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Fat mass predicts food-specific inhibitory control in children

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ABSTRACT

Background/objectives: Impaired inhibitory control has been associated with obesity, high blood pressure and lack of physical fitness. These impairments are thought to be related to decreased cognitive control over excessive food consumption and may start in childhood. However, previous studies in children have examined inhibitory control deficits using general (non-food-specific) tasks and relied on body mass index, which does not distinguish the amount of fat mass. As fat mass, hypertension and physical fitness have been shown to play a role in cognition, the aim of this study was to investigate the relationship between these variables and food specific inhibitory control in children.

Subjects/methods: Children's (n = 48; Age 10.7 ± 0.6 years) general characteristics, fat mass, cardiorespiratory fitness, blood pressure and performance on a food-specific inhibitory control task (Go/No-go) were measured across two sessions.

Results: Fat mass and sex were associated with inhibitory control performance, while no associations were found for cardiorespiratory fitness, blood pressure and other potential confounding variables (i.e. age, pubertal timing, body mass index, waist-to-hip ratio, scholar test performance and heart rate). Linear regression analyses showed that only fat mass predicted poorer food-specific inhibitory control ($\beta = 0.36$; $\Delta R^2 = 0.04$; $p < .05$) and sex predicted inhibitory control for toys (control condition) ($\beta = 0.42$; $\Delta R^2 = 0.11$; $p < .01$). Neither blood pressure nor cardiorespiratory fitness predicted food specific inhibitory control.

Conclusion: These findings suggest that fat mass is an independent predictor of inhibitory control for food in children.

1. Introduction

Obesity is a worldwide public health problem and it is associated with cardiovascular diseases, such as hypertension and diabetes, leading to higher rates of mortality [10]. Commonly seen in adulthood, these comorbidities related to obesity are now being identified in children and are attributed to overeating behavior and sedentariness [11,34]. The characteristics of modern society, with readily available highly palatable foods and sedentary behavior, have been suggested to be one of the major factors contributing to the prevalence of obesity in children [36,59]. The association between cognitive impairment and obesity has recently been highlighted, suggesting that such impairments may directly influence the ability to override the desire for excessive food consumption, leading to overeating and obesity [27,49,57]. Recent evidence has emphasized the brain as one of the first organs to be damaged by hypertension [28], which is highly correlated to obesity [13]. Even though the causal relationship is currently unclear, what is indicated by the research is that obesity and hypertension are related to cognitive impairment, making them a target for intervention. However, the relative roles of obesity and hypertension in cognitive impairment are poorly understood in children. Understanding this relationship is critical as early identification and intervention can affect childhood health, education and behavior for the following years.

Obesity is the consequence of complex aetiological processes, but the simplest view based on the first law of thermodynamics, which posits that obesity results from an imbalance between caloric intake and energy expenditure. This indicates that diet and exercise are likely to be the most important health behaviors to promote organic adaptations

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related to the management of body weight and lower fat mass [21]. Moreover, greater cardiorespiratory fitness is associated with lower fat mass [69], better cognitive performance and improved prefrontal cortex functioning. The release of neurotrophins (i.e. brain-derived neurotrophic factor and vascular endothelial growth factor) during exercise has been shown to induce neuroplasticity [6]. The prefrontal cortex plays an important role in orchestrating several brain functions and determining an individual's behavior by regulating the networks involved in executive functioning [33] and higher Body mass index (BMI) has been associated with lower prefrontal cortex function [67]. Inhibitory control is an important component of executive functioning and it is defined as the ability to keep attention and focus on goal-oriented information, and inhibit automatic, goal-incongruent information [58]. Thus, higher cardiorespiratory fitness and lower fat mass may contribute to better inhibitory control.

