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Differences in Executive Function and Brain-Derived Neurotrophic Factor Among School Children Across Three Thai Growth Reference Categories (Normal Weight, Overweight, and Obesity)

Keerati Intawachirarat[1], Witid Mitranun[1], Raweewan Maphong[2], Sonthaya Sriramatr[1]

[1]Department of Sports Science, Faculty of Physical Education, Sports, and Health, Srinakharinwirot University, Nakhon Nayok, Thailand, [2]Faculty of Sports Science, Chulalongkorn University, Bangkok, Thailand

ABSTRACT

Intawachirarat K, Mitranun W, Maphong R, Sriramatr S. Differences in Executive Function and Brain-Derived Neurotrophic Factor Among School Children Across Three Thai Growth Reference Categories (Normal Weight, Overweight, and Obesity). **JEPonline** 2024;27(4):1-18. The global prevalence of obesity in children has increased over time. Higher body mass index (BMI) is negatively correlated with executive function (EF) and brain-derived neurotrophic factors (BDNF). This study examined the differences in EF and BDNF levels among 66 students. A one-way multivariate analysis of variance was conducted to evaluate group differences, followed by descriptive discriminant analysis for *post-hoc* analysis. This study revealed that there were no significant differences in BDNF levels among school children categorized as normal weight, overweight, or obese. Additionally, children in the normal weight category did not exhibit a better overall EF than their overweight and obese counterparts, except for the EF component related to planning. Future studies should investigate the development of EF and BDNF among school children, and factors like family economic status and parenting practices that may influence these variables.

Key Words: BMI, Brain-Derived Neurotrophic Factor, Executive Function, Obesity

INTRODUCTION

Over the last decade, the prevalence of childhood and teenage obesity has increased worldwide (1). According to the World Health Organization (WHO), over 340 million children and adolescents aged 5 to 19 were overweight or obese in 2016 (51). The number of obese children rose to 44 million globally, and it is predicted that by 2025 there will be over 70 million obese children worldwide (34). Obesity in children is a developing problem in Thailand as it is in other countries due to the rapid socioeconomic development and modifications in eating habits. Tracking these developments requires the establishment of a single growth reference with suitable indicators and cutoff values. The Ministry of Public Health created the Thai Growth References (TGR) in 1999 that is focused on children's potential development. TGR measures overweight and obesity: Weight-for-height-Z-score (WHZ) >1.5 SD to 2 SD of the median was considered overweight, while WHZ >2 SD of the median was considered obese. Some survey results have also calculated prevalence using worldwide growth benchmarks for comparison with those of other nations (29).

Childhood and adolescent obesity continue to be major public health issues. Children who are obese will transform into more adults with non-communicable diseases (50). People with a heavier weight have deficits in the motor functions of the higher brain, including inhibition, working memory, planning, and cognitive flexibility (17). The development of EF is associated with cognitive function, which affects academic achievement and school readiness. Children with varying levels of executive function (EF) exhibit diverse behaviors, character traits, and levels of success in life (8). EF plays an important role in self-regulation and includes the ability to balance energy through proper dietary control and physical activity. Therefore, in people with EF deficiency, especially those who are obese, it results in behavioral problems, such as the inability to manage an environment conducive to balanced energy expenditure that results in being overweight (17).

Childhood obesity is negatively and selectively associated with the prefrontal inhibitory control (20). Moreover, obesity causes more working memory impairment than being overweight (38). Owing to a deficiency in higher-level executive functioning, particularly inhibitory control and working memory, children who are overweight and obese tend to have lower cognitive capabilities and academic accomplishments than children with normal weight (28,35). Obesity in children has been linked to cognitive dysfunction and EF measures are consistently altered. Neurotrophic factors play a key role in these changes, as they are related to certain brain processes negatively influenced by being overweight and/or obese (25).

