DOI: 10.1590/1809-2950/e24016824en

ORIGINAL RESEARCH

Adiposity, stress, and habitual physical activity predict executive function and memory performance in children and adolescents with obesity

Adiposidade, estresse e atividade física habitual são preditores da função executiva e desempenho em tarefas de memória em crianças e adolescentes obesos

La adiposidad, el estrés y la práctica de ejercicio físico son predictores de la función ejecutiva y del rendimiento en tareas de memoria en niños y en adolescentes obesos

Daniel Almeida Freitas[1], Bruno Alvarenga Soares[2], Arthur Rocha Gomes[3], Túlio Pereira Alvarenga e Castro[4], Bethânia Alves de Avelar Freitas[5], Herbert Renato Coelho Gomes[6], Ana Cristina Rodrigues Lacerda[7], Fernanda Cordoba Lanza[8], Fernanda de Oliveira Ferreira[9], Vanessa Amaral Mendonça[10], Hércules Ribeiro Leite[11]

ABSTRACT | Obesity during childhood and adolescence may delay cognitive development. This study aims to evaluate predictors that influence executive functions and memory in children and adolescents with obesity. A cross-sectional study was carried out with children and adolescents with obesity (aged 7–18 years) (n=32). Executive functions; episodic memory; semantic memory; body composition; inflammation biomarkers; cardiorespiratory fitness, stress, socioeconomic status, and regular physical exercise were assessed. A linear stepwise regression was performed with the variables with significant correlation. Adiposity (%fat) and BMI z-scores were associated with worse episodic memory. Verbal fluency was associated with visceral fat. At the tower of Hanoi test, planning and cognitive flexibility were associated with visceral fat, whereas the number of movements was associated with the practice of sports and physical exercise. Regular exercise favored the cognitive planning of children and adolescents with obesity. The number of errors was directly associated with the children stress scale score. In conclusion, body composition, memory, and the executive functions of cognitive flexibility and inhibitory control showed an association between each other. Executive functions and memory in children and adolescents might be associated with stress and regular physical exercise practice regardless of intensity.

Keywords | Children; Adolescents; Obesity; Memory.

1. Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) – Diamantina (MG), Brazil. E-mail: danielalmeidafreitas@hotmail.com. ORCID: https://orcid.org/0000-0003-2295-8765
2. Universidade Federal de Minas Gerais (UFMG) – Belo Horizonte (MG), Brazil. E-mail: brunoalvarengasoares@outlook.com. ORCID: https://orcid.org/0000-0002-1709-3747
3. Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) – Diamantina (MG), Brazil. E-mail: a.gomes.far@gmail.com. ORCID: https://orcid.org/0000-0002-2494-3113
4. Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) – Diamantina (MG), Brazil. E-mail: tulio.castro@ufvjm.edu.br. ORCID: https://orcid.org/0000-0003-0442-3273
5. Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) – Diamantina (MG), Brazil. E-mail: bethania.avelar@ict.ufvjm.edu.br. ORCID: https://orcid.org/ 0000-0002-3874-4799
6. Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) – Diamantina (MG), Brazil. E-mail: herbertrenato26@gmail.com. ORCID: https://orcid.org/0009-0003-8131-5863
7. Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) – Diamantina (MG), Brazil. E-mail: lacerdaacr@gmail.com. ORCID: https://orcid.org/0000-0001-5366-3754
8. Universidade Federal de Minas Gerais (UFMG) – Belo Horizonte (MG), Brazil. E-mail: lanzafe@gmail.com. ORCID: https://orcid.org/0000-0002-4748-6947
9. Universidade Federal de Juiz de Fora (UFJF) – Governador Valadares (MG), Brazil. E-mail: ferreira.ufjf@gmail.com. ORCID: https://orcid.org/0000-0002-5857-2824
10. Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) – Diamantina (MG), Brazil. E-mail: vaafisio@hotmail.com. ORCID: https://orcid.org/0000-0002-1696-6091
11. Universidade Federal de Minas Gerais (UFMG) – Belo Horizonte (MG), Brazil. E-mail: herculesdtnaa@gmail.com. ORCID: https://orcid.org/0000-0001-8977-8131

Corresponding address: Bruno Alvarenga Sares – Avenida Presidente Antônio Carlos, 6627, Belo Horizonte (MG), Brazil – ZIP Code: xx – Contact: 31998387007 – E-mail: brunoalvarengasoares@outlook.com – Financing source: FAPEMIG; CAPES – Conflict of interests: nothing to declare – Presentation: Aug. 16th, 2024 – Accepted for publication: Jan. 02nd, 2025 – Approved by the Research Ethics Committee CAAE No. 82041317.4.0005108

