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RESEARCH

A central role of nutrition in cognitive function among primary school children: a cross-sectional analysis

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Abstract

Background Childhood overweight and obesity have implications that extend beyond physical health. Despite evidence linking obesity to poorer cognition, the combined effects of weight status and dietary habits on cognitive function in children remain insufficiently studied. This study took a comprehensive approach investigating effects of weight status on cognition, incorporating socio-economic factors, parental anthropometrics, and detailed nutrition assessments in primary school children.

Methods Anthropometric measurements, cognitive testing and short interviews were performed in schools from October 2021 until July 2022 in the Rhein-Neckar region, Germany. Cognitive testing included the distractibility and flexibility modules of the PSYTEST KiTap battery, alongside a self-designed short-term memory assessment. Parents were asked to provide information on physical activity, socioeconomic status (SES) and nutrition (3-day food diary and a questionnaire). Pearson's correlations were used for normally distributed continuous data, and Spearman's correlations for nonparametric data Pearson's or Spearman's correlation coefficients were calculated based on data distribution.

Results A total of 256 children with a mean age of 8.0 years participated in the study. According to German growth reference tables, 16% were underweight, 75% normal weight, 5% overweight and 5% obese. Cognitive testing resulted in an average age- and sex adjusted performance. No significant correlations were found between any of the anthropometric variables collected and the cognitive domains studied. At the same time, cognition was associated with nutrition, physical activity and SES with strongest associations between reaction time in the flexibility task and fat consumption (R -0.35, $p < 0.001$), total kilocalories (R -0.30, $p < 0.001$) and protein (R -0.30, $p < 0.001$).

Conclusions The cognitive domains studied are not associated with anthropometric variables in primary school children. Nutrition appears to have strongest associations with cognition followed by other factors such as physical activity and SES. This study underlines the importance of nutrition for cognitive function and emphasizes the need

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to include nutrition in studies on cognitive performance and body weight status in schoolchildren. The study was registered at clinicaltrials.gov on September 21st 2021 under the registration number NCT05077059.

Keywords Nutrition, Schools, Psychometrics, Community child health, Pediatrics, Obesity, Child development, Cognitive flexibility, Distractibility, Memory

Introduction

Currently, one in five school-age children worldwide can be classified as overweight or obese, a figure that has more than doubled from 8% in 1990 to 2022 [1]. The consequences of childhood obesity and overweight are not limited to physical health but include psychiatric, psychological and psychosocial aspects [2, 3] affecting school absenteeism [4] and possibly even school performance [5]. The relationship between weight status and cognition is complex with numerous confounders such as nutrition, physical activity, socioeconomic status and parental education [6–8]. Current evidence suggests a bidirectional relationship between brain function and weight status. Cognitive functions and associated behaviors may influence weight, and weight status may in turn impact brain structure and function [6, 9–12]. These associations were specifically shown for both age and sex adjusted z-score of Body Mass Index (zBMI) and also for visceral adipose tissue measured using dual-energy x-ray absorptiometry (DEXA) or magnetic resonance imaging (MRI) [13, 14] and at the same time interventions targeting overweight and obesity in children appear to benefit both weight status and cognitive function [15]. The "brain as a risk factor" perspective suggests that higher level cognitive functions such as cognitive flexibility and inhibition play a central role in resisting temptations in an obesogenic environment with a high availability of palatable and instantly rewarding foods [16] and also may impact physical activity [11, 17, 18]. The influence of weight status on cognition may on the other hand be mediated by proinflammatory adipokines and cytokines secreted by excess adipose tissue, crossing the blood-brain barrier and prompting morphologic changes in the brain [12]. While the causality is debated and may cut both ways, the interrelation appears to manifest itself in morphological differences between healthy and obese children and adults in the prefrontal cortex, grey matter, amygdala, nucleus accumbens as well as in differences in cortical activity [9, 12, 19, 20].