Brain-derived neurotrophic factors (BDNF) is an important protein that is distributed within the brain, especially in the hippocampus and frontal lobes (33). This protein is crucial for the formation of new neurons, the survival of existing neurons, the stimulation of neurogenesis, and the control of neuroplasticity. It is a key protein that makes neurons alert and ready to perform the tasks necessary for learning. When neurons are active, they lead to cognitive and executive functions, including thinking, problem-solving, decision-making, planning, and learning new things (19). Obese individuals have lower levels of circulating BDNF. Low levels of BDNF have also been linked to cognitive impairment and to EF in inhibiting behavior and cognitive flexibility (43).

Research indicates that children who are overweight or obese have lower levels of several neurotrophic factors than their normal weight peers, which highlights the importance of understanding these factors in addressing obesity-related cognitive issues (37). However, only a few studies have examined the relationship among obesity, executive function (EF), and brain-derived neurotrophic factors (BDNF) in children. Limited evidence exists for such studies within this specific population. Therefore, an important research question arises: Are EF and BDNF levels different among children classified in one of the three Thai growth reference (TGR) categories (normal weight, overweight, and obesity)? It has been hypothesized that children in the different TGR categories exhibit varying EF and BDNF levels.

METHODS

Participants

We conducted a cross-sectional survey. Based on TGR, weight-for-height (WH) was used to classify overweight and obesity in children. Thus, the heights and weights of all 336 students in Kham Khuean Kaeo School were measured to assess each student's WH for the academic year 2022. Using the TGR, the students were divided into 3 Groups. A child with a normal weight (WHZ between -1.5 SD to 1.5 SD) was proportionate to their height. A child who is overweight (WHZ > 1.5 SD to 2 SD) is at risk of being overweight and developing obesity. A child with obesity (WHZ > 3 SD) indicates that a child is obese and may be classified as having obesity level 2 (29). Sixty-six students (36 females and 30 males) with an average age of 10.28 years were randomly chosen to participate in the present study (22 students per group). In addition, the suitability of the participants was determined through interviews.

Criteria for eligibility included the following: (a) must not participate in sports or an exercise program; (b) must not have mental retardation, brain lesions, or developmental delays; (c) must not have any visual or hearing abnormalities; and (d) must voluntarily agree to participate in the research, and their parents or legal guardians must give consent by signing the Consent Form. Participants who (a) engage in sports; (b) are currently on a diet; (c) have recognized conditions that might jeopardize blood samples, such as moderate bleeding difficulties and poor blood coagulation; and (e) are at the onset of puberty (Tanner stage 2 and above) were excluded. The sample size for this inquiry was calculated using the G*Power program with an effect size of 0.4 and a test power of 0.80. The effect size was calculated using the earlier studies (25,43). This study was approved by the Srinakharinwirot University Human Research Ethics Committee in Bangkok, Thailand (research registration number: SWUEC/F-219/2565). The parents/guardians of each child provided written informed consent, and the children verbally consented to participate in the study.

Outcome Measures

Information on background variables was acquired on the day of the test. Blood samples were used to evaluate the BDNF levels. Body mass index (BMI), body fat percentage, and waist to hip ratio (WHR) were measured. Neuropsychological tests [Trail Making Test (TMT), Digit Span (DS), Stroop Color-Word Test (SCWT), and Tower of London (TOL)] were conducted. The participants were requested to refrain from physical activity the day before the measurement, and the teachers ensured that the students adhered to the request.

BDNF

The blood samples were collected between 7:00 a.m. and 9:00 a.m. Blood samples were collected from the antecubital veins of the participants in a serum separator tube using an anticoagulant-free vacuum tube. After collection, the samples were allowed to clot for 30 min and then centrifuged at 1500 × g for 15 min. This process separated the serum from the cellular components of the blood, and the resulting serum samples were stored at a very low temperature (-80°C) until they were ready for assay. Serum BDNF levels were quantified using an enzyme-linked immunosorbent assay (Human BDNF Quantikine Immunoassay, RAB0026; Sigma-Aldrich). According to the manufacturer's instructions, the Human BDNF ELISA Kit RAB0026 had a sensitivity of 7.25 pg/mL and a detection range of 15.6-1000 pg/mL. The BDNF serum intra- and inter-assay coefficients of variation were less than 10% and less than 12%, respectively. It has been validated for use in human samples and has a high degree of accuracy and reproducibility.