RESUMO | A obesidade na infância e adolescência pode contribuir para atrasos no desenvolvimento cognitivo. Este estudo tem como objetivo avaliar preditores que influenciam as funções executivas e a memória em crianças e adolescentes obesos. Foi realizado um estudo transversal com crianças e adolescentes obesos (7-18 anos) (n=32). Foram avaliadas funções executivas; memória episódica; memória semântica; composição corporal; biomarcadores de inflamação; aptidão cardiorrespiratória; estresse; nível socioeconômico; e prática regular de exercícios físicos. Para análise dos dados, foi realizada regressão linear (modo Stepwise), com as variáveis com correlação significativa. Adiposidade (% gordura) e escore z do Índice de Massa Corporal (IMC) foram associados à pior memória episódica. Fluência verbal foi associada à gordura visceral. No teste da Torre de Hanói, as funções de planejamento e flexibilidade cognitiva foram associadas à gordura visceral, enquanto o número de movimentos foi associado à prática de esportes e exercícios físicos. A prática regular de exercícios físicos favoreceu o planejamento cognitivo de crianças e adolescentes obesos. O número de erros foi diretamente associado à pontuação da *children stress scale*. Concluindo, houve associação entre composição corporal, memória e funções executivas de flexibilidade cognitiva e controle inibitório. Funções executivas e memória em crianças e adolescentes podem estar associadas ao estresse e ao hábito de exercícios físicos regulares, independentemente da intensidade.
Descritores | Crianças; Adolescentes; Obesidade; Memória.

RESUMEN | La obesidad en la infancia y la adolescencia puede contribuir a retrasos en el desarrollo cognitivo. Este estudio tiene como objetivo evaluar los predictores que influyen en las funciones ejecutivas y en la memoria de niños y adolescentes obesos. Se realizó un estudio transversal con niños y adolescentes obesos (7-18 años) (n=32). Se evaluaron las funciones ejecutivas; la memoria episódica; la memoria semántica; la composición corporal; los biomarcadores de inflamación; la aptitud cardiorrespiratoria; el estrés; el nivel socioeconómico; y la práctica de ejercicio físico regular. Para el análisis de datos se realizó regresión lineal (modo Stepwise), con variables con correlación significativa. La adiposidad (% de grasa) y la puntuación z del Índice de Masa Corporal (IMC) se asociaron con una peor memoria episódica. La fluidez verbal se asoció con la grasa visceral. En la prueba de la Torre de Hanoi, las funciones de planificación y la flexibilidad cognitiva se asociaron con la grasa visceral, mientras que el número de movimientos se asoció con la práctica de deportes y de ejercicio físico. La práctica regular de ejercicios físicos favoreció la planificación cognitiva de niños y adolescentes obesos. El número de errores se asoció directamente con la puntuación de la escala de estrés infantil. Se pudo concluir que hubo una asociación entre la composición corporal, la memoria y las funciones ejecutivas de la flexibilidad cognitiva y del control inhibitorio. Las funciones ejecutivas y la memoria de niños y adolescentes pueden estar asociadas con el estrés y con la práctica de ejercicio físico regular, independientemente de la intensidad.
Palabras clave | Niños; Adolescentes; Obesidad; Memoria.

INTRODUCTION

Obesity represents a significant Public Health challenge due to the marked increase in its global prevalence, affecting adults, children, and adolescents alike[1]. The overall prevalence rates of pediatric obesity, overweight, and excess weight total 8.5, 14.8, and 22.2%, respectively. Obesity has substantial regional variations; Polynesia shows the highest prevalence across all categories, whereas Middle and Western Africa report the lowest rates[2]. In Brazil, the prevalence of obesity among children and adolescents has risen dramatically in recent decades. In children aged from five to nine years, obesity prevalence is slightly higher in girls (9.2%) than in boys (9.0%), whereas for adolescents, boys have a higher prevalence (6.7%) than girls (6.2%)[3].

Obesity during childhood and adolescence can lead to the early development of other comorbidities, resulting in a poorer health prognosis for individuals throughout their lives[4]. Additionally, juvenile obesity may contribute to cognitive developmental delays and impairments in memory function[5].

Executive functions and memory undergo refinement and maturation during early childhood and adolescence, making these periods crucial for their proper development[6]. Obesity during childhood and adolescence induces metabolic, cerebrovascular, and structural changes in the developing central nervous system. These progressive alterations might negatively impact the performance of executive function, memory retention, consolidation, and retrieval[5,7].

Several aspects may be involved as predictive mechanisms that interrelate childhood obesity with impairments in executive functions. Studies suggest that higher body mass index (BMI) or visceral fat, low physical activity levels, elevated levels of stress and cortisol, and lower socioeconomic status may be associated with poorer performance in cognitive and memory tests in children and adolescents with obesity. However, most studies addressing this topic have evaluated each predictor in isolation rather than using a linear regression with independent variables[5,7]. It has been speculated that the development of these functions in children does not constitute a unilateral phenomenon and can be impacted by different factors. A more robust assessment with multiple parameters becomes imperative.

