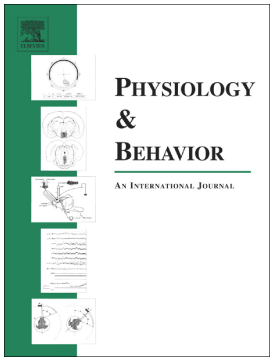

Fat mass predicts food-specific inhibitory control in children

Kell Grandjean da Costa, Menna Price, Henrique Bortolotti, Maria Luíza de Medeiros Rêgo, Daniel Aranha Rêgo Cabral, Raquel David Langer, Gleydciane Alexandre Fernandes, Hassan Mohamed Elsangedy, Eduardo Bodnariuc Fontes

PII: S0031-9384(18)30638-3
DOI: https://doi.org/10.1016/j.physbeh.2019.02.031
Reference: PHB 12469

To appear in: *Physiology & Behavior*

Received date: 13 August 2018
Revised date: 24 February 2019
Accepted date: 24 February 2019

Please cite this article as: K.G. da Costa, M. Price, H. Bortolotti, et al., Fat mass predicts food-specific inhibitory control in children, Physiology & Behavior, https://doi.org/10.1016/j.physbeh.2019.02.031

Fat Mass Predicts Food-Specific Inhibitory Control in Children

Kell Grandjean da Costa[a,*] kellgrandjean@gmail.com, Menna Price[b], Henrique Bortolotti[a], Maria Luíza de Medeiros Rêgo[a], Daniel Aranha Rêgo Cabral[a], Raquel David Langer[c], Gleydciane Alexandre Fernandes[a], Hassan Mohamed Elsangedy[a], Eduardo Bodnariuc Fontes[a]

[a]NEUROex – Research Group on Physical Activity, Cognition and Behavior, Federal University of Rio Grande do Norte, Brazil

Address: Av. Senador Salgado Filho, 3000, Zip Code: 5078-970, Natal/RN, Brazil

[b]Department of Psychology, Swansea University, United Kingdom

[c]Growth and Development Laboratory, University of Campinas, Brazil

[*]Corresponding author.

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 ($\beta = 0.36$; $\Delta R^2 = 0.04$; $p<0.05$) and sex predicted inhibitory control for toys (control condition) ($\beta = 0.42$; $\Delta R^2 = 0.11$; $p<0.01$). 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.

Keywords: cognition; inhibition control; obesity; body fat; cardiorespiratory fitness; hypertension.

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 (Bhurosy & Jeewon, 2014). Commonly seen in adulthood, these comorbidities related to obesity are now being identified in children and

are attributed to overeating behavior and sedentariness (Brambilla, Bedogni, Pietrobelli, Cianfarani, & Agostoni, 2016; Kral, 2018). 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 (Lake & Townshend, 2006; Speakman, 2013). 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 (Houben, Nederkoorn, & Jansen, 2014; Nederkoorn, Coelho, Guerrieri, Houben, & Jansen, 2012; Sellaro & Colzato, 2017). Recent evidence has emphasized the brain as one of the first organs to be damaged by hypertension (Iadecola et al., 2016), which is highly correlated to obesity (Drozdz et al., 2009). 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 related to the management of body weight and lower fat mass (González-Muniesa et al.,