The sandwich enzyme immunoassay was performed using aliquots of serum samples diluted in the range of 1:25 to 1:2000. The BDNF concentration in serum was calculated based on a standard curve, which was linear between 7.8 and 125 pg/mL. The BDNF concentration in serum was measured by microplate absorbance reader, Epoch microplate spectrophotometer with the Gen5 software interface, Agilent BioTek BioStack microplate stacker, and third-party automation compatible ("R" configuration) using standard methodology. The absorbance of the serum samples was measured using a microplate reader set at a wavelength of 450 nm to determine the concentration of BDNF based on a standard curve (10).

BMI

BMI is the ratio of weight to height. It was calculated by dividing a participant's weight in kilograms by height in meters squared. BMI provides a rough estimate of body fat, and it is widely used as a screening tool to determine whether an individual is underweight, normal weight, overweight, or obese (47).

Body Fat Percentage

Body fat percentage refers to the proportion of body weight composed of fat tissue. Body fat percentage is a useful indicator of overall health and fitness. A high percentage of body fat is often associated with an increase in risk of various health problems (49). The Omron HBF-375 Body Composition Monitor measures body fat percentage. It uses a technology called bioelectrical impedance analysis (BIA) to estimate body fat percentage by sending a small electrical current through the body and measuring the resistance of the current.

WHR

WHR is a measurement of the ratio of the circumferences of the hip and waist. WHR was measured at the umbilical level to the nearest 0.1 cm, while the hip circumference was measured at the maximum extension of the buttocks to the nearest 0.1 cm. It is calculated by dividing the waist measurement by the hip measurement (9). A high WHR suggests more abdominal fat that is linked to a higher risk of a number of health issues, such as above 0.96 for boys and 0.83 for girls is associated with an increased risk of developing diabetes and cardiovascular disease, especially when accompanied by obesity (31).

Neuropsychological Testing

Neuropsychological testing is a non-invasive and internationally recognized method for evaluating cognitive function that involves processes, such as information discovery, interpretation, storage, and utilization within the brain. This testing assesses diverse cognitive skills, such as executive function, memory, attention, spatial ability, and intellect (5). It aids in confirming the diagnosis of brain disorders and effectively measures the functional capacity of the brain, thus providing a safe and validated approach (4).

TMT

The TMT is a neuropsychological assessment instrument used to gauge cognitive flexibility and visual-motor coordination. High test-retest reliability has been observed for both Part A ($r = 0.92$-0.97) and Part B ($r = 0.85$-0.96) in a variety of populations (2). In Part A of the TMT, the participants were required to connect a set of numbers in ascending order; whereas, in Part B, they were required to connect alternate sets of numbers and letters in ascending order. The participants were asked to finish the test quickly and as accurately as possible because it was timed. The completion time of each test component was used as a performance indicator, with longer times indicating worse performance. The total amount of time required to complete the test, including the time required to correct mistakes, was recorded. The participants were prompted to rectify their faults before moving on, and they were not permitted to omit any if they made mistakes.

DS

The DS test was used to assess the working memory, concentration, and attention span. According to one study, the reliability of the DS ranged from $r = 0.81$ to 0.94, indicating that the test is a reliable measure of cognitive function (13). The DS test is a cognitive assessment that consists of two parts: The DS Forward test and the DS Backward test. In the DS Forward test, the participant must repeat a series of numbers in the same order as they were presented, starting with a small set and growing in length, with each sequence rising by one number. There are 8 items on the test, and the maximum score is 16. In the DS Backward test, the participant was asked to repeat a sequence of numbers in reverse order as they were presented, starting from a small set and increasing in length, with each sequence increasing by one number. The test consisted of 7 items with a possible score of 14 points.