Although nutrition is a central factor influencing both weight status and cognition, most studies that investigate these outcomes do not account for dietary measures, which are cumbersome to assess. After adjustment for potential confounders, associations between cognition and anthropometrics may weaken or are lost, as seen for example in a study by Black et al. where sociodemographic confounding factors played an important role [6]. In a study by Marinho et al., that included detailed information on nutritional patterns, the link between nutrition and cognition did not appear to be mediated by adiposity in children [21].

With the goal of exploring the relationship between weight status and cognition, three cognitive tests were chosen for this cross-sectional study. The data was collected alongside weight status, nutrition, physical activity, socioeconomic status and other variables known to influence weight status in primary schoolchildren. The cognitive domains studied are flexibility, distractibility and short-term memory. Cognitive flexibility is an executive function and resembles the capability of an individual to adapt to changing circumstances and readjust focus, which is known to be associated with weight status [9, 11, 22]. Distractibility is a component of attention regulation and tests susceptibility to diverting attention, which is related to attention deficit and executive functions [23]. Short-term memory is responsible for temporarily holding and processing a limited amount of information for a short period of time, typically from a few seconds to a minute [24] and related to working memory and executive functions [25].

The aim of this study is to examine how weight status, nutritional intake, physical activity, and socioeconomic status are related to cognitive function in primary school children - specifically, cognitive flexibility, distractibility, and short-term memory.

Materials and methods

Between October 2021 and July 2022 schools were selected and contacted in cooperation with the local health authority with the intent of including children from different socioeconomic backgrounds. Approximately 60 schools were invited to participate with 31 schools agreeing to participate. All children attending the second grade at the schools contacted, were invited to participate. The inclusion criteria were written consent from legal guardians, age between 7 and 9 and the presence of the child at school on the day of the study visit. Children were weighed and tested in small groups in the schools with the individual logistics optimized for each school and number of participating children. Cognitive functions studied included the executive function cognitive flexibility as well as distractibility and short-term memory. Flexibility and distractibility tests were computer based and used the KiTAP test battery developed by PSYTEST (Psychologische Testsysteme, Herzogenrath, Germany), which is widely used in German speaking countries [26–30]. The tests were designed to be playful and perceived as a computer game by the children. The testing was performed adhering to the developer's manual. The simple short-term memory test was designed specifically for this study and consisted of eight items to be memorized by the child (chocolate, cat, pizza, guitar, lemon, fire-fighter truck, fork, and classroom), presented both visually (card with picture) and verbally and to be repeated directly after the items having been shown and 5 min later.

The KiTAP flexibility module is designed to assess cognitive flexibility by a task, which requires adaptation to changing stimuli– specifically, the children were instructed to swiftly switch between blue and green dragons according to their color in an alternating manner with the dragons randomly appearing at one of two different locations, using dedicated buttons provided by the test. This test is assessed using age and sex normalized T-values (as per manufacturer's specifications) for total number of errors, median reaction time, overall performance and speed-accuracy trade-off. T-values are interpreted similarly to percentiles and were derived by the test manufacturer based on a sample of 620 children aged 6–7 and 599 children aged 8–12 with 50 being an average performance higher values representing better performance.

The KiTAP distractibility module requires the child to focus on a certain screen area (a window of a castle), in which a ghost figure briefly appears with either a smiling or frowning facial expression (critical stimulus) at random intervals for brief moments. Additional distractive stimuli (other fantasy creatures) appear at some distance from the ghost area to potentially distract the child, who is instructed to swiftly press a dedicated button, when the briefly appearing ghost is frowning. This test was assessed by evaluating the omission difference (OD) and the T-value for the total number of errors. OD represents the effect of distractive stimuli (as per manufacturer's specifications). Half (20) of the 40 critical stimuli in the test include a distracting stimulus– thus the theoretical value range is between −20 (if only all stimuli without a distractor were missed/omitted) and +20 (if only all stimuli with distractor were missed). A large positive value indicates an increased distractibility, since a reaction to the critical stimulus was more frequently omitted in the case of the presence of a distracting stimulus. The test was standardized by the manufacturer on the basis of a sample of 785 children aged 6–7 and 1,112 children aged 8–12.