2017). Moreover, greater cardiorespiratory fitness is associated with lower fat mass (Wong et al., 2004), 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 (Baek, 2016). 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 (Koechlin, 2016) and higher Body mass index (BMI) has been associated with lower prefrontal cortex function (Volkow et al., 2009). 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 (Song et al., 2016). 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 (Lavagnino, Arnone, Cao, Soares, & Selvaraj, 2016; Spitoni et al., 2017) and results from a meta-analysis demonstrate that impulsivity is positively associated with BMI (Emery & Levine, 2017). However the small effect size of this results have been criticized (Meule, 2017). Moreover, only food-specific (and not general) inhibitory control is independently predicted by body fat in adults (Price, Lee, & Higgs, 2016) and inhibitory control deficits have also been found to be related to BMI in children (Nederkoorn et al., 2012; Reyes, Peirano, Peigneux, Lozoff, & Algarin, 2015). 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 (Houben et al., 2014; Nederkoorn et al., 2012; Sellaro & Colzato, 2017). BMI has been criticized as it does not accurately distinguish between fat mass and fat-free mass (Freedman, Ogden, Berenson, & Horlick, 2005). 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) (González-Muniesa et al., 2017). 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 (Houben et al., 2014; Nederkoorn et al., 2012; Pauli-Pott, Albayrak, Hebebrand, & Pott, 2010) 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 (Drozdz et al., 2009). High blood pressure has been related to remodeling on cerebral vessels, microvascular rarefaction, lower cerebral blood flow, smaller brain volume and prefrontal cortex dysfunction (Iadecola et al., 2016). This may serve to reduce cognitive functioning, with previous studies showing that hypertensive children and adults have lower general inhibitory control (Elias, Elias, Sullivan, Wolf, & D'Agostino, 2003; Kupferman, Lande, Adams, & Pavlakis, 2013; Lande et al., 2017). 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 (Appelhans, 2009). 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 (Henrich, Heine, & Norenzayan, 2010) 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 (Fradkin, Valentini, Nobre, & dos Santos, 2018) 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

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 (Thomas, Reading, & Shephard, 1992); 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.

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 24h**.** 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.

2.1. Primary variables

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 seven minutes). The percent of fat mass (%FM) was calculated with total body and FM (%FM = (FM*100)/weight) values.

Cardiorespiratory Fitness Test

The children performed the progressive effort test proposed by Léger (1984) known as multistage 20m shuttle-run. In this test, subjects perform an incremental run between two points that are 20 meters 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 meters points in sync with the recording. The estimative maximum oxygen consumption (VO_2max) was calculated by a predicted equation described (Léger, Lambert, Goulet, Rowan, & Dinelle, 1984). 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 (Mayorga-Vega, Merino-Marban, & Viciana, 2014).

Blood Pressure Measurement

The children sat down in a chair to rest for at least five minutes and, then, three blood pressure measurements, intercalated by two minutes, were taken using a validated (Takahashi, Yoshika, & Yokoi, 2011) automatic blood pressure monitor and specific cuff for children. The average of the three measurements for both systolic and diastolic blood pressure were calculated.

Food Specific inhibitory control test

An adapted protocol from Price et al., (Price, Lee, & Higgs, 2016) 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) (Figure 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.

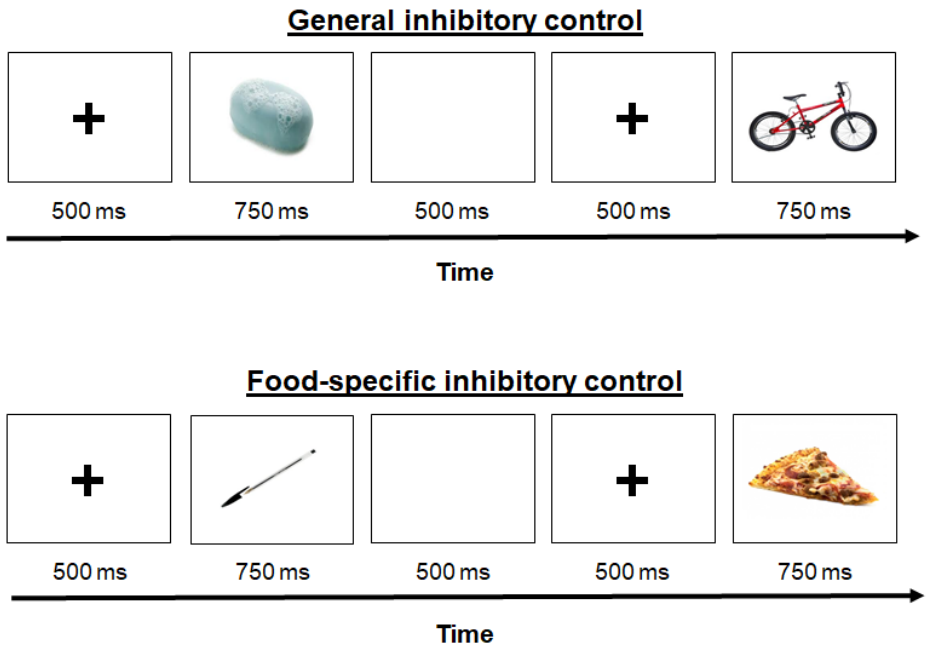

Figure 1. Food-specific and general inhibitory control task.