Previous findings in adults have demonstrated that poorer general and food-specific inhibitory control is related to obesity, with more consistent results associated to general inhibitory control [38,60] and results from a meta-analysis demonstrate that impulsivity is positively associated with BMI [15]. However the small effect size of this results have been criticized [44]. Moreover, only food-specific (and not general) inhibitory control is independently predicted by body fat in adults [54] and inhibitory control deficits have also been found to be related to BMI in children [49,56]. However, studies to date have not investigated the role of cardiorespiratory fitness or fat mass in food-specific inhibitory control in children and have mainly used BMI as a marker of obesity [27,49,57]. BMI has been criticized as it does not accurately distinguish between fat mass and fat-free mass [19]. Adipose tissue is a defining feature of obesity and secretes hormones (i.e., leptin, adipokines, pro and anti-inflammatory cytokines), which act on brain centers associated with hunger control (i.e. hypothalamus) [21]. Thus, measuring the amount of fat mass with a highly precise method may be more sensitive to changes in inhibitory control.

It has been suggested that food-specific inhibitory control might be particularly important to capture, as it may influence an individuals ability to inhibit inappropriate unhealthy behaviors such as overeating in response to the obesogenic environment [27,49,52] and, therefore, prevent obesity and its comorbidities such as hypertension. No research to date has investigated the role of blood pressure in food specific inhibitory control, which is associated with higher fat mass and obesity [13]. High blood pressure has been related to remodeling on cerebral vessels, microvascular rarefaction, lower cerebral blood flow, smaller brain volume and prefrontal cortex dysfunction [28]. This may serve to reduce cognitive functioning, with previous studies showing that hypertensive children and adults have lower general inhibitory control [14,35,37]. However, eating behavior is suggested to be determined by an interaction of top-down inhibitory control and bottom-up food reward motivation, making the choice of stimulus relevant [5]. Thus, the non-food specific measurements of inhibitory control in these studies might weaken the generalization to eating behaviors such as high-calorie food.

Therefore, this study was designed to fill gaps in the literature by investigating the relationship between fat mass, blood pressure, cardiorespiratory fitness and food specific inhibitory control in children. Accordingly, cognition might be influenced by fat mass, blood pressure and cardiorespiratory fitness status. Hence, we hypothesized that higher fat mass, elevated levels of blood pressure and lower cardiorespiratory fitness would be related to poorer performance on an inhibitory control task. It was further predicted that any effects would be stronger for food versus neutral stimuli. Additionally, most studies in the behavior and psychology area are based on western populations [24] while obesity rates are rising globally. Therefore, this study has used a non-western sample of Brazilian children, which are at increasing risk for obesity [18] and are an important target for intervention. These investigations in a cross-cultural sample should afford new insights for studies that investigate inhibitory control related to childhood obesity.

2. Material and methods

2.1. Participants

We recruited 133 children aged 9 to 11 years from three local schools in the city of Natal, Brazil. The following inclusion criteria were evaluated at the first meeting with the children in the schools: 1) free of cardiovascular risk and physical limitation assessed by the physical activity readiness questionnaire [63]; 2) Able to read and free of cognitive impairment assessed by a regular scholar test; 3) Not taking any medicine. Eighty-five children were excluded from the analysis since they did not perform the second testing session at the university. This was due to absence to regular school day (n = 48) or problems while completing any of the measurements for body composition (n = 10), cognitive test (n = 4) or blood pressure (n = 23) due to the lack of time during the school regular hours available for this research study. Thus, data from 48 children (23 girls and 25 boys) were reported in the study. The study followed the standards of the Declaration of Helsinki and was approved by the local ethics committee.

2.2. Study design

In this cross-sectional study, students were initially informed about the aims, procedures and risks of the research and received an invitation to participate. If the children and their parents agreed to participate, measurements were conducted a week later in two testing sessions separated by 24 h. The first session was carried out in the children's school where anthropometric measurements and the cardiorespiratory fitness test were completed. At the second session, the children visited the lab at the university where fat mass, blood pressure and both general and food-specific Go/No-go inhibitory control tasks were completed. Linear regression analyses were used to examine which physiological variables (fat mass, cardiorespiratory fitness, and blood pressure) predicted variance in inhibitory control. Possible covariables (age, pubertal timing, body mass index, waist-to-hip ratio, scholar test performance, sex and baseline heart rate) were identified using bivariate correlations and later included in the linear regression analyses models if they were significantly related to inhibitory control outcomes.

