g/day)	−.048	−.016	−.080	−.128*
Nuts (g/day)	−.052	−.053	−.029	−.151*
Fast food (g/day)	.108	.229**	−.089	.003
Snacks (g/day)	.093	−.004	.133*	.134*
Chocolate (g/day)	.007	−.064	.093	.149*

Significant difference by partial correlation, adjusted for age and total calorie intake, *p < 0.05, **p < 0.01.
RT: Reaction time, STD_RT: standard deviation of reaction time.

contrast, a greater intake of vegetables and nuts showed positive correlation with consistency in reaction time in all subjects (Table 5).

DISCUSSION

This study finds many meaningful correlations between food and nutrition intake and cognitive function in pediatric and adolescent subjects, which are rigorously measured herein by computer-based cognitive function tests and visual continuous performance tests. Widely recognized sources of good nutrition such as vitamins B1, B6, and C, rice with mixed grains, and mushrooms are positively correlated with better cognitive function. In contrast, processed carbohydrates such as white rice and noodles or fast food and Coca-Cola are negatively correlated with cognitive capacities. These findings support our understanding that nutrition and diet affect brain health and cognitive function.

Digit span tasks are utilized for testing short-term memory in subjects. The tasks involve the longest list of numbers that a person is able to accurately repeat. The forward or backward versions of this test refer to the order of numbers that a subject is expected to repeat in forward or backward sequence immediately following presentation. Verbal memory refers to a subject's capacity for language-based working memory, and visual memory refers to his or her capacity for sight-based working memory. The symbol digit modality test (SDMT) involves the matching of specific numbers with given geometric figures within 90 seconds. The SDMT is considered to be a highly sensitive test in distinguishing organic brain dysfunction form psychological problems. Lower SDMT scores indicate poor organic brain function. Shift attention tests are conducted to assess the overall executive function of the frontal lobe [22]. Higher omission error scores indicate a lack of attention, and higher commission errors mean higher impulsivity. Reaction time stands for the speed of information processing, and less variability in reaction time is related to better capacity to maintain consistent attention during vCPT [23].

When the relationships between each cognitive function test and discrete elements of nutrition were explored, it was observed that the digit span forward test is significantly correlated with vitamin B1 and vitamin B6. The symbol digit modality test is significantly correlated with vitamin C, vitamin B1, and potassium. Meat or poultry, which are foods that are rich in vitamin B1, are positively related to digit span tests (forward and backward). These findings support assertions that these specific nutrients and foods may enhance working memory function. Vitamin B1 or thiamine is sometimes referred to as "energy nutrition," playing an essential role in the production of energy. But it also works for the synthesis of neurotransmitters. Vitamin B6 works for the brain as an important coenzyme of synthesis for neurotransmitters and it is known to have protective effects against cognitive decline [9]. Omission errors are more significantly related to a variety of nutrients. As the intake of vitamin B complex, vitamin C, vitamin D, zinc, and protein increases, omission errors decrease. This finding implies that these nutrients enhance the attention capacity of subjects. Dopamine plays an essential role in maintaining attention and controlling impulsive behavior, and the dysfunction of dopamine usage can induce ADHD symptoms including inattention or hyperactivity [24]. Vitamin B6 and vitamin C act as coenzymes during the production of dopamine. If these vitamins are lacking, then dopamine production may decrease. On the other hand, caffeine intake positively correlates with prolonged reaction time, which means that caffeine may deteriorate the speed of information processing. Previous research reports that caffeine has stimulant effects on the brain, and can improve the speed of information processing [25]. Currently, many Korean students ingest caffeine-containing beverages to raise and maintain alertness [19]. Immediately following the intake of caffeine, its stimulant effects will elevate levels of alertness and will acutely hasten information processing. But our study shows that the habitual intake of caffeine may have adverse effects to the contrary over time.

Regarding the relationships between specific foods and cognitive function tests, a high intake of noodles significantly correlates with the impairment of verbal memory function, SDMT scores, executive function (as measured by shift attention tests), and reasoning. The consumption of fast food also correlates with the deterioration of SDMT and reasoning tests. Consumption of white rice and ramyeon is significantly related with increases in inattention and impulsivity. On the contrary, the consumption of rice with mixed grains is negatively correlated with omission errors, which means that consuming rice with mixed grains may have positive effects on attention. Much previous research has reported that refined sugars are related to mood or cognitive problems [10,26]. Our results support these previous findings. On the other hand, our data implies that when rice with mixed grains is consumed, the adverse effects of consuming white rice can be mitigated. Accordingly, we highly recommend that children and adolescents consume rice with mixed grains instead of white rice. In the findings of our study, the consumption of fast food and Coca-Cola is also related to poor cognitive function, especially in working memory, SDMT, and reasoning tests. The consumption of fast food also increases impulsivity [17]. Snacks and chocolate are shown to have negative effects on reaction time, as well as on consistency in reaction time. In contrast, vegetables and nuts show protective effects on consistency in reaction time.

Another interesting finding is that girls are superior to boys in terms of verbal memory, SDMT, and consistency in reaction time. There may be several tentative predisposing factors around this finding, but this result is observed over the scope of this study.

Our study verifies that there are various significant relationships between many nutrients, food additives, and specific foods and cognitive function. We were unable to conduct a prospective clinical trial to observe these relationships. But our study includes a great number of subjects, and all the cognitive functions are measured by standardized and sophisticated methods. We can conclude from our results that good nutrition and eating behaviors are highly related to good cognitive function in pediatric and adolescent subjects. On the contrary, bad foods and ingredients contribute to the deterioration of healthy brain function. To further clarify this association, a greater number of subjects and longitudinal research are needed in studies going forward.

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