2.2. Secondary variables

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.

Pubertal timing

Somatic maturation was calculated according to a standardized equation (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002) 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 (Mirwald et al., 2002).

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 (Knijnik, Giacomoni, & Stein, 2013).

2.3. 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 $p < 0.05$.

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 = 0.007).

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 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) ($p=0.02$) and sex with toys errors ($p<0.001$). No correlations were found between cognitive performance with VO_2 max, blood pressure (SBP and DBP) or the potential confound variables (secondary variables).

Table 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).

	Primary variables	
	Toys errors	**Food errors**
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

*p<0.05; **p<0.01. 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.

Table 3 summarizes the linear regression analyses results for cognitive performance. Results show that only fat mass predicts inhibitory control for food ($t = 2.75$; $\beta = 0.387$; $p = 0.009$) even when controlling for toy errors ($t = 3.99$; $\beta = 0.544$; $p < 0.001$). Moreover, sex predicted toys errors ($t = 3.02$; $\beta = 0.373$; $p = 0.004$) 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 ($t = 7.11$; $p < 0.001$) 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	

*p<0.05; **p<0.01. SBP: Systolic Blood Pressure; DBP: Diastolic Blood Pressure.

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 (Houben et al., 2014; Nederkoorn et al., 2012; Sellaro & Colzato, 2017), 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 (Jasinska et al., 2012). Another study found associations with BMI only for commission errors scores (difference between food errors and neutral errors) (Meule et al., 2014). 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 (Price et al., 2016). 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 (Verbruggen, McLaren, & Chambers, 2014). Therefore, the task we used was designed to address the limitations across the various methods used to measure food-specific inhibitory control (Price et al., 2016) 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 (Ogden, Li, Freedman, Borrud, & Flegal, 2011). 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 (Liang, Matheson, Kaye, & Boutelle, 2014). As inhibitory control is defined by the ability to inhibit habitual impulses or behaviors according to advantageous future consequence (Meule & Blechert, 2017), 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 (Ailhaud, 2000), secreting molecules, such as leptin, which its serum concentration correlates with body fat content (Tsai, 2017). In the obese state, leptin has effects on hypothalamus function, by negatively modulating food intake behavior (Ahima, 2008). 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 (Belegri et al., 2018). 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 (Nederkoorn et al., 2012), and that humans have a natural instinct to find high-calories, salty and sweet foods highly salient

and rewarding (Davis, 2014; Harris & Bargh, 2009; Keller et al., 2012), 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 (Alonso-Alonso et al., 2015), as well as with salient reward cues, such as food images in individuals with obesity (Ihssen, Sokunbi, Lawrence, Lawrence, & Linden, 2017). 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 (Meyers-Levy & Loken, 2015). Previous studies suggested differences in cognitive abilities between girls and boys (Mansouri, Fehring, Gaillard, Jaberzadeh, & Parkington, 2016). For instance, neuroimaging studies have shown different patterns in brain activation between boys and girls during cognitive tasks (Bell, Willson, Wilman, Dave, & Silverstone, 2006). 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 (Ngun, Ghahramani, Sánchez, Bocklandt, & Vilain, 2011). 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 (Hosseini-Kamkar & Morton, 2014). 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 (Tsujimoto, 2008), 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 (Batterink, Yokum, & Stice, 2010) and adults (Volkow et al., 2009) 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 (Goldstein & Volkow, 2011; Sellaro & Colzato, 2017). On the other hand, it has been shown that higher cardiorespiratory fitness is associated with improved cognition and brain function in different populations (Erickson & Kramer, 2009; Hillman et al., 2008). 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 (Raine et al., 2017). 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 (Westfall, Kao, Scudder, Pontifex, & Hillman, 2017). 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 (Swain, Parrott, Bennett, Branch, & Dowling, 2004). 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 (Malachias et al., 2016). 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 (Iadecola et al., 2016). These factors are associated with organ damage, including in the brain, resulting in impaired cognition (Amenta, Di Tullio, & Tomassoni, 2003; Grant, Bhambhani, & Singhal, 2015) as shown in previous studies (Lande et al., 2017). 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 to 6 years and between 5 to 11 years (Porter et al., 2018). In children aged between 7 and 10 years, response inhibition training was found to decrease high-calorie food intake (Folkvord, Veling, & Hoeken, 2016). 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 (Veling, Lawrence, Chen, van Koningsbruggen, & Holland, 2017). 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; Henrich, Heine, & Norenzayan, 2010). 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 (Houben et al., 2014; Nederkoorn et al., 2012; Reyes et al., 2015; Sellaro & Colzato, 2017), 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 (Verbruggen et al., 2014), 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.