2.3. Primary variables

2.3.1. Fat mass

Body composition was determined using an iDXA (GE Healthcare Lunar, Madison, WI, USA) and version 13.6 enCore™2011 software (GE Healthcare Lunar). Total body measurements were performed to determine fat mass (FM), bone mineral content (BMC) and lean soft tissue (LST). The subjects remained in the supine position on the machine, wore light clothing and no shoes (for approximately 7 min). The percent of fat mass (%FM) was calculated with total body and FM (% FM = (FM ∗ 100)/weight) values.

2.3.2. Cardiorespiratory fitness test

The children performed the progressive effort test proposed by Léger [39] known as multistage 20 m shuttle-run. In this test, subjects perform an incremental run between two points that are 20 m apart. The displacement rhythm should occur in agreement with sound signals emitted by an audio recorded specifically for the execution of the test. The test is finished when the subject cannot keep running between the 20 m points in sync with the recording. The estimative maximum oxygen consumption (VO_2max) was calculated by a predicted equation described [39]. This approach has shown reliability and validity to be used as a cardiorespiratory fitness marker when individual's maximum oxygen uptake attained during a laboratory-based test is not feasible [43].

2.3.3. Blood pressure measurement

The children sat down in a chair to rest for at least 5 min and, then, three blood pressure measurements, intercalated by 2 min, were taken using a validated [62] automatic blood pressure monitor and specific cuff for children. The average of the three measurements for both systolic and diastolic blood pressure were calculated.

2.3.4. Food specific inhibitory control test

An adapted protocol from Price et al. [54] was used. This protocol is a Go/No-go task performed on a computer where Go stimulus are represented by object pictures (neutral), and No-go stimulus are represented by high-calorie food or toys images. Subjects were instructed to press the space bar whenever they saw an object picture (Go stimulus) and withhold for toys or food (No-go stimulus). One block was performed with toys as the No-go stimulus (used as general inhibitory control), and another block with food as No-go stimulus (used as food-specific inhibitory control). Each block consisted of 100 trials. The images were presented randomly with a ratio of 80% for neutral images and 20% for images of foods or toys. For each stimulus (Go/No-go) 10 images were chosen and presented in random order. The children completed two blocks of general inhibitory control, followed by two blocks of food-specific inhibitory control, making four blocks in total per child. In total, there were 320 neutral trials (Go) and 80 food and toy image trials (No-go). The image was shown on the screen for 750 ms and between each image, a blank screen (500 ms) was shown, followed by another blank screen with the signal of fixation "+" (500 ms) (Fig. 1). Each food and toy image were interspersed, in random order, by at least 3, 4 or 5 neutral images. The test lasted about 7 min. Number of errors in No Go trials (commission errors) were used to indicate cognitive performance. Instructions were standardized and comprehension and willingness of the children were assured by a short preceding practice trial (one block of each condition). To avoid hunger during the test, half an hour before, a standard snack was consumed by all children.

2.4. Secondary variables

2.4.1. Anthropometry

Body weight (kg) and total height (cm) were measured. Seated height was measured and the leg length was calculated by the subtraction of seated height from the total height. Hip and waist circumference (cm) were measured and used to calculate the Waist-hip ratio (WHR). Body mass index (BMI kg/m^2) was also calculated.

2.4.2. Pubertal timing

Somatic maturation was calculated according to a standardized equation [48] for boys and girls. The estimated results from this measure represent the distance in years from/to reach the peak height velocity (PHV). For negative maturity offset prediction, the individual classification was considered as pre-PHV, and for positive prediction post-PHV [48].