SCWT

The SCWT is a popular neuropsychological test that evaluates various cognitive abilities that includes inhibitory control and attention (21). The primary goal was to assess cognitive interference inhibition, a phenomenon in which one stimulus attribute affects how a stimulus is processed by another sensory attribute. The strong reliability of the test ($r = 0.81$) has been previously reported (40). The most common version of the test, proposed by Stroop in 1935, required the participants to read 3 tables as quickly as possible. In the first 2 tables, the participants read color words printed in black ink (W) and named different color patches (C), while in the 3rd table (CW), color words were printed in a color that is inconsistent with their meaning (e.g., "red" printed in green ink). This incongruent condition required the participants to name the color of the ink rather than read the word, which involved inhibiting the interference of a more automated task of reading the word. This task also measured the ability to inhibit the automatic responses as well as the speed of processing and accuracy. This difficulty in inhibiting a more automated process is known as the Stroop effect (44).

TOL

The TOL test is a widely used neuropsychological test designed to assess planning, problem solving, and executive functioning skills in individuals. The reliability of the test was r = 0.80 (7). The test required the participants to solve a series of problems presented on a board consisting of three pegs of varying heights and a series of colored balls placed on the pegs. Ten distinct patterns are observed. At the beginning of each trial, the experimenter presented the participant with a picture of the target configuration of the colored balls on the pegs. The participants were tasked to move the balls from the initial position to the target position with a minimum number of moves, while following certain rules. The rules require that only one ball be moved at a time, and a ball may only be placed on a peg if there is sufficient space to do so without violating the rule that no larger ball should be placed on top of a smaller ball. The participants were required to plan and visualize the necessary moves to solve the problem, and then execute the moves in a specific order to achieve the target configuration. The TOL test measures 7 aspects: (a) the total number of moves made; (b) the average time taken for the first move (initiation time); (c) the average time taken for all moves (execution time); (d) the total number of rule violations (time violations); (e) the average number of rule violations; (f) the total score of correct moves made within the specified time; and (g) the average efficiency in solving the problem within the allotted time.

Data Analysis

A one-way multivariate analysis of variance (MANOVA) was used to evaluate the differences among the 3 Groups (i.e., normal weight, overweight, and obesity) for the dependent variables. A descriptive discriminant analysis (DDA) was conducted as a *post-hoc* analysis to: (a) determine if there were group differences among the 3 TGR on the composite dependent variable for BDNF and EF; and (b) evaluate which observed dependent variables contributed to the composite (3). A preliminary assumption testing was performed for the analysis. No univariate outliers were assessed using boxplot examination. The Shapiro-Wilk Test for the three levels of the independent variable for all dependent variables indicated that the assumption of normality was accepted ($P > 0.05$). The assumptions of linearity were satisfactory based on inspection of the scatterplots. The association between the dependent variables was significant. The correlation coefficients were .20 and .93. Since the correlation between body weight and BMI was highly positive (r = .93), BMI was used for MANOVA to avoid multicollinearity problems (45).

RESULTS

Participants' Characteristics

Table 1 presents the socioeconomic status (SES) of the parents. Tables 2 and 3 provide the descriptive statistics for the participant characteristics and dependent variables disaggregated by independent variables. The analysis revealed no significant differences in age between the Groups ($P > 0.05$).

Table 1. The Socioeconomic Status (SES) of the Parents.

		Normal Weight n = 22	Overweight n = 22	Obese n = 22
Sex	Male (n = 30)	10	10	10
	Female (n = 36)	12	12	12
Parental Education	Elementary School / lower	10	7	5
	High School	7	7	11
	Associate degree	2	2	1
	Bachelor's Degrees / higher	1	3	1
Family Income	Less than 3,000 baht	7	1	6
	3,000-10,000 baht	9	8	8
	10,001-30,000 baht	4	8	3
	More than 30,000 baht	0	2	1

Table 2. Means, Standard Deviations, and Correlations for Body Composition.