ACKNOWLEDGEMENT

We thank Gary Freegard to the assistance on the development of the cognitive task, Professors Arthur Kramer, Charles Hillman and the reviewer's suggestions for their inputs on the manuscript. In addition, we also would like to thank the schools staff and the children for participating in this study.

FUNDING

This study was financed with student's scholarships by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) – Finance Code 001.

DECLARATION OF INTEREST: none.

REFERENCES

Ahima, R. S. (2008). Revisiting leptin's role in obesity and weight loss. *The Journal of Clinical Investigation*, *118*(7), 2380–2383. https://doi.org/10.1172/JCI36284

Ailhaud, G. (2000). Adipose tissue as an endocrine organ. *International Journal of Obesity and Related Metabolic Disorders: Journal of the International Association for the Study of Obesity*, *24 Suppl 2*, S1-3.

Alonso-Alonso, M., Woods, S. C., Pelchat, M., Grigson, P. S., Stice, E., Farooqi, S., … Beauchamp, G. K. (2015). Food reward system: current perspectives and future research needs. *Nutrition Reviews*, *73*(5), 296–307. https://doi.org/10.1093/nutrit/nuv002

Amenta, F., Di Tullio, M. A., & Tomassoni, D. (2003). Arterial hypertension and brain damage--evidence from animal models (review). *Clinical and Experimental Hypertension (New York, N.Y.: 1993)*, *25*(6), 359–380.

Appelhans, B. M. (2009). Neurobehavioral inhibition of reward-driven feeding: implications for dieting and obesity. *Obesity (Silver Spring, Md.)*, *17*(4), 640–647. https://doi.org/10.1038/oby.2008.638

Baek, S.-S. (2016). Role of exercise on the brain. *Journal of Exercise Rehabilitation*, *12*(5), 380–385. https://doi.org/10.12965/jer.1632808.404

Batterink, L., Yokum, S., & Stice, E. (2010). Body mass correlates inversely with inhibitory control in response to food among adolescent girls: an fMRI study. *NeuroImage*, *52*(4), 1696–1703. https://doi.org/10.1016/j.neuroimage.2010.05.059

Belegri, E., Eggels, L., Unmehopa, U. A., Mul, J. D., Boelen, A., & la Fleur, S. E. (2018). The effects of overnight nutrient intake on hypothalamic inflammation in a free-choice diet-induced obesity rat model. *Appetite*, *120*, 527–535. https://doi.org/10.1016/j.appet.2017.10.006

Bell, E. C., Willson, M. C., Wilman, A. H., Dave, S., & Silverstone, P. H. (2006). Males and females differ in brain activation during cognitive tasks. *NeuroImage*, *30*(2), 529–538. https://doi.org/10.1016/j.neuroimage.2005.09.049

Bhurosy, T., & Jeewon, R. (2014). Overweight and obesity epidemic in developing countries: a problem with diet, physical activity, or socioeconomic status? *TheScientificWorldJournal*, *2014*, 964236. https://doi.org/10.1155/2014/964236

Brambilla, P., Bedogni, G., Pietrobelli, A., Cianfarani, S., & Agostoni, C. (2016). Predictors of blood pressure at 7-13 years: The 'new millennium baby' study. *Nutrition, Metabolism, and Cardiovascular Diseases: NMCD*, *26*(8), 706–712. https://doi.org/10.1016/j.numecd.2015.11.005

Davis, C. (2014). Evolutionary and neuropsychological perspectives on addictive behaviors and addictive substances: relevance to the 'food addiction' construct. *Substance Abuse and Rehabilitation*, *5*, 129–137. https://doi.org/10.2147/SAR.S56835