This study aimed to identify potential predictors of cognitive performance related to the development of executive functions and memory in children and adolescents with obesity. It considered socioeconomic status, concentration biomarkers, physical activity level, and functioning level as potential predictors.

METHODOLOGY

Design

This is a cross-sectional study with 32 children and adolescents of both sexes who were aged from seven to 18 years.

Participants

The following inclusion criteria were chosen: children or adolescents with BMI z-scores for age and sex greater than or equal to +2 who did not have orthopedic, neurological, or systemic conditions nor used continuous medication. Additionally, those who obtained up to two negative standard deviations from the mean for their age (that is, without cognitive deficit) on the mini-mental state examination (adapted for the pediatric population) were included in the study[8].

Procedures

In total, two meetings were held with participants. In the first one, executive functions (tower of Hanoi – ToH and the Stroop test - ST); episodic memory (the Rey Auditory Verbal Learning Test - RAVLT); semantic memory (verbal fluency - VF); body composition (dual-energy X-ray absorptiometry); cardiorespiratory fitness (the modified shuttle test - MST), stress (child stress scale - CSS); socioeconomic level (Brazilian Market Research Association - ABEP), and regular physical exercise (Baecke's habitual physical activity questionnaire) were assessed. After 72 hours, the second meeting was held, in which blood was collected for future assessment of cortisol and C-reactive protein levels.

Variables

Regarding socioeconomic status, the ABEP questionnaire consists of a list of household appliances and consumer goods owned by the family and the educational level of the head of the family. The questionnaire classifies participants into the D-E, C2, C1, B2, B1, and A class (from the lowest to the highest socioeconomic class)[9].

Cardiorespiratory fitness was assessed by the modified shuttle test (MST), following European Respiratory Society/American Thoracic Society standards[10]. The MST consists of an externally cadenced test in which the speed increases each minute, to be performed in a 10-meter corridor in which volunteers are allowed to walk or run. The test was performed twice with a 30-minute interval between instances. The walked distance from the best test was considered the outcome[11].

Weight and height were measured using scales with a stadiometer. Lean mass, fat mass, and bone mineral density were analyzed by dual-energy X-ray absorptiometry (model DPX; Lunar Radiation Corporation, Madison, Wisconsin, USA)[12].

The RAVLT protocol consisted of describing a series of verbal stimuli in a list containing 15 nouns. Participants' age was considered when examining parameters related to immediate memory, learning curve of word recall across attempts, and learning rate[13].

In the VF test, participants were given the task of generating as many words as possible within a 1-minute time limit, starting with the letters "F," "A," and "S" in the following semantic classes: "animals," "body parts," and "food." Scoring was done according to the number of distinct words per category, considering words with multiple meanings[14].

The ToH task was conducted using a board with three graduated disks arranged on three pegs. In total, two rules were explicitly stated by the examiner: (1) participants could only move one disk at a time and (2) placing a larger disk on top of a smaller disk was prohibited. The ToH task was conducted twice, once for training and once to test the participants. Planning time (defined as the duration between participants' first and last move) was measured using a stopwatch. Average time to complete each set of disks, number of moves, and the total number of errors were computed[15].

ST measures participants' ability to shift their attention and suppress a habitual response in favor of an unconventional one (selective attention and aspects of executive functions, such as cognitive flexibility and susceptibility to interference). In this study, three cards were utilized. The first card consisted of rectangles colored in blue, brown, green, and pink. The second card contained various meaningless words written in the colors corresponding to the rectangles from the first card. The third card displayed the names of the colors but were written in different colors than their actual names. Duration required to conclude reading each of the three cards and the cumulative count of errors were computed[16].

The CSS consists of 35 items with a Likert scale from 0 to 4 points that is grouped into four factors linked with stress symptoms: physical reactions, psychological reactions, psychological reactions with a depressive component, and psycho-physiological responses[17].

To assess habitual physical activity level (HPAL), a subsection from the Baecke's Physical Activity Questionnaire was used[18]. HPAL was classified into three categories: 1) sufficiently active: intensity equal to or above 150 minutes per week; 2) insufficiently active: intensity below 150 minutes per week; and 3) those who engaged in no physical activities.

Blood samples for cortisol and C-reative protein were assessed after a fasting period of more than eight hours in a specific time point (7:30–8:30 a.m.). A cortisol assay test kit was used for the automated chemiluminescence immunoassay following the manufacturer's recommendations (LIASON® XL, DiaSorin®, Italy).

Statistics

Categorical data are shown by absolute and relative frequencies. Quantitative data are shown by means and standard deviations or medians (IQ 25–75%), depending on data normality. Data normality was analyzed by the Shapiro-Wilk test.