Anthropometric measurements, including weight and height, were conducted using calibrated SECA 877 and SECA 899 scales, along with a SECA 437 adapter and a SECA 217 height measurement ruler, following the manufacturer's instructions. Children were asked to remove their shoes and any bulky jackets before being weighed. German national guidelines set cut offs at 90th percentile for overweight and 97th percentile for obesity as well as 10th percentile for underweight [31].

Nutrition was assessed using two tools: a 3-day food diary and a self-designed food questionnaire (provided in Annex 1). Parents received detailed written instructions on how to fill out the food diary with an example page and could contact the team via phone or e-mail if they had questions. The instructions included recommendations on how to specify the quantity e.g. bread in slices, drinks as 150-200 ml glasses, soup as scoops of around 150 ml. The food diary entries were entered into PRODI® Software (version 6.1.1, Nutri-Science GmbH, Freiburg Germany, 2022, https://www.nutri-science.de) for analysis. PRODI® Software uses the German Nutrient Database (Bundeslebensmittelschlüssel) to on one hand provide the macronutrient and micronutrient composition of all foods consumed, at the same time providing 22 food group categories (1. beef, veal, pork, mutton; 2. sausage, meat products; 3. game, poultry, offal; 4. fish, crustaceans, shellfish, mollusks; 5. eggs and egg products, pasta; 6. milk and milk products, cheese; 7. menu components, predominantly animal; 8. oils, fats, butter, lard; 9. legumes; 10. fruits, fruit and fruit products; 11. vegetarian foods; 12. menu components, predominantly vegetable; 13. vegetables and vegetable products; 14. grains and grain products, rice; 15. potatoes and starchy foods, mushrooms; 16. bread and pastries; 17. long-life baked goods, cake, pastries; 18. confectionery, sugar, ice cream; 19. dietary foods; 20. spices, seasonings, additives; 21. non-alcoholic beverages; 22. infant and baby food). In order to further explore the data for potential patterns, the 22 food group categories were clustered into plant-based foods overall (obviously plant-based categories 9–15), carbohydrate-rich foods (14–18), meat and fish (1–4), animal products total (1–7), animal products non-meat (5–7). The food categories were then analyzed on their own and in clusters. The food questionnaire captured more general food patterns such as adherence to special diets, frequency of the consumption of food cooked at home and at restaurants as well as a detailed consumption of drinks and water (queried as 150–200 ml portions). Information on supplements or medication taken by children was not collected and thus micronutrient data may not be precise and is thus only included in the supplementary tables as shown in Annex 2.

Physical activity was assessed using a questionnaire directed towards parents (see Annex 3) and a questionnaire filled out by the study team in a short interview based on the Physical Activity Questionnaire for Children (PAQ-C) together with the child [32] with a total score being the central variable for the PAQ-C and times spent in different activity levels (sports, sedentary activity, sleep and other) being the outcome variables for the questionnaire directed at parents (See Annex 4).

Parents' anthropometrics were collected via a further questionnaire including the highest level of education attained by parents as well as their monthly net household income and migration background. A total socioeconomic status score for within group ranking was calculated similar to the procedure described in the KiGGS Study [33]. Highest education level of the father and mother each being assigned a score between 1 and 6 as well as the household income with ranging from 1 to 5, resulting in a maximum total score of 17. The questionnaire is provided in Annex 5.

Data was tested for normality using the Kolmogorov-Smirnov test, if both variables were normally distributed, Pearson's correlations were calculated, if at least one of two variables was not normally distributed, Spearman's correlations were calculated. IBM SPSS Statistics Version 29 (IBM Corp, Armonk, New York, United States) was used for analyses in this study. Due to the heterogeneous nature of the collected data which included anthropometrics, cognitive tests, nutritional diaries, physical activity assessments, and socioeconomic information data imputation was not performed. Imputing missing values could have led to bias or distort the complex relationships within these varied datasets. Therefore, analyses were restricted to individuals with complete data sets in regards to the reported variables to preserve data integrity. The number of available datasets for variables in question is reported alongside results.