Drozdz, D., Kwinta, P., Korohoda, P., Pietrzyk, J. A., Drozdz, M., & Sancewicz-Pach, K. (2009). Correlation between fat mass and blood pressure in healthy children. *Pediatric Nephrology (Berlin, Germany)*, *24*(9), 1735–1740. https://doi.org/10.1007/s00467-009-1207-9

Elias, M. F., Elias, P. K., Sullivan, L. M., Wolf, P. A., & D'Agostino, R. B. (2003). Lower cognitive function in the presence of obesity and hypertension: the Framingham heart study. *International Journal of Obesity and Related Metabolic Disorders: Journal of the International Association for the Study of Obesity*, *27*(2), 260–268. https://doi.org/10.1038/sj.ijo.802225

Emery, R. L., & Levine, M. D. (2017). Questionnaire and behavioral task measures of impulsivity are differentially associated with body mass index: A comprehensive meta-analysis. *Psychological Bulletin*, *143*(8), 868–902. https://doi.org/10.1037/bul0000105

Erickson, K. I., & Kramer, A. F. (2009). Aerobic exercise effects on cognitive and neural plasticity in older adults. *British Journal of Sports Medicine*, *43*(1), 22–24. https://doi.org/10.1136/bjsm.2008.052498

Folkvord, F., Veling, H., & Hoeken, H. (2016). Targeting implicit approach reactions to snack food in children: Effects on intake. *Health Psychology: Official Journal of the Division of Health Psychology, American Psychological Association*, *35*(8), 919–922. https://doi.org/10.1037/hea0000365

Fradkin, C., Valentini, N. C., Nobre, G. C., & dos Santos, J. O. L. (2018). Obesity and Overweight Among Brazilian Early Adolescents: Variability Across Region, Socioeconomic Status, and Gender. *Frontiers in Pediatrics*, *6*. https://doi.org/10.3389/fped.2018.00081

Freedman, D. S., Ogden, C. L., Berenson, G. S., & Horlick, M. (2005). Body mass index and body fatness in childhood. *Current Opinion in Clinical Nutrition and Metabolic Care*, *8*(6), 618–623.

Goldstein, R. Z., & Volkow, N. D. (2011). Dysfunction of the prefrontal cortex in addiction: neuroimaging findings and clinical implications. *Nature Reviews. Neuroscience*, *12*(11), 652–669. https://doi.org/10.1038/nrn3119

González-Muniesa, P., Mártinez-González, M.-A., Hu, F. B., Després, J.-P., Matsuzawa, Y., Loos, R. J. F., … Martinez, J. A. (2017). Obesity. *Nature Reviews Disease Primers*, *3*, 17034. https://doi.org/10.1038/nrdp.2017.34

Grant, H., Bhambhani, Y., & Singhal, A. (2015). Hemodynamic changes in the prefrontal cortex during working memory in essential hypertension. *Journal of the American Society of Hypertension: JASH*, *9*(8), 628–639. https://doi.org/10.1016/j.jash.2015.06.007

Harris, J. L., & Bargh, J. A. (2009). The Relationship between Television Viewing and Unhealthy Eating: Implications for Children and Media Interventions. *Health Communication*, *24*(7), 660–673. https://doi.org/10.1080/10410230903242267

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *The Behavioral and Brain Sciences*, *33*(2–3), 61–83; discussion 83-135. https://doi.org/10.1017/S0140525X0999152X

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: exercise effects on brain and cognition. *Nature Reviews. Neuroscience*, *9*(1), 58–65. https://doi.org/10.1038/nrn2298

Hosseini-Kamkar, N., & Morton, J. B. (2014). Sex differences in self-regulation: an evolutionary perspective. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00233

Houben, K., Nederkoorn, C., & Jansen, A. (2014). Eating on impulse: the relation between overweight and food-specific inhibitory control. *Obesity (Silver Spring, Md.)*, *22*(5), E6-8.