Pearson's or Spearman's correlation analysis were performed for dependent variables (performance on tests of executive functions and memory) and independent variables (age; percentage of body fat; visceral fat in relation to total weight; BMI z-score for age; stress scale score; cortisol levels; ABEP score; distance walked and speed reached in MST; HPAL score). A stepwise linear regression was performed for variables with significant correlation (p: 0.05). Multicollinearity between the independent variables and the interaction between variables were tested. Participants were categorized into distinct age groups: from seven to 10 years (late childhood), 11 to 14 years (early adolescence), and 15 to 18 years (late adolescence). Data were analyzed by the statistical package IBM SPSS Statistics, version 22 (Inc, USA).

Sample size

Sample size was determined by a study that found an association between cardiorespiratory fitness and executive function among children and adolescents with obesity/overweight, with a 23% effect size. Considering a 5% significance level and a 80% poweranalysis showed that a minimum sample size (n) of 29 participants was necessary[19].

RESULTS

The sample consisted of 32 participants of both sexes (56% boys) with a mean age of 11 years. Participants with socioeconomic strata B2 and C showed a higher fat mass percentage (Table 1).

Table 1. Characteristics of participants

Parameter		Mean±SD or %
Sex (F/RF)		
	Male	18 (56.20%)
	Female	14 (43.80%)
Age		11.25±3.14
Anthropometric characteristics		
	BMI (Kg/m²)	27.18±3.78
	Fat mass (%)	42.38±5.43
	VF/BW (g/Kg)	6.22±2.88
	Z-score (BMI)	2.71±0.63
Stress		31.03±18.55
MMSE		34.87±2.34
Cortisol (mcg/dL)		11.16±5.03
	Distance covered (m)	429.87±170.35
	Speed (m/s)	1.59±0.29
Economic status		
	A	2 (6.25%)
	B1	2 (6.25%)
	B2	10 (31.25%)
	C1	4 (12.50%)
	C2	7 (21.87%)
	D-E	7 (21.87%)
Maternal education (F/RF)		
	Incomplete elementary	5 (15.60%)
	Complete elementary	3 (9.40%)
	Incomplete high school	3 (9.40%)
	Complete high school	15 (46.90%)
	Undergraduate	1 (3.10%)
	Graduated	5 (15.60%)
HPAL (F/RF)		
	Does not practice	20 (62.50%)
	Insufficiently active	6 (18.75%)
	Sufficiently active	6 (18.75%)

Note: standard deviation (SD); frequency/relative frequency (F/RF); body mass index (BMI); visceral fat/body weight (VF/BW); mini-mental state examination (MMSE); mcg/dL (micrograms/deciliters); habitual physical activity level (HPAL).

Regarding the possible predictors of performance in the RAVLT test, the fat mass was negatively correlated with learning and interference indices ($p<0.05$; $r=-0.36$). This study found a negative correlation between the BMI z-score ($p<0.05$; $r=-0.37$) and the recall index in the RAVLT ($p<0.05$; $r=-0.35$) (Table 2).

Regarding VF test, this study observed, for the semantic category of animals, no significant differences with the independent variables. As for the categories "parts of the body" ($p<0.05$; $r=-0.43$) and "food" ($p<0.05$; $r=-0.35$), the VF/BW variable showed negative correlations. Similarly, the VF total score also showed a negative correlation ($p<0.05$; $r=-0.41$) with this variable (Table 2).

The ToH test showed some correlations with the analyzed variables. The number of errors on this test was negatively correlated ($p<0.01$; $r=-0.49$) with stress levels. The number of novices in the ToH test showed a negative correlation ($p<0.01$; $r=-0.47$) with the HPAL (Table 3).

Table 2. Analyses of correlations between variables related to performance in the Rey Auditory Verbal Learning and verbal fluency tests

Parameter	RAVLTL	RAVLTI	RAVLTRe	RAVLTR	VFA	VFB	VFF	VF Total
Age	0.12	0.07	0.18	−0.02	0.10	0.17	0.16	0.13
Fat mass (%)	−0.36*	−0.35*	−0.34	0.08	0.01	−0.12	−0.07	−0.06
VF/BW	−0.35*	−0.20	−0.17	−0.43*	0.29	−0.43*	−0.35*	−0.41*
BMI Z-score	−0.33	−0.12	−0.37*	−0.10	−0.10	−0.18	−0.19	−0.12
Cortisol	0.06	−0.03	−0.13	−0.28	−0.13	−0.14	−0.06	−0.15
Physical functioning - Distance	−0.07	−0.16	0.07	−0.09	0.02	−0.06	0.14	0.04
Physical functioning - Speed	−0.10	−0.16	0.04	−0.14	0.02	−0.06	0.14	0.04
Stress	0.18	−0.08	−0.13	0.06	0.00	−0.02	0.17	0.05
ABEP	0.01	0.12	0.15	−0.04	0.12	0.12	0.31	0.23
HPAL	−0.33	−0.03	−0.22	−0.21	0.20	0.10	−0.10	0.03

Note: RAVLT Learning (RAVLTA); RAVLT Interference (RAVLTI); RAVLT Recall (RAVLTRe); RAVLT Recognition (RAVLTR); semantic category of animals in the verbal fluency test (VFA); semantic category of parts of the body in the verbal fluency test (VFB); semantic category of food in the verbal fluency test (VFF); verbal fluency test Total (VF total); proportion of visceral fat in relation to body weight (VF/BW); body mass index (BMI); Brazilian Market Research Association (ABEP); habitual physical activity level (HBAL); Pearson's correlation was used to analyze the data. The symbol * (*p*<0.05) indicates a significant correlation.