Results

The study was conducted between October 2021 and July 2022. Due to the ongoing pandemic situation and lockdown measures, the study had to be paused from January 2021 to April 2022. Study visits could be conducted in 24 out of the 31 schools agreeing to participate with 1,401 potential participants. Ultimately, participation consent was obtained from 256 children (18%), with participation rates varying between 4% and 47% per school.

The study population ($n = 255$) showed an average overall performance in the flexibility task (mean T-value 50.5) with slightly more than average number of errors (mean T-value 47.5) but at the same time a slightly over average reaction time (mean T-value 53.6). This was also reflected in the speed-accuracy trade-off index (mean T-value 45.0; speed over accuracy preference corresponds to lower T-values). Mean T-value for errors in the distractibility task was slightly below average with a mean test value of 47.1. The mean omission difference was 1.4, meaning that the distractors provoked on average 1.4 errors more when presented together with the critical stimulus as compared to the critical stimulus on its own. Participants could memorize an average 5.19 items (from 8 possible) in the first round and recall 4.54 items 5 min later.

Anthropometric data was available for all 256 children. Mean age was 8.0 years. The mean zBMI was – 0.25 (range: -3.8 to 3.0). According to national growth standards, 40 children (15.6%) were underweight, 191 (74.5%) had a normal weight, 12 (4.7%) were overweight, and 13 (5.2%) were obese.

The food questionnaire was returned for 172 children, Parents reported a mean total fluid intake of 5.9 (Standard Deviation (SD) = 2.2) portions per day, which equates to about 0.89–1.18 L daily, 77.0% as water, 8.0% as cow's milk, 7.5% as juice and 7.5% as others. The food diary was returned from 142 households. Macro nutrient and micronutrient perspective obtained by analyzing the 3-day food diary can be found in Table 1. Food category and food group perspective is presented in Fig. 1.

Of the 256 children a PAQ-C interview for physical activity was conducted with 254 children, after exclusion of participants due to high number of unanswered questions, 193 questionnaires available for evaluation. The values obtained in the questionnaire ranged between 1.56 and 4.22. The mean total PAQ-C score was 3.04 points (SD = 0.55). According to the total scores 138 (71.5%) could be classified as active (above 2.75) and 55 (28.5%) as inactive (below 2.75). Data availability for the parent questionnaire varied depending on the question between 150 and 174 due to some questions being left out. In median, children were active for at least 60 min 5 days a week (interquartile range (IQR): 3–7) with a median 96 min (mean 106 min) of physical activity per day (IQR: 80–122) and with 97% of children reaching the World Health Organization (WHO) recommendation

Table 1 Macronutrient consumption from food and drink as calculated from the data supplied in the 3-day food diary. Values not reaching or exceeding recommendations of the German Society for Nutrition (DGE) are highlighted red

***n* = 142**	**Min**	**Percentile**			**Max**	**RDA**
		25	**50**	**75**		
Kilocalories	828	1170	1308	1494	2359	1500–2100
Carbohydrates %	35.6	48.0	52.2	55.8	64.1	> 50
Sugar in g	17.8	45.3	56.6	70.8	157.9	< 24 g / 10% of calories
Protein in g	22.5 (8.0%)	35.9 (11.9%)	42.3 (13.1%)	49.6 (14.1%)	66.5 (20.2%)	> 26 g
Fat %	20.2	28.8	32.3	37	48	30–35
Dietary fiber in g per 1000 kilocalories	1.1	7.8	9.9	12.1	21.5	> 14.6