Iadecola, C., Yaffe, K., Biller, J., Bratzke, L. C., Faraci, F. M., Gorelick, P. B., … American Heart Association Council on Hypertension; Council on Clinical Cardiology; Council on Cardiovascular Disease in the Young; Council on Cardiovascular and Stroke Nursing; Council on Quality of Care and Outcomes Research; and Stroke Council. (2016). Impact of Hypertension on Cognitive Function: A Scientific Statement From the American Heart Association. *Hypertension (Dallas, Tex.: 1979)*, *68*(6), e67–e94. https://doi.org/10.1161/HYP.0000000000000053

Ihssen, N., Sokunbi, M. O., Lawrence, A. D., Lawrence, N. S., & Linden, D. E. J. (2017). Neurofeedback of visual food cue reactivity: a potential avenue to alter incentive sensitization and craving. *Brain Imaging and Behavior*, *11*(3), 915–924. https://doi.org/10.1007/s11682-016-9558-x

Jasinska, A. J., Yasuda, M., Burant, C. F., Gregor, N., Khatri, S., Sweet, M., & Falk, E. B. (2012). Impulsivity and inhibitory control deficits are associated with unhealthy eating in young adults. *Appetite*, *59*(3), 738–747. https://doi.org/10.1016/j.appet.2012.08.001

Keller, K. L., Kuilema, L. G., Lee, N., Yoon, J., Mascaro, B., Combes, A.-L., … Halford, J. C. G. (2012). The impact of food branding on children's eating behavior and obesity. *Physiology & Behavior*, *106*(3), 379–386. https://doi.org/10.1016/j.physbeh.2012.03.011

Knijnik, L. F., Giacomoni, C., & Stein, L. M. (2013). Test for School Achievement: a survey study. *Psico-USF*, *18*(3), 407–416. https://doi.org/10.1590/S1413-82712013000300007

Koechlin, E. (2016). Prefrontal executive function and adaptive behavior in complex environments. *Current Opinion in Neurobiology*, *37*, 1–6. https://doi.org/10.1016/j.conb.2015.11.004

Kral, T. V. E. (2018). Behavioral phenotypes for childhood obesity: 2017 Alan N. Epstein Research Award. *Physiology & Behavior*, *192*, 206–209. https://doi.org/10.1016/j.physbeh.2018.01.003

Kupferman, J. C., Lande, M. B., Adams, H. R., & Pavlakis, S. G. (2013). Primary hypertension and neurocognitive and executive functioning in school-age children. *Pediatric Nephrology (Berlin, Germany)*, *28*(3), 401–408. https://doi.org/10.1007/s00467-012-2215-8

Lake, A., & Townshend, T. (2006). Obesogenic environments: exploring the built and food environments. *The Journal of the Royal Society for the Promotion of Health*, *126*(6), 262–267.

Lande, M. B., Batisky, D. L., Kupferman, J. C., Samuels, J., Hooper, S. R., Falkner, B., … Adams, H. R. (2017). Neurocognitive Function in Children with Primary Hypertension. *The Journal of Pediatrics*, *180*, 148-155.e1. https://doi.org/10.1016/j.jpeds.2016.08.076

Lavagnino, L., Arnone, D., Cao, B., Soares, J. C., & Selvaraj, S. (2016). Inhibitory control in obesity and binge eating disorder: A systematic review and meta-analysis of neurocognitive and neuroimaging studies. *Neuroscience and Biobehavioral Reviews*, *68*, 714–726. https://doi.org/10.1016/j.neubiorev.2016.06.041

Léger, L., Lambert, J., Goulet, A., Rowan, C., & Dinelle, Y. (1984). [Aerobic capacity of 6 to 17-year-old Quebecois--20 meter shuttle run test with 1 minute stages]. *Canadian Journal of Applied Sport Sciences. Journal Canadien Des Sciences Appliquees Au Sport*, *9*(2), 64–69.

Liang, J., Matheson, B., Kaye, W., & Boutelle, K. (2014). Neurocognitive correlates of obesity and obesity-related behaviors in children and adolescents. *International Journal of Obesity (2005)*, *38*(4), 494–506. https://doi.org/10.1038/ijo.2013.142

Malachias, M. V. B., Gomes, M. a. M., Nobre, F., Alessi, A., Feitosa, A. D., Coelho, E. B., … Coelho, E. B. (2016). 7th Brazilian Guideline of Arterial Hypertension: Chapter 2 - Diagnosis and Classification. *Arquivos Brasileiros de Cardiologia*, *107*(3), 7–13. https://doi.org/10.5935/abc.20160152

Mansouri, F. A., Fehring, D. J., Gaillard, A., Jaberzadeh, S., & Parkington, H. (2016). Sex dependency of inhibitory control functions. *Biology of Sex Differences*, *7*, 11. https://doi.org/10.1186/s13293-016-0065-y

Mayorga-Vega, D., Merino-Marban, R., & Viciana, J. (2014). Criterion-Related Validity of Sit-and-Reach Tests for Estimating Hamstring and Lumbar Extensibility: a Meta-Analysis. *Journal of Sports Science & Medicine*, *13*(1), 1–14.