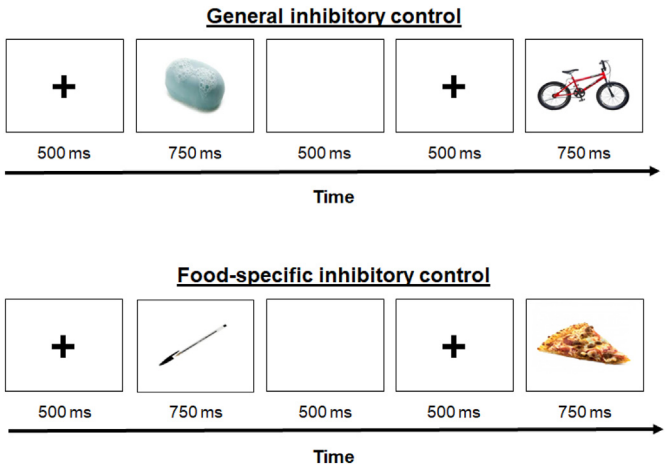

Fig. 1. Food-specific and general inhibitory control task.

2.4.3. School performance test (SPT)

The SPT is a psychometric instrument developed to evaluate fundamental capacities for scholarly performance in reading, writing and arithmetic. This test has been validated for the age range and nationality of the children included in the current study [32].

2.5. Statistical analyses

Parametric data are expressed as mean and standard deviation (SD) and non-parametric data are expressed as median and confidence interval (CI). Shapiro-Wilk test was used for data normality analysis and Levene's test for homogeneity. For non-parametric variables (toy errors, food errors, BMI, age, PHV and SPT) Blom's transformation was completed to achieve homogeneity and normality. The differences in inhibitory control for food and general (toys) stimuli and pubertal timing between boys and girls were analyzed by paired t-tests. Pearson correlations were conducted for the dependent variables from the Go/No-go task (food and toys) with primary (fat mass, VO_2 max and blood pressure) and secondary variables (age, sex, PHV, BMI, WHR, SPT, BHR) to identify associations and covariates in order to include in following linear regression analysis. Two separate linear regression analyses were used to investigate the independent contributions of the four possible predictor variables (fat mass, VO_2 max, SBP, DBP) to the variance in food and toy commission errors (with food or toy commission errors included as covariates in each model as relevant). Assumptions of equality of variance, independence, linearity and normality were plotted, inspected, and verified using Studentized residuals. Multicollinearity was not observed among any of the independent variables. The significance level was set at $p < .05$.

3. Results

Basic descriptive demographic data are displayed in Table 1. A median split of the participants based on fat mass [Lower fat mass (LFM) vs Higher fat mass (HFM)] is provided only for informational purposes. Across the whole sample the number of errors in toys was lower compared to food errors (t = 2.76; p = .007).

Table 1
Sample characteristics, body composition, cardiorespiratory fitness, cardiovascular responses, food-specific and general inhibitory control performance.

Variables	All sample (n = 48)	LFM (n = 22)	HFM (n = 26)
Age (years)	10.5 ± 0.7	10.2 ± 0.6	10.6 ± 0.7
Sex (male) (%)	52%	54%	50%
PHV (years)[#a]	2 (1.6–1.9)	3 (3–2)	2 (2–1.6)
Fat mass (%)	33.9 ± 8.0	26.7 ± 4.5	39.9 ± 4.7
BMI (kg/m^2)[#]	18.5 (18.3–19.9)	18 (16–18)	20 (19–21)
WHR (cm)	0.8 ± 0.05	0.8 ± 0.05	0.8 ± 0.05
VO_2max (ml/kg/min)	43.2 ± 3.4	45.2 ± 3.0	41.5 ± 2.8
SPT (score)[#]	99 (88–102)	100 (78–104)	97 (92–105)
SBP (mmHg)	109.8 ± 10.8	108.7 ± 12.2	110.7 ± 9.7
DBP (mmHg)	67.3 ± 7.9	65.6 ± 8.0	68.6 ± 7.8
BHR (bpm)[#]	83 (62–104)	77 (66–88)	81 (74–88)
Toys errors[#]	3 (2.5–3.8)	3 (1.8–4.1)	3 (2.1–4.1)
Food errors[#]	4.5 (3.5–5.2)	3 (2.3–4.6)	5 (4–6)

Data presented as mean and standard deviation; LFM: Lower fat mass; HFM: Higher fat mass; PHV: Peak height velocity; BMI: Body mass index; WHR: Waist-hip ratio; SPT: Scholar performance test; SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; BHR: Baseline heart rate.