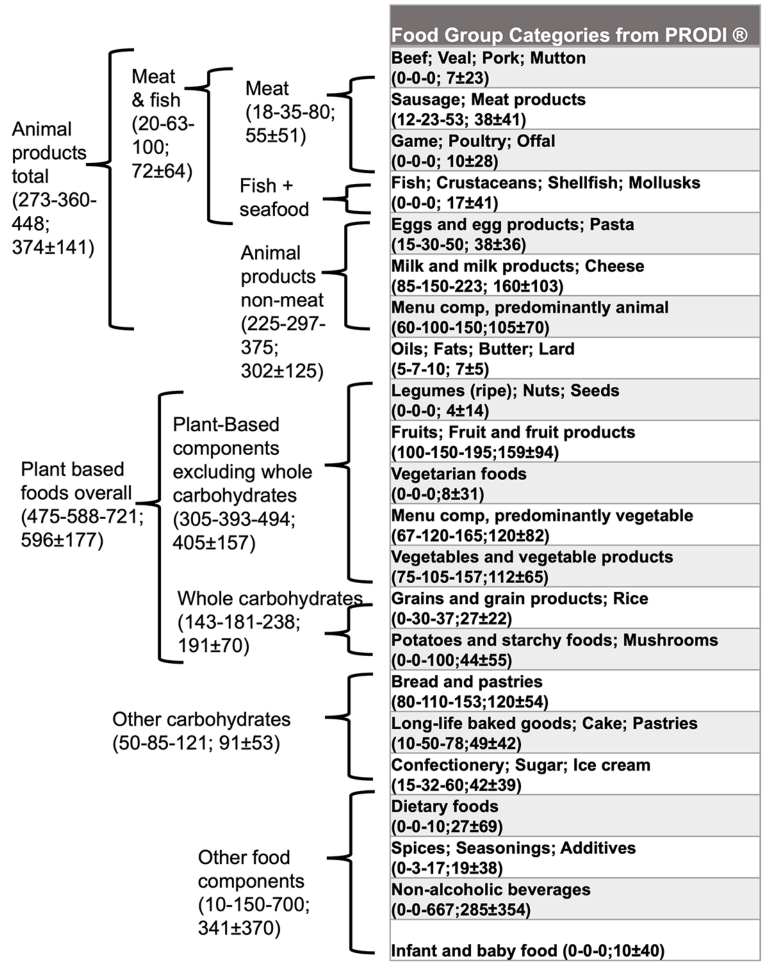

Fig. 1 Food group categories from Prodi® Software and food group clusters, which were used for the analysis are listed here. Food quantity estimates for categories and category clusters are listed in grams per day and presented as 25th percentile– median– 75th percentile; mean ± SD

of average physical activity of 60 min per day or more and 89% as active and 11% as inactive based on the former WHO criterion of at least 60 min of physical activity every day [34]. The median screen time was 45 min (IQR: 30–60) and time reading or listening to stories was 30 min in median (IQR: 30–60). Children slept in median 10 h a night (IQR: 9.5–10.5). On average physical activity and sedentary behavior constituted 7.4% and 6.6% of the day, sleep accounted for up to 40.9% of the day and 45.4% consisted of other activities.

Socioeconomic data was available for $n = 179$ children. Household net income was over 4000€ in 67% with only 4% having an income below 1800€. 59.9% of mothers and 55.1% of fathers had a university degree. In 91% of the participants, both parents lived in the same household as the child. In 77% of the households, German was the only spoken language, 21.4% of children spoke two languages at home, in only 1.7% of the cases German was not spoken at home at all.

Childrens zBMI had strongest correlations with the BMI of father (0.28, $p < 0.001$, parametric) and mother (0.24, $p = 0.002$, parametric) as well as weak positive correlations with cow's milk intake (0.18, $p = 0.020$, nonparametric), total fluid intake (0.16 $p = 0.035$, nonparametric), animal products total (0.16, $p = 0.050$, nonparametric) and animal products non-meat (0.18, $p = 0.028$, parametric) as well as saturated fatty acids (0.17, $p = 0.047$, nonparametric); higher SES and both parents living in the household correlated with a lower zBMI, but no associations were found with cognitive variables collected.