Meule, A. (2017). Commentary: Questionnaire and behavioral task measures of impulsivity are differentially associated with body mass index: a comprehensive meta-analysis. *Frontiers in Psychology*, *8*, 1222. https://doi.org/10.3389/fpsyg.2017.01222

Meule, A., & Blechert, J. (2017). Indirect effects of trait impulsivity on body mass. *Eating Behaviors*, *26*, 66–69. https://doi.org/10.1016/j.eatbeh.2017.01.012

Meule, A., Lutz, A. P. C., Krawietz, V., Stützer, J., Vögele, C., & Kübler, A. (2014). Food-cue affected motor response inhibition and self-reported dieting success: a pictorial affective shifting task. *Frontiers in Psychology*, *5*, 216. https://doi.org/10.3389/fpsyg.2014.00216

Meyers-Levy, J., & Loken, B. (2015). Revisiting gender differences: What we know and what lies ahead. *Journal of Consumer Psychology*, *25*(1), 129–149. https://doi.org/10.1016/j.jcps.2014.06.003

Mirwald, R. L., Baxter-Jones, A. D. G., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise*, *34*(4), 689–694.

Nederkoorn, C., Coelho, J. S., Guerrieri, R., Houben, K., & Jansen, A. (2012). Specificity of the failure to inhibit responses in overweight children. *Appetite*, *59*(2), 409–413. https://doi.org/10.1016/j.appet.2012.05.028

Ngun, T. C., Ghahramani, N., Sánchez, F. J., Bocklandt, S., & Vilain, E. (2011). The Genetics of Sex Differences in Brain and Behavior. *Frontiers in Neuroendocrinology*, *32*(2), 227–246. https://doi.org/10.1016/j.yfrne.2010.10.001

Ogden, C. L., Li, Y., Freedman, D. S., Borrud, L. G., & Flegal, K. M. (2011). Smoothed percentage body fat percentiles for U.S. children and adolescents, 1999-2004. *National Health Statistics Reports*, (43), 1–7.

Pauli-Pott, U., Albayrak, O., Hebebrand, J., & Pott, W. (2010). Association between inhibitory control capacity and body weight in overweight and obese children and adolescents: dependence on age and inhibitory control component. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *16*(6), 592–603. https://doi.org/10.1080/09297049.2010.485980

Porter, L., Bailey-Jones, C., Priudokaite, G., Allen, S., Wood, K., Stiles, K., … Lawrence, N. S. (2018). From cookies to carrots; the effect of inhibitory control training on children's snack selections. *Appetite*, *124*, 111–123. https://doi.org/10.1016/j.appet.2017.05.010

Price, M., Lee, M., & Higgs, S. (2016). Food-specific response inhibition, dietary restraint and snack intake in lean and overweight/obese adults: a moderated-mediation model. *International Journal of Obesity (2005)*, *40*(5), 877–882. https://doi.org/10.1038/ijo.2015.235

Raine, L. B., Khan, N. A., Drollette, E. S., Pontifex, M. B., Kramer, A. F., & Hillman, C. H. (2017). Obesity, Visceral Adipose Tissue, and Cognitive Function in Childhood. *The Journal of Pediatrics*, *187*, 134-140.e3. https://doi.org/10.1016/j.jpeds.2017.05.023

Reyes, S., Peirano, P., Peigneux, P., Lozoff, B., & Algarin, C. (2015). Inhibitory control in otherwise healthy overweight 10-year-old children. *International Journal of Obesity (2005)*, *39*(8), 1230–1235. https://doi.org/10.1038/ijo.2015.49