Group	NW	OW	OB	Correlations			
Variables	**M (SD)**	**M (SD)**	**M (SD)**	**1**	**2**	**3**	**4**
Age	**10.27(1.07)**	**10.11(1.05)**	**10.47(1.12)**				
1. Weight (kg)	32.01 (7.25)	42.98 (10.54)	59.36 (9.81)	-			
2. Height (cm)	139.00 (9.46)	141.79 (10.19)	148.72 (8.21)	.73	-		
3. BMI	16.38 (1.98)	21.48 (2.14)	27.02 (4.84)	.93	.45	-	
4. Body fat (%)	18.92 (2.44)	25.44 (2.07)	35.76 (5.96)	.68	.42	.69	-
5. WHR	.83 (.08)	.88 (.04)	.96 (.06)	.51	.20	.59	.62

NW = Normal weight; **OW** = Overweight; **OB** = Obesity; **BMI** = body mass index; **WHR** = Waist-hip ratio

Table 3. Means, Standard Deviations, and Correlations for the Dependent Variables.

Group	NW	OW	OB	Correlations			
Variables	**M (SD)**	**M (SD)**	**M (SD)**	**1**	**2**	**3**	**4**
1. BDNF	4540.37 (764.33)	4564.20 (1497.00)	4285.21 (1007.01)	-			
2. TOL (score)	102.29 (4.32)	102.01 (3.38)	97.50 (6.40)	.29	-		
3. TMT (sec)	84.27 (33.81)	91.29 (25.46)	94.54 (36.08)	-.04	.02	-	
4. SCWT (sec)	41.42 (9.32)	42.98 (10.62)	47.75 (8.82)	-.03	-.36	-.27	-
5. DS (sec)	6.45 (1.20)	7.22 (1.14)	7.37 (1.16)	-.07	-.27	.32	-.27

NW = Normal weight; **OW** = Overweight; **OB** = Obesity; **BDNF** = Brain-derived neurotrophic factor; **TOL** = Tower of London; **TMT** = Trail-making test; **SCWT** = Stroop color and word test; **DS** = Digit span

The results of the MANOVA revealed that there was a statistically significant difference between the 3 TGR Groups (normal weight, overweight, and obesity) in the combined variables (height, BMI, body fat percentage, and waist-hip ratio) Pillai's trace = .80, F (8, 178) = 14.72, P < 0.001, partial eta = .40). Box's M value (115.04) was significant, P < 0.001. Thus, a follow-up DDA was performed. In summary of the canonical discriminant function, the full model indicated that the grouping variable explained 78% of the variance in the composite dependent variable, with Wilks' lambda = .21, (x^2 (8) = 138.37, P < .001, R_c^2 = .78. Thus, it can be concluded that the composite characteristics of the children differed among the TGR Groups. The other function was not considered noteworthy because it explained less than 1% of the variance in the composite and, therefore, was not interpreted. Structural and standardized function coefficients were used to identify the dependent variables that contributed to Group differences in the first function (Table 4). Of the 4 dependent variables, body fat had the strongest relationship with the composite score, yielding a structural coefficient of .81. By squaring this value, it can be determined that body fat accounted for approximately 66% of the variance in the composite. In summary, the composite dependent variable was largely body fat, with substantial effects on BMI, WHR, and height.

Table 4. Canonical Correlations, Standardized Discriminant Coefficients, and Structure Coefficients.