Associations found between nutrition and cognition variables were strongest (up to 0.35, $p < 0.001$, non-parametric between fat intake and reaction time in the flexibility task) when correlations between variables of the same cognitive test were not considered. Correlations between nutrition and cognitive flexibility were strongest (see Table 2) followed by memory (see Table 3) and distractibility (see Table 4). There were strong correlations within the flexibility domain, correlations between

Table 2 Correlations between central variables in the flexibility task and nutritional variables. All listed correlations are significant ($p < 0.05$). Positive correlations are associated with better performance. For normally distributed variables Pearson's correlations were calculated, Spearman's correlations were calculated for non-normally distributed variables and are marked with a *

	Reaction time (t)	Errors (t)	Overall performance (t)	Speed-accuracy trade-off (t)
Macronutrients				
Fat	-0.35	-	-	0.32
Protein	-0.30	-	-0.22	0.21
Kilocalories	-0.30	-	-0.19	0.23
Fat %	-0.22	-	-	0.25
Carbohydrates %	0.20 *	-	-	-0.21 *
Food Groups				
Meat	-0.24	-	-	-
Plant based overall	-	-0.20 *	-0.20	-0.21
Animal based non-meat	-	-	-	0.18
Animal based total	-	-	-	0.22 *
Plant based total excluding whole carbohydrates	-	-0.26 *	-	-0.21 *
Nuts and legumes	-	-0.17 *	-	-
Oil, fat, butter lard	-	0.17 *	-	-
Foods				
Soft drinks	-	-0.17 *	-0.23 *	-

Table 3 Spearman's correlations between central memory variables and nutritional variables. All listed correlations are significant ($p < 0.05$). Positive correlations are associated with better performance for memory round 1 and round 2 as well as less forgotten items

	Memory round 1	Memory round 2	Items forgotten between 1 and 2 (inverse)
Food Groups			
Plant based overall	0.19	-	-
Carbohydrate-rich foods	0.20	-	-
Meat and fish	-0.17	-	-
Animal products total	-0.21	-	0.21
Animal products non-meat	-0.22	-	0.22
Oil, fat, butter lard	-	-	0.21
Foods			
Sugar free soft-drinks	-	-0.18	-

cognitive domains were weak. The same was the case for correlations between physical activity and other collected variables. In general, better performance in one cognitive test was associated with better performance in other cognitive tests. Significant correlations between central flexibility variables and other variables are shown in Table 5. Significant correlations between distractibility variables and other variables are shown in Table 6. Significant correlations between memory variables and other variables are shown in Table 7. Correlations in tables are presented in a way that positive correlations represent better performance in cognitive tests, for this the variable omission difference and items forgotten were inverted. Associations with micronutrients are available in the supplement tables.

Table 4 Spearman's correlations between central distractibility variables and nutritional variables. All listed correlations are significant ($p < 0.05$). Positive correlations are associated with better performance for total errors and inverse of omission difference

	Total Errors (t)	Omission Difference (inverse)
Food Groups		
Oil, fat, butter lard	-	0.19
Foods		
Soft Drink Consumption	-0.19	-0.18
Water	-	0.18

Discussion

In this study, the strongest correlation (0.35, $p < 0.001$, nonparametric) was observed between cognitive performance (specifically, reaction time in the cognitive flexibility test) and dietary fat intake. Pronounced correlations were found for other nutrition variables as well (see Tables 2, 3 and 4). The link between cognition and nutrition appeared more robust than correlations between any of the three cognitive domains studied between themselves (strongest correlation here was 0.022, $p < 0.01$ between the t-value for total errors in the distractibility task and the speed-accuracy-trade off t-value in the flexibility task). These results emphasize the importance of nutrition for cognition in children. In this study, which included mainly normal weight children, we did not find significant correlations between the cognitive domains studied and anthropometric data collected, although both were influenced by similar factors. Nutrition showed the strongest associations with cognition, despite the smaller sample size for dietary data compared to the anthropometric data (which was available for all participants). This finding is consistent with some of the previously published data [6, 21]. At the same time, despite the participating children belonging to families with above average incomes and a high percentage of the parents holding a university degree, the analysis of their 3-day food diaries suggests an inadequate nutrition, when compared with the recommendations of the German Society for Nutrition– insufficient calories, excessive sugar intake and insufficient fiber intake.