Table 3. Analyses of correlations between variables related to performance in the Tower of Hanoi and Stroop tests

Parameter	ToH M	ToH E	Stroop 1	Stroop 2	Stroop 3	Stroop E
Age	0.04	0.01	−0.10	−0.05[a]	−0.05[a]	−0.02
Fat Mass (%)	0.18	0.17	0.05	0.03[a]	0.04[a]	0.12
VF/BW	−0.01	0.10	0.13	0.10[a]	0.01[a]	0.03
BMI Z-score	0.16	0.13	−0.09	0.04[a]	0.03[a]	0.04
Cortisol	0.01	0.18	0.40*	0.19	0.28[a]	0.02
Distance – MST	0.04	0.20	−0.02	−0.12[a]	−0.12[a]	−0.06
Speed – MST	−0.02	−0.16	−0.05	−0.11[a]	−0.11[a]	−0.08
Stress	0.14	0.49**	0.36*	0.35*[a]	0.37*[a]	0.43*
ABEP	−0.01	0.22	−0.38*	−0.26[a]	−0.28[a]	−0.40
HPAL	−0.47*	−0.30	0.14	0.07[a]	0.02[a]	0.06

Note: Tower of Hanoi (ToH); number of errors in the Stroop test (Stroop E); proportion of visceral fat in relation to body weight (VF/BW); body mass index (BMI); modified shuttle test (MST): Brazilian Market Research Association (ABEP); habitual physical activity level (HBAL). Pearson's (symbol "a") and Spearman's correlations were used to analyze the data. Bold values with the symbols * (p<0.05) and ** (p<0.01) indicate a significant correlation.

After analyzing the correlations of performance in cognitive tests and probable predictors, a linear regression analysis was carried out. The description of results followed significance level (p), a standardized coefficient (β), and the coefficient of determination (R^2).

In the RAVLT, learning showed a negative association with fat percentage and GV/PT (p:0.04, β:−0.36 and R^2:0.13). Interference was significantly associated with % fat (p:0.01, β:−0.51 and R^2:0.25). Recall index showed an association with the BMI z-score (p:0.01, β:−0.51, R^2:0.25). Visceral fat influenced recognition index (p: 0.01, β:−0.43 and R^2:0.19).

Semantic memory (in the VF test) showed a significant association only with VF/BW (p:0.04, β:−0.36, R^2:0.13).

Execution time in the ToH showed a significant association with visceral fat proportion (p:0.04, β:−0.38, R^2:0.14), whereas the number of movements was associated with sport dominance and exercise (p:0.007, β:−0.45 R^2:0.22) and the number of errors was correlated with the stress scale score (p:0.004, β:0.49, R^2:0.25).

The ST showed significant associations for the first ST card (ST1) with the CSS score (p:0.04, β:0.36, R^2:0.13), the ABAEP socioeconomic score (p:0 .03, β:−0.38, R^2:0.15), and with blood cortisol concentrations (p:0.03, β:0.40, R^2:0.16). For the second (ST2) and third ST card (ST3), significant associations occurred with the stress scale score (p:0.04, β:0.35, R^2:0.12 and p:0.04, β:0.37, R^2:0.14, respectively). The total number of errors showed significant associations with CSS (p:0.01, β:0.43, R^2:0.19) and the ABAEP socioeconomic score (p:0.02, β:−0.40, R^2:0.17).

Figure 1 summarizes this information.

↑ Fat %	↓ RAVLT Learning ↓ RAVLT Interference
↑ z-score BMI	↓ RAVLT Recall
↑ VF/BW	↓ RAVLT Recognition ↓ VF body parts ↓ Tower of Hanoi time
↑ Habitual Physical Activity Level	↓ Tower of Hanoi moves
↑ Stress	↑ Errors Tower of Hanoi ↑ Errors Stroop Test; Time ST1, ST2 e ST3
↑ Cortisol	↑ Time ST1
↑ Economic levels	↓ Errors Stroop Test; Time ST1

Figure 1. Summary of results obtained in linear regression analyses

Note: Rey auditory verbal learning test (RAVLT); body mass index (BMI); proportion of visceral fat in relation to body weight (VF/BW); Stroop test card one (ST1); Stroop test card two (ST2); Stroop test card three (ST3).