[#] Median and confidence interval values.

[a] Values were multiplied for −1 to better visualization.

Table 2
Correlations between primary and secondary variables with cognitive performance [commission errors for food-specific and general (toy)] in the inhibitory control test for the total sample (n = 48).

	Toys errors	Food errors
	Primary variables	
Fat mass	0.12	0.24*
VO_2max	−0.08	0.04
SBP	−0.07	−0.11
DBP	0.00	0.06
	Secondary variables	
Age	−0.00	0.11
Sex	0.40**	0.19
PHV	0.10	0.18
BMI	−0.05	0.01
WHR	0.12	0.18
SPT	0.03	−0.2
BHR	−0.20	−0.10

SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure; PHV: Peak height velocity; BMI: Body mass index; WHR: Waist-hip ratio SPT: Scholar performance test; BHR: Baseline heart rate.
* $p < .05$.
** $p < .01$.

Table 2 summarizes the Pearson correlation analyses between cognitive performance with primary variables and secondary variables for inclusion in the linear regression analyses. Significant correlations were found for fat mass with cognitive performance (food errors) ($p = .02$) and sex with toys errors ($p < .001$). No correlations were found between cognitive performance with VO_2 max, blood pressure (SBP and DBP) or the potential confound variables (secondary variables).

Table 3 summarizes the linear regression analyses results for cognitive performance. Results show that only fat mass predicts inhibitory control for food ($t = 2.75$; $\beta = 0.387$; $p = .009$) even when controlling for toy errors ($t = 3.99$; $\beta = 0.544$; $p < .001$). Moreover, sex predicted toys errors ($t = 3.02$; $\beta = 0.373$; $p = .004$) showing that girls make more errors than boys (i.e. 0 = boys and 1 = Girls). No other measures predict inhibitory control. Exploratory analysis showed that girls presented lower ($t = 7.11$; $p < .001$) somatic maturation compared to boys (PHV: Girls = −3.1 ± 0.62 vs Boys = −1.3 ± 0.83).

Table 3
Summary of linear regression analyses for the general and food-specific inhibitory control test dependent variables (toy errors and food errors).

Predictors	Toy errors		Food errors	
	β	ΔR^2	β	ΔR^2
Model 1		0.039		0.139
Fat mass	0.004		0.370*	
VO_2max	−0.031		0.165	
SBP	−0.258		−0.194	
DBP	0.152		0.049	
Model 2		0.225*		0.229**
Fat mass	−0.197		0.368*	
VO_2max	−0.120		0.180	
SBP	−0.153		−0.068	
DBP	0.125		−0.025	
Food errors	0.544**		–	
Toys errors	–		0.488**	
Model 3		0.129**		0.015**
Fat mass	−0.236		0.387*	
VO_2max	−0.100		0.176	
SBP	−0.162		−0.052	
DBP	0.066		−0.011	
Food errors	0.508**		–	
Toys errors	–		0.544*	
Sex	0.373**		−0.139	

SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure.
* $p < .05$.
** $p < .01$.

4. Discussion

The main finding of the present study indicated that food-specific inhibitory control was predicted by fat mass. Linear regression analyses (Table 3) examining the predictors of food-specific and general inhibitory control showed that fat mass independently predicted food errors, even when controlling for important correlates (VO_2 max and blood pressure) that may contribute to deficits in inhibitory control. Moreover, adding toys errors to the model did not reduce the variance explained by fat mass, indicating that this result is specific to food stimulus regardless of general inhibitory control. Thus, our study is important for guiding new directions for investigating the relationship between these variables in school-aged children.