Nutritional patterns were associated with different performance and even strategies applied during the cognitive testing. This was mostly apparent in the

Table 5 Correlations between the central variables in the flexibility task with other collected variables, all listed correlations are significant ($p < 0.05$). For normally distributed variables Pearson's correlations were calculated, Spearman's correlations were calculated for non-normally distributed variables and are marked with a *

Correlations with Flexibility Errors (t)	*R*
Cognition	
Flexibility - Overall performance index (t) *	0.77
Flexibility - Speed-accuracy trade-off index (t) *	0.71
Memory items Round 1 *	0.15
Memory items Round 2 *	0.18
Distractibility / Total errors (t) *	0.19
Physical activity	
Total physical activity per day *	-0.21
PAQ-C Score *	-0.17
Other	
Age of mother *	-0.23
Age of father *	-0.17
Mother's education level *	0.16
Correlation median reaction time flexibility (t)	
Cognition	
Flexibility - Overall performance index (t)	0.65
Flexibility - Speed-accuracy trade-off index (t)	-0.65
Other	
BMI of father *	-0.20
Correlations flexibility - overall performance index (t)	
Cognition	
Flexibility - Errors (t) *	0.77
Flexibility - Median (t)	0.65
Flexibility - Speed-accuracy trade-off index (t)	0.13
Physical Activity	
PAQ-C Score *	-0.22
Other	
Mother's age *	-0.15
Father's age *	-0.20
Correlations for flexibility - speed-accuracy trade-off index (t)	
Cognition	
Distractibility / Total errors (t) *	0.14
Flexibility - Errors (t) *	0.71
Memory items round 2 *	0.13
Flexibility - Median (t)	-0.65
Flexibility - Overall performance index (t)	0.13

flexibility task, where consumption of more total calories, fat, protein as well as meat in general were associated with longer reaction times and the strategy of prioritizing precision over speed (positive association with the speed-accuracy trade-off) and the consumption of plant-based components was associated with a higher number of errors and prioritizing speed over precision (negative association with the speed-accuracy trade-off). An additional noteworthy finding is the weak correlation between the soft drink consumption and worse performance in the flexibility and the distractibility tasks, which is compatible to findings in prior studies looking at effects of sugar sweetened beverages on cognition [35]. Despite the correlations being robust, specific conclusions on how nutrition could be optimized for cognition outcomes remains speculative. The findings presented warrant further research in this area and underline the importance of including nutrition in studies evaluating factors affecting cognition in children. At the same time, this study defines a role of nutrition in childhood beyond obesity prevention. A shift in nutritional patterns as for example an increase of vegetarian and vegan diets among younger children in western countries may have influences on their cognitive development.

Table 6 Correlations between the central variables in the distractibility task with other collected variables, all listed correlations are significant ($p < 0.05$). For normally distributed variables Pearson's correlations were calculated, Spearman's correlations were calculated for non-normally distributed variables and are marked with a *. Positive correlations signify better performance

Correlations with Distractibility / Total Errors (t)	*R*
Cognition	
Omission Difference *	-0.19
Flexibility - Errors (t) *	0.18
Flexibility - Speed-Accuracy Trade-Off Index (t)	0.20
Correlations with Distractibility Omission Difference (inverse)	
Cognition	
Memory Items Round 2 *	0.15
Distractibility / Total Errors (t) *	0.19