DISCUSSION

This study showed that adiposity was associated with worse episodic memory in children and adolescents with obesity. Semantic memory (VF test) was associated with visceral fat. In the ToH, planning task and cognitive flexibility were associated with visceral fat, whereas the number of movements was correlated with the practice of sports and physical exercise. Regular exercise favors planning tasks in children and adolescents with obesity. The number of errors in the tower of Hanoi was directly associated with stress levels (CSS). Stress levels (CSS and cortisol levels) and socioeconomic status were associated with selective attention and executive functions.

This study found a negative association between adiposity (evaluated by fat mass, VF/BW, and BMI z-scores) and performance on the RAVLT learning, interference, recall, and recognition domains. A previous study has observed diminished performance in adolescents with obesity (evaluated by BMI) aged 12–18 years, specifically in the indices of recall and recognition[20]. This suggests that heightened adiposity indices in children could be associated with reduced performance across the assessed parameters evaluated in the test. The results in our study indicate that childhood obesity negatively impact the entire process of episodic memory from the learning stage to the final processes of recall and recognition. Deficiencies in the interference domain means relevant data is forgotten due to the encroachment of novel information, constituting a mechanism that assesses the consolidation of memory[21].

This study observed a correlation between VF within the semantic domain of "body parts" and VF/BW, suggesting a potential relationship. It showed that heightened levels of visceral adiposity in participants were associated with diminished proficiency in executing this cognitive task. Other authors have shown compromised outcomes in VF assessments within the population of children with obesity/overweight (average age of 4.59 years)[22]. Hippocampus is responsible for the consolidation of episodic and spatial memories[23]. A plausible connection exists between childhood obesity and potential effects on the hippocampal consolidation process for episodic memory, supported by previous research[24]. In future studies, neuroanatomical image analysis of this structure may identify possible causal relationships.

Childhood and adolescence are periods with significant neurodevelopmental activity, encompassing vital processes such as synaptogenesis and pruning, which are critical to establish precise neuronal connections[25].

The association of the VF test with cortical regions has been extensively investigated. The frontal lobes, especially the prefrontal cortex, play a pivotal role in VF tasks[25]. In studies involving children with obesity, anatomical alterations in the cortical region were associated with a lower ability in the VF test[26]. The outcomes of the current investigation align with previous findings and could be linked to the neurodevelopmental timeframe between childhood and adolescence.

Executive functions comprise a set of intricate cognitive processes associated with the frontal cortex, playing a pivotal role in planning, decision-making, inhibitory control, cognitive flexibility, selective attention, problem solving, and other activities demanding the coordination of mental processes to attain specific goals[27]. In this context, a body of evidence links childhood obesity with impaired executive function. For example, children with obesity showed deficits in inhibitory control and attention, the main components of executive functions assessed by the ST[28]. Similarly, children with obesity/overweight also show a greater number of errors in performing the ToH test[22].

Successful resolution of the ToH or achieving minimal errors in the ST arises from complex interactions among various executive functions[27]. In the current study, there were positive correlations between cortisol, stress levels, and performance on these two tasks. This suggests that stress serves as a predictive factor in the cognition of children with obesity, compromising several domains of executive functions. The body releases cortisol when faced with stressors. Elevation of cortisol levels from prolonged and sustained stress can modify cognitive processes and behavioral patterns[29]. Elevated cortisol levels and high reactivity to stressful situations consistently occur in children with obesity[30].

The performance on the ST showed associations with socioeconomic status as participants of lower economic status showed poorer performance on the initial component. A study involving preschoolers from lower socioeconomic backgrounds showed their inferior performance in inhibitory control tasks and reading skills[31].

The number of ToH movements was negatively associated with the HPAL score. This suggests that children with obesity who regularly practice physical exercise are more assertive in tests involving executive functions, which is in line with previous data[5]. The habitual physical activity level can promote greater neuroplasticity, especially in a critical window of neurodevelopment[32]. This process enables the brain to modify neural pathways, strengthen synaptic connections, and generate new neurons in certain regions, which can reduce deleterious effects of obesity on neurodevelopment[33].

Several parameters of body composition serve as predictors of performance in cognitive and memory assessments. Stress and cortisol levels impacted executive functions. Also, the engagement in regular physical activity might configure a protective effect. These findings hold substantial implications for enhancing our understanding of predictive factors and formulating guidelines to reduce adverse impacts on cognitive and memory functions in obese children and adolescents.

The limitations of this study include its broad age range. To reduce this limitation, z-scores of performances were applied to the sample segmented by age groups. This research ignored assessments of inflammatory states and neuroanatomical images, which may offer a strong predictor for evaluation in future studies.