Interestingly, we did not find an association between BMI and cognitive performance as shown in other studies [27,49,57], suggesting that fat mass is more sensitive to changes in inhibitory control. Similar to our results, no relationship between BMI and commission errors was reported in a larger sample (n = 204) of male and female adults [30]. Another study found associations with BMI only for commission errors scores (difference between food errors and neutral errors) [46]. These different results may be related to different sample sizes and characteristics (i.e. age, sex, socioeconomic status) or lack of neutral control stimulus. It may also be a result of different methodological approaches of inhibitory control tasks (i.e. Go/No-go vs stop signal test), that may influences the stage at which inhibition is required [54]. Moreover, the process of signal detection, action selection and action execution involved in the task can be influenced by other cognitive process (i.e. attention) rather than response inhibition [66]. Therefore, the task we used was designed to address the limitations across the various methods used to measure food-specific inhibitory control [54] and has been shown to be sensitive to fat mass in our study of Brazilian children.

Besides the more practical application of BMI and the classifications of obesity according to the World Health Organization (WHO), the use of fat mass reference values related to obesity have been described previously [51]. Our sample was not considered obese following those classifications, but still showed food-specific inhibitory control impairment related to fat mass. Thus, we suggest fat mass as an important marker not only for obesity and for its comorbidities (i.e. diabetes and cardiovascular diseases), but also for cognitive impairment even when obesity is not reached. Similar to our study, a review has demonstrated a negative association between body adiposity and neurocognitive functioning in children and adolescents [40]. As inhibitory control is defined by the ability to inhibit habitual impulses or behaviors according to advantageous future consequence [45], impairments in food-specific inhibitory control in children not considered obese could contribute to the development of uncontrolled eating behaviors, thus leading to obesity.

Importantly, fat mass tissue can act as an endocrine organ [2], secreting molecules, such as leptin, which its serum concentration correlates with body fat content [64]. In the obese state, leptin has effects on hypothalamus function, by negatively modulating food intake behavior [1]. Moreover, animal studies have shown that the secretion of pro inflammatory cytokines [i.e. tumor necrosis factor α (TNF-α) and interleukin-6] induce inflammation in the hypothalamus, which leads to neuronal death (apoptosis) and deregulation of the signaling on the centers of feeding behavior [8]. Although we did not measure any of these specific markers in the current study, this research highlights the importance of fat mass as a marker of obesity and possibly cognitive impairment. In addition, it explains some possible mechanisms that alter responses in humans with higher fat mass and how it can affect eating behaviors, such as the indication of impaired specific inhibitory control shown in our results.

No association was found between fat mass and toy errors (Table 2)

or for fat mass predicting toys errors (Table 3). Considering that toy stimulus is related to general inhibitory control [49], and that humans have a natural instinct to find high-calories, salty and sweet foods highly salient and rewarding [12,23,31], the inclusion of such foods in the task allowed us to measure food-specific (versus general) response inhibition. It has been shown that chronic intake of sweet foods is linked to hyperactivation of dopaminergic neurons of the reward system [3], as well as with salient reward cues, such as food images in individuals with obesity [29]. Therefore, a possible explanation is that the food presented might look more pleasurable than the toys, becoming more difficult to inhibit. This might explain our results, in which higher fat mass is associated with food related errors in the cognitive test even when controlling for toys errors.

Of note, we found that toy errors were predicted by sex, showing that girls made more commission errors compared to boys. There has been a long debate regarding sex differences influencing behavior [47]. Previous studies suggested differences in cognitive abilities between girls and boys [42]. For instance, neuroimaging studies have shown different patterns in brain activation between boys and girls during cognitive tasks [9]. As sex promotes different biological characteristics, we speculate that it might influence cognitive functions, such as general inhibitory control shown in our study, by altering brain structure and function [50]. Moreover, it has been suggested that girls have higher degree of self-regulation and inhibition compared to boys due to differences in evolutionary trends (i.e. responsibilities and constraints within groups) and hormones exposure [26]. Nevertheless, our study shows poorer general inhibitory control in girls that might be related to our sample of children (age: 10.5 ± 0.7 years), which have not achieved maturation. Our exploratory analysis showed that, the boys were at a higher maturation level than the girls and since the prefrontal cortex is sensitive to maturation [70], this may explain the poorer performance found in the girls. Moreover, it might be that the toys were more appealing for boys than girls, so they are recognized and processed more easily leading to a reduction in errors. Further research, matching boys and girls for somatic maturation and other type of neutral stimulus are needed to confirm this finding.