	R_c^2	SDCs	r_s	r_s^2
Body Composition				
	.78			
Height (cm)		.14	.25	.06
BMI		.42	.61	.37
Body fat (%)		.68	.81	.66
WHR (cm)		.34	.48	.23
BDNF and EF				
	.27			
BDNF		-.08	-.19	.04
TOL (score)		-.45	-.69	.48
TMT (sec)		.61	.21	.04
SCWT (score)		.58	.51	.26
DS (score)		.49	.52	.27

BMI = Body mass index; **WHR** = Waist-hip ratio; **BDNF** = Brain-derived neurotrophic factor; **EF** = Executive function; **TOL** = Tower of London; **TMT** = Trail making test; **SCWT** = Stroop color and word test; **DS** = Digit span; R_c^2 = *squared canonical correlation (inverse of Wilks' lambda);* ***SDCs*** = standardized discriminant coefficients; r_s = *structure coefficients;* r_s^2 = *squared structure coefficients.*

Subsequently, we determined the Groups that differed in the composite. This was accomplished by referring to Group centroids, which are the means of each Group in the composite dependent variable (32). The Group centroids for the analysis are shown in Table 5. Children who were in the normal weight and overweight categories for TGR had lower Group centroids, indicating that they had lower body fat, BMI, WHR, and height than the Obesity Group based on the direction of the structure coefficients. To examine the differences among the Group centroids, a one-way ANOVA was conducted with TGR as the independent variable and the saved discriminate function score as the dependent variable. The results indicated that the Group centroid for the Normal Weight Group was significantly lower than that of the Overweight Group and the Obesity Group (all P < .001). The Group centroid for the Overweight Group was also lower than that of the Obesity Group (P <.001).

Table 5. Group Centroids for Synthetic Composite for Body Composition, BDNF, and EF.

	Centroids	**95% CI**
	Body Composition	
Normal Weight	-2.88	[-3.23, -2.53]
Overweight	-1.02	[-1.32, -.72]
Obesity	1.56	[1.24, 1.88]
	BDNF and EF	
Normal Weight	-.87	[-1.24, -.50]
Overweight	-.30	[-.81, .19]
Obesity	.51	[.17, .84]

BDNF = Brain-derived neurotrophic factor; **EF** = Executive function

BDNF, TOL, TMT, SCWT, and DS Variables

The results of the MANOVA revealed that there was a statistically significant difference between the 3 TGR Groups (normal weight, overweight, and obesity) in the combined variables (BDNF, TOL, TMT, SCWT, and DS) Wilks' lambda = .69 *F* (10,146) = 2.94, P < 0.01, partial eta = .19. The Box's M value (48.39) was not significant (P > 0.05). Thus, a follow-up DDA was performed. In summary of the canonical discriminant function, the full model indicated that the grouping variable explained 27% of the variance in the composite dependent variable, with Wilks' lambda = .69, (x^2 (10) = 27.50, P < 0.01, R_c^2 = .27. Thus, it can be concluded that the dependent variable composite discriminated among the 3 TGR Groups. The other function was not considered noteworthy because it explained less than 1% of the variance in the composite and, therefore, was not interpreted. Structural and standardized function coefficients were used to identify the dependent variables that contributed to Group differences in the first function (Table 4). Of the 5 dependent variables, TOL had the strongest relationship with the composite and yielded a structure coefficient of -.69. By squaring this value, it can be determined that TOL accounted for approximately 48% of the variance in the composite. This was followed by DS (r_s = .52, r_s^2 = .27), and SCWT (r_s = .51, r_s^2 = .67). Because the structural coefficients for BDNF and TMT were nearly zero, they were not included in the substantive interpretation because they did not directly contribute to Group differences in the synthetic composite. In summary, the composite dependent variable was largely the result of TOL, DS, and SCWT playing substantial roles. Subsequently, we determined the Groups that differed in the composite. This was accomplished by referring to Group centroids, which are the means of each Group in the composite dependent variable (42). The Group centroids used in the analysis are listed in Table

5. The results indicated that the Group centroid for the Normal Weight Group was significantly better than that for the Obesity Group (P < 0.001). The Group centroid for the Overweight Group was also better than that of the Obesity Group (P < 0.05). There was no significant difference between the Overweight and Obesity Groups. Figure 1 presents the mean values of each dependent variable for the three TGR Groups.