Table 7 Spearman's correlations between the number of items remembered in round 2; all listed correlations are significant ($p < 0.05$). Positive correlations signify better performance

Correlations with Memory Items Round 1	*R*
Cognition	
Memory Items Round 2	0.60
Number of items forgotten (inverse)	-0.22
Flexibility Errors (t)	0.15
Correlations with Memory Items Round 2	
Cognition	
Memory Items Round 1	0.60
Number of items forgotten (inverse)	0.52
Flexibility - Errors (t)	0.18
Flexibility– overall performance index (t)	0.13
Flexibility– speed-accuracy trade-off	0.13
Distractibility– omission difference (inverse)	0.15
Correlation with number of items forgotten (inverse)	
Cognition	
Memory items Round 1	-0.22
Memory items Round 2	0.52
Other	
Age of mother	0.15

Nutrition is central for brain function from early childhood [7, 36] into senescence [37]. For schoolchildren, dietary quality and diversity have previously been shown to predict academic performance [38, 39]. Regular school meals were shown to consequently improve cognitive function, school performance, BMI [40–44] as well as quality of life [45, 46]. This study suggests a direct influence of nutrition on the cognitive performance in second grade children, highlighting the necessity of better understanding the link between nutrition and cognition and how it can be leveraged to benefit them in the context of schools. Further evidence in this field could be generated by monitoring cognitive function and school performance when implementing school food policies.

The implications of the data presented are limited by the fact that it is cross-sectional and based on food diaries which strongly depended on compliance of the parents. Only 55% of the participants delivered food diaries resulting in potential bias, since e.g. more health-conscious households may have been overrepresented. At the same time, weight and zBMI do not seem to be substantially related to the cognitive domains studied based on the full and in normal-weight sample of 256 children,. To the authors' knowledge, while there are studies looking at influence factors like physical activity, certain aspects of nutrition such as sugar sweetened beverages on academic performance [35, 47–49] or supplementation in different scenarios, especially in undernourished children [48, 50, 51], no prior study assesses anthropometrics, physical activity and nutritional components and their relation to standardized cognitive tests in this age group.

Despite the above mentioned limitations, this study clearly defines a close relationship between nutrition and cognitive function in children and suggests that effects of nutrition on academic performance may be mediated via the effects of nutrition on cognitive functions.

Conclusions

In this cross-sectional study of second-grade children, certain nutrients were strongly linked to cognitive function, whereas anthropometric variables (such as zBMI) showed no clear association with cognition. The results warrant further studies, which should evaluate effects of children's diet and how this could potentially benefit cognition. The study also showed that current nutritional recommendations are not met even in children from a high socioeconomic background in Germany.

Abbreviations

DEXA	Dual-energy x-ray absorptiometry (DEXA)
DGE	Deutsche Gesellschaft für Ernährung (German Society for Nutrition)
IQR	Interquartile range
MRI	Magnetic resonance imaging
OD	Omission difference
PAQ-C	Physical Activity Questionnaire for Children
SES	Socioeconomic status
WHO	World Health Organization
zBMI	Age and sex standardized z-score of Body Mass Index

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40795-025-01016-2.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

Supplementary Material 5

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Author contributions

AS, MM, RS; RÖ, ES, PH were substantially involved in the study conception and design, AS, JG, and GG were centrally involved in collecting data in schools. AS, JG, GG and PH were centrally involved in data analysis. AS, JG, GG, MM, PH were involved in the data interpretation. AS, JG and PH drafted and revised the work. All authors read and approved the submitted version and agreed both to be personally accountable for the author's own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

The study was performed in accordance with the Declaration of Helsinki and approved by the local ethics committee (Ethikkommission der Landesärztekammer Baden-Württemberg, Aktenzeichen: F-2021-037) and the school authority (Regierungspräsidium Karlsruhe, Aktenzeichen: 71f1-6499.25). Individual informed consent from legal guardians/parents was necessary for participation.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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