Studies in adolescents [7] and adults [67] have found an inverse correlation between metabolic function of prefrontal cortex and BMI. Poorer inhibitory control may be explained by reduced metabolic functioning of the prefrontal cortex [20,57]. On the other hand, it has been shown that higher cardiorespiratory fitness is associated with improved cognition and brain function in different populations [16,25]. Although we have not found an association between cardiorespiratory fitness and inhibitory control, other research analyzing the chronic positive effects of exercise in children with obesity observed associations between changes in visceral adipose tissue and improvements in general inhibitory control and brain function [55]. Moreover, associations between general inhibitory control and laboratory-based test of VO_2 max were found in a similar cross-sectional study with a larger sample size [68]. One possible explanation for not finding an association between cardiovascular fitness and inhibitory control in our sample is that the measurement of the VO_2 max is an indirect measure and may not be a reliable indicator of cardiovascular fitness in children [61]. It may be the case that the food-specific inhibitory control test is only sensitive to more direct and accurate measurements, such as laboratory-based tests of VO_2 max, or that a larger sample size is needed to detect these potential effects.

We also found no association between cognitive performance and blood pressure variables (SBP and DBP). This may be related to our sample being under-powered to detect any effects as only 33% of the sample was considered Pre-hypertensive [41]. Hypertension has been related to remodeling on cerebral vessels and to induces endothelial disease, lower brain oxygenation, arteriosclerosis, reduction of vascular elasticity, as well as greater arterial stiffness and pulse wave [28]. These factors are associated with organ damage, including in the brain, resulting in impaired cognition [4, 22] as shown in previous studies [37]. We speculate that research using a larger sample size of non-normotensive children, or specifically investigating only hypertensive children, may be more sensitive to associations between blood pressure and food-specific inhibitory control.

Response inhibition training has previously been shown to improve cognitive performance on a Go/No-go task in non-obese children aged between 4 and 6 years and between 5 and 11 years [53]. In children aged between 7 and 10 years, response inhibition training was found to decrease high-calorie food intake [17]. Thus, this strategy holds potential for developing healthier eating behaviors. However, there is a discussion in the literature on whether Go/No-go training increases inhibitory control and can be translated to eating behaviors or not. This discussion is mainly based on the effects of training in the development of automatic inhibition (bottom-up) to No-go responses, making it difficult to differentiate from the top-down inhibitory control over food-related responses necessary to control eating behaviors [65]. Further longitudinal studies are necessary to untangle this and investigate the causal relationship between fat mass and modulation of food-specific inhibitory control.

The strengths of this study are noteworthy. Firstly, our sample is from a vulnerable Brazilian population. Psychology and behavioral studies have been criticized for mainly using samples of western, educated, industrialized, rich, and democratic societies (Weird; [24]). Therefore, we contribute to this field with a cross-cultural study of the relationship between inhibitory control and obesity, specifically in a population of south-american children. Secondly, to our knowledge, this study is novel in investigating cognitive impairment, specifically inhibitory control for food, as being related to fat mass in children between 9 and 11 years old. Contrary to other studies that used BMI as an index of overweight/obesity to investigate the relationship with food-specific inhibitory control [27,49,56,57], our study used the amount of fat mass obtained by DXA as a more precise marker.

We recognize the limitations of our study as reduced sample size, the absence of a hunger scale before the test and the absence of neurobiological markers. In addition, it may be that toy images during the inhibitory control task are appealing to children, and may not be strictly 'neutral' resulting in less errors being made. However, these preliminary results indicate the importance of studying the role of fat mass in food specific response inhibition in children. Given the complexity of human behavior in real world environments, where individuals are continually coordinating responses (action and inaction) between internal and external stimuli [66], we speculate that food-specific inhibitory control has a role to play in eating behaviors.

Our results indicate that fat mass is related to our ability to inhibit automatic responses to food. This may in turn influence eating behaviors and the development of obesity. This also demonstrates the importance of measuring fat mass (versus BMI) in future research in order to investigate the mechanisms underlying inhibitory control, eating behaviors and obesity.

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Declaration of interest

None.

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