Figure 1. Displays Levels of BDNF, TOL, TMT, SCWT, and DS in the Normal Weight, Overweight, and Obesity Groups. **NW** = Normal weight; **OW** = Overweight; **OB** = Obesity; **BDNF** = Brain-derived neurotrophic factor; **TOL** = Tower of London; **TMT** = Trail making test; **SCWT** = Stroop color and word test; and **DS** = Digit span

Regarding the EF variables, children in the Normal Weight and Overweight Groups exhibited significantly lower centroids in the direction of the structural coefficient than those in the Obesity Group (P < 0.001). This finding suggests that the Normal Weight Group obtained higher scores on the Tower of London (TOL) Test. Conversely, the Normal Weight Group scored lower on the Digit Span (DS) and the Stroop Color and Word Test (SCWT) than the Obesity Group. These differences were confirmed by analyzing the centroid values.

DISCUSSION

According to the findings in this study, the participants in the Normal Weight Group had considerably lower heights, BMIs, percentages of body fat, and WHR than those in the Overweight and Obese Groups. Compared with the Obesity Group, the Overweight Group had considerably lower height, BMI, body fat percentage, and WHR values. These results confirm that the TGR can be used to classify body weight differences in children. The research also revealed that there were statistically significant differences among the 3 Groups (Normal Weight, Overweight, and Obesity) in the TOL, DS, and SCWT. However, the BDNF levels and the TMT scores did not differ significantly between the Groups.

The research findings align with the research hypothesis, demonstrating that the Tower of London (TOL) task revealed the most significant differences among the Groups, with the strongest correlations observed. This indicates that volunteers with normal weight had better TOL test scores than those in the other 2 Groups. Thus, it can be inferred that children with normal weight exhibit better frontal lobe function and higher executive thinking skills than the overweight or obese children. The TOL test reflects frontal lobe activities related to planning and problem solving. This finding is consistent with other studies indicating a relationship between Body Mass Index (BMI) and gray matter volume in the brain, particularly in the prefrontal cortex (30).

Previous studies have also suggested that obesity impairs brain function and affects executive function in the frontal lobe (16,48). Additionally, a higher weight is associated with reduced cognitive processing abilities (26). Research on planning and problem-solving skills using the TOL in school children (7 to 12 years of age) with varying BMIs found that overweight and obese children exhibited more executive function (EF) deficits in problem solving and planning than children with normal BMIs (36).

However, for the Digit Span (DS) task, the Obesity Group scored better than the Overweight and Normal Weight Groups, contradicting the results of the previous studies. Prior research found that normal weight children completed DS tasks faster and scored better on both forward and backward DS tasks compared to the overweight or obese children (6). This discrepancy may be explained by earlier studies showing an inverse relationship between increasing BMI and working memory skills (22,32). Conversely, students with normal weight and regular physical activity performed better on memory tests than sedentary and overweight, or obese students (32).

Similarly, the Stroop Color and Word Test (SCWT) results indicated that the Obesity Group performed better than the Overweight and Normal Weight Groups. This contrasts with previous research that found that the normal weight students took less time to complete the SCWT than the overweight children or the obese children; normal weight children showed better functioning of the lateral prefrontal cortex, anterior cingulate cortex, and temporal and parietal lobes, leading to better attention, processing speed, and inhibition (6).

A meta-analysis by Likhitweerawong et al. (24) investigated the relationship between weight status and EF levels in children and adolescents and concluded that while many studies suggest that obesity affects EF deficits, some studies found no significant differences between weight status and EF levels. The researchers identified potential confounding factors, such as sex, family income, maternal education, maternal stress, parenting style, and family structure with other risk factors. The families of the volunteers exhibited similar income and education levels, although the data indicated that all the participants were from low-income backgrounds. Given the low SES of the parents in our study sample, this factor could significantly affect the EF variables, possibly more than the obesity levels.