This study suggests a significant association between adiposity and episodic and semantic memory. Additionally, executive functions are linked to stress, cortisol levels, and economic status, whereas engagement in habitual physical activity might positively influence executive function. Therefore, it is essential for healthcare systems to implement policies to combat childhood obesity, particularly by initiatives promoting physical activity, as this has a protective effect on executive functions and may help reduce stress and cortisol levels, which are also associated with cognitive memory performance. This study highlights the potential utility of adiposity as a body composition parameter to predict performance in memory assessments. If future research corroborates these findings, they could inform strategies to address obesity in children and adolescents, ultimately enhancing cognitive development.

CONCLUSION

This study indicates that adiposity might be associated with worse episodic memory and that visceral fat might be related with semantic memory (verbal fluency test) and planning task and cognitive flexibility (tower of Hanoi) in children and adolescents with obesity. Also, sports practice and physical exercise might be associated with planning tasks (the number of movements in the Tower of Hanoi) in children and adolescents with obesity. The number of errors was directly associated with stress (child stress scale). Stress (CSS and cortisol levels) and socioeconomic status might be associated with selective attention and executive functions.

AKNOWLEDGEMENT

The authors thank the FAPEMIG, CNPq, and CAPES for their financial support and scholarships.

REFERENCES

1. Kim HJ, Lee KJ, Jeon YJ, Ahn MB, Jung IA, et al. Relationships of physical fitness and obesity with metabolic risk factors in children and adolescents: Chungju city cohort study. Ann Pediatr Endocrinol Metab. 2016;21(1):31. doi: 10.6065/apem.2016.21.1.31.
2. Zhang X, Liu J, Ni Y, Yi C, Fang Y, et al. Global Prevalence of Overweight and Obesity in Children and Adolescents. JAMA Pediatr. 2024;178(8):800-13. doi: 10.1001/jamapediatrics.2024.1576.
3. Guedes DP, Mello ERB. Prevalence of overweight and obesity among Brazilian children and adolescents: systematic review and meta-analysis. ABCS Health Sci. 2021;46:1-12. doi: 10.7322/abcshs.2019133.1398.
4. Faienza MF, Chiarito M, Molina-Molina E, Shanmugam H, Lammert F, et al. Childhood obesity, cardiovascular and liver health: a growing epidemic with age. World J Pediatr. 2020;16(5):438-45. Doi: 10.1007/s12519-020-00341-9.
5. Sun X, Li Y, Cai L, Wang Y. Effects of physical activity interventions on cognitive performance of overweight or obese children and adolescents: a systematic review and meta-analysis. Pediatr Res. 2021;89(1):46-53. doi: 10.1038/s41390-020-0941-3.
6. Thompson A, Steinbeis N. Sensitive periods in executive function development. Curr Opin Behav Sci. 2020;36:98-105. doi: 10.1016/j.cobeha.2020.08.001.
7. Dennis E, Manza P, Volkow ND. Socioeconomic status, BMI, and brain development in children. Transl Psychiatry. 2022;12(1):33. doi: 10.1038/s41398-022-01779-3.
8. Jain M, Passi GR. Assessment of a Modified Mini-Mental Scale for Cognitive Functions in Children [Internet]. Indian Pediatr. 2005;42(9):907-12 [cited 2025 Jan 3]. Available from: https://www.indianpediatrics.net/sep2005/907.pdf.
9. ABEP. Critério de classificação econômica Brasil [Internet]. São Paulo: ABEP; 2008 [cited 2025 Jan 3]. Available from: www.abep.orgPo.
10. Singh SJ, Puhan MA, Andrianopoulos V, Hernandes NA, Mitchell KE, et al. An official systematic review of the European Respiratory Society/American Thoracic Society: Measurement properties of field walking tests in chronic respiratory disease. Eur Respir J. 2014;44(6):1447-78. doi: 10.1183/09031936.00150414.
11. Lanza FDC, Zagatto EDP, Silva JC, Selman JPR, Imperatori TBG, et al. Reference Equation for the Incremental Shuttle Walk Test in Children and Adolescents. J Pediatr. 2015;167(5):1057-61. doi: 10.1016/j.jpeds.2015.07.068.
12. Soares LA, Lima LP, Prates ACN, Arrieiro AN, Teixeira LAC, et al. Accuracy of handgrip and respiratory muscle strength in identifying sarcopenia in older, community-dwelling, Brazilian women. Sci Rep. 2023;13(1):1553. doi: 10.1038/s41598-023-28549-5.
13. Boake C. Edouard Claparede and the auditory verbal learning test. J Clin Exp Neuropsychol. 2000;22(2):286-92. doi: 10.1076/1380-3395(200004)22:2;1-1;FT286