Sellaro, R., & Colzato, L. S. (2017). High body mass index is associated with impaired cognitive control. *Appetite*, *113*, 301–309. https://doi.org/10.1016/j.appet.2017.03.008

Song, T.-F., Chi, L., Chu, C.-H., Chen, F.-T., Zhou, C., & Chang, Y.-K. (2016). Obesity, Cardiovascular Fitness, and Inhibition Function: An Electrophysiological Study. *Frontiers in Psychology*, *7*, 1124. https://doi.org/10.3389/fpsyg.2016.01124

Speakman, J. R. (2013). Evolutionary perspectives on the obesity epidemic: adaptive, maladaptive, and neutral viewpoints. *Annual Review of Nutrition*, *33*, 289–317. https://doi.org/10.1146/annurev-nutr-071811-150711

Spitoni, G. F., Ottaviani, C., Petta, A. M., Zingaretti, P., Aragona, M., Sarnicola, A., & Antonucci, G. (2017). Obesity is associated with lack of inhibitory control and impaired heart rate variability reactivity and recovery in response to food stimuli. *International Journal of Psychophysiology: Official Journal of the International Organization of Psychophysiology*, *116*, 77–84. https://doi.org/10.1016/j.ijpsycho.2017.04.001

Swain, D. P., Parrott, J. A., Bennett, A. R., Branch, J. D., & Dowling, E. A. (2004). Validation of a new method for estimating VO2max based on VO2 reserve. *Medicine and Science in Sports and Exercise*, *36*(8), 1421–1426.

Takahashi, H., Yoshika, M., & Yokoi, T. (2011). Validation of home blood pressure-monitoring devices, Omron HEM-1020 and Omron i-Q132 (HEM-1010-E), according to the European Society of Hypertension International Protocol. *Blood Pressure Monitoring*, *16*(4), 203–207. https://doi.org/10.1097/MBP.0b013e328348b688

Thomas, S., Reading, J., & Shephard, R. J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Canadian Journal of Sport Sciences = Journal Canadien Des Sciences Du Sport*, *17*(4), 338–345.

Tsai, J.-P. (2017). The association of serum leptin levels with metabolic diseases. *Ci Ji Yi Xue Za Zhi = Tzu-Chi Medical Journal*, *29*(4), 192–196. https://doi.org/10.4103/tcmj.tcmj_123_17

Veling, H., Lawrence, N. S., Chen, Z., van Koningsbruggen, G. M., & Holland, R. W. (2017). What Is Trained During Food Go/No-Go Training? A Review Focusing on Mechanisms and a Research Agenda. *Current Addiction Reports*, *4*(1), 35–41. https://doi.org/10.1007/s40429-017-0131-5

Verbruggen, F., McLaren, I. P. L., & Chambers, C. D. (2014). Banishing the Control Homunculi in Studies of Action Control and Behavior Change. *Perspectives on Psychological Science: A Journal of the Association for Psychological Science*, *9*(5), 497–524. https://doi.org/10.1177/1745691614526414

Volkow, N. D., Wang, G.-J., Telang, F., Fowler, J. S., Goldstein, R. Z., Alia-Klein, N., … Pradhan, K. (2009). Inverse association between BMI and prefrontal metabolic activity in healthy adults. *Obesity (Silver Spring, Md.)*, *17*(1), 60–65. https://doi.org/10.1038/oby.2008.469

Westfall, D. R., Kao, S.-C., Scudder, M. R., Pontifex, M. B., & Hillman, C. H. (2017). The Association between Aerobic Fitness and Congruency Sequence Effects in Preadolescent Children. *Brain and Cognition*, *113*, 85–92. https://doi.org/10.1016/j.bandc.2016.12.005

Wong, S. L., Katzmarzyk, P., Nichaman, M. Z., Church, T. S., Blair, S. N., & Ross, R. (2004). Cardiorespiratory fitness is associated with lower abdominal fat independent of body mass index. *Medicine and Science in Sports and Exercise*, *36*(2), 286–291. https://doi.org/10.1249/01.MSS.0000113665.40775.35

Highlights

- Higher fat mass was related to poorer food-specific inhibitory control in children.
- Impaired inhibitory control for food might further exacerbate to overeating behaviors and obesity.
- Our study highlights the importance of assessing fat mass in school-aged children.