Previous research has shown that the parents' SES, which includes financial resources, educational level, and occupation, significantly affects a child's executive function (23). Higher SES is generally associated with better EF development in children that is likely due to the increased availability of financial and social resources to facilitate opportunities for growth. These opportunities often require monetary investments to create an enriched environment that supports EF development. Moreover, parents with higher SES are more likely to have the resources to provide such environments, but the quality of parenting itself plays a critical role, regardless of SES (18). Furthermore, the study did not collect data on parenting styles. The absence of data on parenting styles introduces another variable that could account for the differences in our findings compared to the existing literature.

Several studies have highlighted the crucial role of positive parenting in the development of EF in children. For instance, parents who employ empathetic, supportive, and responsive parenting strategies tend to have children with superior EF skills, such as better attention regulation, working memory, and cognitive flexibility. These parenting behaviors foster an environment where children can practice and enhance their self-regulatory skills, which are essential components of EF (12,46). The research by Fay-Stammbach et al. (11) suggests that parental responsiveness and the provision of cognitive stimulation at home are strong predictors of EF development in children.

Regarding Brain-Derived Neurotrophic Factor (BDNF), average data showed a tendency for lower serum BDNF levels in the Obesity Group compared to the Normal Weight Group. However, statistically significant differences were not found among the 3 Groups. Most previous research indicates that obese individuals have lower serum BDNF levels than normal weight individuals (14). However, some studies present conflicting results, and a clear consensus on BDNF levels among different growth levels does not exist. Some research did not find any difference in circulating BDNF levels between obese patients and non-obese controls (39).

In contrast, Villalobos Gutierrez and colleagues (15) found that plasma BDNF levels were significantly higher in overweight and obese children aged 5 to 13 years of age compared to normal weight children (15). Furthermore, Selvaraju et al. (41) found significantly higher salivary BDNF and β-NGF levels in obese children than in normal weight children. They suggested that salivary BDNF levels were positively correlated with obesity, blood pressure, and salivary insulin levels. Multinominal regression analysis indicated a relationship between salivary BDNF levels, β-NGF, insulin, systolic pressure, and variables such as age, sex, income, and maternal education.

Roth et al. (37) reported that obese children have higher serum BDNF levels than non-obese children, highlighting the relationship between BDNF and fat mass. Differences in obesity levels, severity, and sample age may have contributed to these findings. Other factors potentially affecting the relationship between growth and BDNF levels include genetics, body fat content, metabolic disorders, and dietary behavior (27).

Limitations in this Study

It is important to acknowledge that the cross-sectional design employed in this study does not allow the establishment of causality and may limit the generalizability of the results. Additionally, the relatively small sample size used in this study may have limited the statistical power and precision of our findings. The low socioeconomic status of the parents in our sample may also be a critical factor influencing EF, potentially having a greater impact than obesity. The lack of information on parenting styles adds another layer of complexity to our findings.

CONCLUSIONS

The findings in this study indicate that there were no significant differences in BDNF levels among school children categorized as normal weight, overweight, or obese. Additionally, children in the normal weight category did not exhibit a better overall EF than their overweight and obese counterparts, except for the EF component related to planning. This exception may have been influenced by other factors affecting EF and BDNF in the sample group, such as genetic and environmental factors, including the family's economic status and parenting practices. Notably, the entire sample group comprised children from families with a relatively low economic status. Future studies should investigate the development of EF and BDNF among school children and the factors influencing these variables. To validate the current findings further, future studies should use longitudinal designs and recruit larger and more diverse samples. This allows for a more robust evaluation of the relationships between the variables of interest while also providing stronger evidence of the generalizability of the results.

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Address for correspondence: Sonthaya Sriramatr, Department of Sports Science, Faculty of Physical Education, Sports, and Health, Srinakharinwirot University, Nakhon Nayok, Thailand, Email: sonthase@g.swu.ac.th

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