14. Machado TH, Fichman HC, Santos EL, Carvalho VA, Fialho PP, et al. Dados normativos de idosos saudáveis na prova de fluência verbal fonêmica - FAS. Dement Neuropsychol. 2009;3(1):55-60. doi: 10.1590/S1980-57642009DN30100011.
15. Vakil E, Lowe M, Goldfus C. Performance of children with Developmental Dyslexia on two skill learning tasks—serial reaction time and tower of hanoi puzzle: a test of the specific procedural learning difficulties theory. J Learn Disabil. 2015;48(5):471-81. doi: 10.1177/0022219413508981.
16. Charchat-Fichman H, Oliveira RM. Performance of 119 Brazilian Children on StrooP Paradigm-Victoria VerSion. Arq. Neuro-Psiquiatr. 2009;67(2-8):445-9. doi: 10.1590/S0004-282X2009000300014.
17. Lucarelli MDM, Lipp MEN. Validação do inventário de sintomas de stress infantil - ISS - I. Psicol Reflex Crit. 1999;12(1):71-88. doi: 10.1590/S0102-79721999000100005.
18. Baecke, JA, Burema J, Frijiters JE. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. Am J Clin Nutr. 1982;36(5):936-42. doi: 10.1093/ajcn/36.5.936.
19. Mora-Gonzalez J, Esteban-Cornejo I, Cadenas-Sanchez C, Migueles JH, Molina-Garcia P, et al. Physical fitness, physical activity, and the executive function in children with overweight and obesity. J Pediatr. 2019;208:50-6. doi: 10.1016/j.jpeds.2018.12.028.
20. Vantieghem S, Bautmans I, Guchtenaere A, Tanghe A, Provyn S. Improved cognitive functioning in obese adolescents after a 30-week inpatient weight loss program. Pediatr Res. 2018;84(2):267-71. doi: 10.1038/s41390-018-0047-3.
21. Zuanetti PA, Lugli MB, Fernandes ÂCP, Soares MST, Silva K. Memory performance, oral comprehension and learning process between children with attention deficit hyperactivity disorder and children with anxiety disorder. Rev CEFAC. 2018;20(6):692-702. doi: 10.1590/1982-0216201820614218.
22. Fernandes AC, Viegas ÂA, Lacerda ACR, Nobre JNP, Morais RLS, et al. Association between executive functions and gross motor skills in overweight/obese and eutrophic preschoolers: cross-sectional study. BMC Pediatr. 2022;22(1):1-17. doi: 10.1186/s12887-022-03553-2.
23. Danieli K, Guyon A, Bethus I. Episodic Memory formation: A review of complex Hippocampus input pathways. Prog Neuropsychopharmacol Biol Psychiatry. 2023;126:110757. doi: 10.1016/j.pnpbp.2023.110757.
24. Nyberg CK, Fjell AM, Walhovd KB. Level of body fat relates to memory decline and interacts with age in its association with hippocampal and subcortical atrophy. Neurobiol Aging. 2020;91:112-24. doi: 10.1016/j.neurobiolaging.2019.10.005.
25. Gaillard WD, Sachs BC, Whitnah JR, Ahmad Z, Balsamo LM, et al. Developmental aspects of language processing: fMRI of verbal fluency in children and adults. Hum Brain Mapp. 2003;18(3):176-85. doi: 10.1002/hbm.10091.
26. Reinert KRS, Po'e EK, Barkin SL. The relationship between executive function and obesity in children and adolescents: a systematic literature review. J Obes. 2013;2013:820956. doi: 10.1155/2013/820956.
27. Mamrot P, Hanć T. The association of the executive functions with overweight and obesity indicators in children and adolescents: A literature review. Neurosci Biobehav Rev. 2019;107:59-68. doi: 10.1016/j.neubiorev.2019.08.021.
28. Chen S, Jia Y, Woltering S. Neural differences of inhibitory control between adolescents with obesity and their peers. Int J Obes (Lond). 2018;42(10):1753-1761. doi: 10.1038/s41366-018-0142-x.
29. Russell G, Lightman S. The human stress response. Nat Rev Endocrinol. 2019;15(9):525-34. doi: 10.1038/s41574-019-0228-0.

30. Christaki EV., Pervanidou P, Papassotiriou I, et al. Stress, Inflammation and metabolic biomarkers are associated with body composition measures in lean, overweight, and obese children and adolescents. Children (Basel). 2022;9(2):1-16. doi: 10.3390/children9020291.

31. Abreu PMJE, Abreu N, Nikaedo CC, Puglisi ML, Tourinho CJ, et al. Executive functioning and reading achievement in school: a study of Brazilian children assessed by their teachers as "poor readers". Front Psychol. 2014;5(550):1-14. doi: 10.3389/fpsyg.2014.00550.

32. Crova C, Struzzolino I, Marchetti R, Masci I, Vannozzi G, et al. Cognitively challenging physical activity benefits executive function in overweight children. J Sports Sci. 2014;32(3):201-11. doi: 10.1080/02640414.2013.828849.

33. Zysset AE, Kakebeeke TH, Messerli-Bürgy N, Meyer AH, Stülb K, et al. Predictors of executive functions in preschoolers: Findings from the SPLASHY Study. Front Psychol. 2018;9(2060):1-11. doi: 10.3389/fpsyg.2018.02060.