Being overweight or obese is associated with inhibition control in children from six to ten-years-of-age

Running title: Neurocognitive function and obesity

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ABSTRACT

Aim: This study investigated the relationship between being overweight or obese and executive function in six to ten-year-olds.

Methods: The participants were 515 children (250 boys) from schools in Reus, Spain. The initial sample was measured and weighed and assessed with the Children's Color Trail Test. Children classified as overweight, including obese, and their age and gender-matched controls (n=221), were assessed in a second phase with the Five Digit Test (FDT) and the Symbol Digit Modalities Test. Logistic regression models were applied to analyse the effect of executive functions on being overweight, including obese.

Results: We found that 28.9% of the children were overweight and 7.2% were obese. The FDT showed that inhibition (odds risk of 1.04, range 1.00-1.08, p=0.04) and flexibility (odds risk of 1.04, range 1.00-1.07, p=0.02) were significantly associated with overweight, including obesity, regardless of sociodemographic and psychopathological variables.

Conclusion: These results suggest that children who were overweight or obese had a reduced ability to mobilise the cognitive effort required to inhibit involuntary responses and to switch between different mental operations. A developmental trajectory would provide important insights into the relationship between executive functioning pattern and the risk of being overweight or obese.

Keywords: altered inhibitory control, cognitive function, executive function, obesity, overweight

Key Notes

- This study investigated the relationship between being overweight or obese and executive function in six to ten-year-olds.
- Children who were overweight or obese had a reduced ability to mobilise the cognitive effort required to inhibit involuntary responses and to switch between different mental operations.
- A developmental trajectory would provide important insights into the relationship between executive functioning pattern and the risk of being overweight or obese.

INTRODUCTION

The increasing prevalence of obesity is a serious public health problem in most developed countries and in societies undergoing rapid social transitions. In the World Health Organization (WHO) European Region, overall overweight and obesity in children ranges from about 10% in countries such as Denmark, to about 32% in Spain and 39% in Greece (1). This increase in childhood overweight and obesity may be driven by changes in psychosocial and environmental factors that affect nutrition and physical activity patterns (2).

Obesity has a complex aetiology, which not only includes a dysbalanced energy intake in relation to energy expenditure, but may also be modulated by neuropsychological factors such as impulsivity, altered inhibitory control, altered reward perception and motivation or addictive behaviour (3). Cserjési et al (4) found that in 12-year-old children - 12 obese and 12 controls - obesity was associated with lower attention and flexibility/shifting, but not with memory, reasoning or verbal fluency. This may suggest that obesity in children could be associated with deficits in executive functions, a behavioural marker of prefrontal cortex functioning, despite the presence of normal intelligence and memory similar to normal weight children. A case-control study performed on adolescents consistently showed significantly poorer performance among overweight versus normal weight individuals in indexes of inhibition, flexibility and decision making but not in tests of working memory, planning and reasoning (5). Other studies have found that higher body weight was associated with lower inhibitory control due to impulsiveness (6) and that overweight children displayed a stronger tendency to act on impulse than normal weight children (7). A cohort-based study conducted on four to six-year-old children (8) found a higher risk of becoming overweight at the age of six among those children with lower verbal and executive function performance at the age of four. This study suggested that cognitive abilities could influence the development of overweight, whereas other studies carried out in adults, children and adolescents suggest that overweight could impair cognitive function (9, 10).

Given the considerations cited above, there have been few studies that have investigated the relationship between overweight, including obesity, and executive function in school-age children. The aim of this study was, therefore, to investigate the relationship between overweight, including obesity, and executive function in children aged six to ten-years-old. We hypothesised, regardless of any possible causal relationship, that overweight and obese children could show deficits in tasks associated with executive functions.

PARTICIPANTS AND METHODS

Participants

We recruited 515 children, 250 boys and 265 girls, in the second, third and fourth grades of primary school from a potential population of 1,623 students from 20 randomly selected schools - 80% state schools and 20% private schools - in Reus, Spain. The age of the participants ranged from six to ten years, with a mean of 8.54 (±0.64) years.

We divided the sample into three groups according to their Body Mass Index (BMI) as defined by Cole (11): obese children (BMI > 97th), overweight children (BMI from 95th to 97th) and normal weight children (BMI ≤ 95th). We excluded 13 underweight children (BMI ≤ 16th) from the analyses. The study had two phases: the first was conducted with all those children whose parents gave permission to participate (n=515) and the second comprised a random subsample of 221 overweight and normal weight children, matched by age and sex. The sample information and study design are presented in Figure 1. Socioeconomic status was low (27.4%), middle (42.7%) and high (22.1%) in the first phase. There were no significant differences in socioeconomic status and school grade between boys and girls in either phase.

Measures

Anthropometric data. Weight and height were measured using a portable scale (SECA 702) and stadiometer (SECA 2014) (precision 50g and 1mm, respectively) by two professionals who were trained for the purpose, with the children standing in light clothing and barefoot. BMI was calculated as weight in kilograms divided by the square of height in meters. In order to be consistent with international research, as proposed by the International Obesity Task Force, age and sex-specific cut-off points for BMI for overweight and obesity in children using datasetspecific centiles linked to adult cut-off points (25 kg/m2 for overweight and 30 kg/m2 for obesity) were estimated.

Child Behavior Checklist (CBCL) (12). This checklist consists of two parts and the first is the scale of social competence. In this part both parents were asked about their occupation and then classified according to the Statistical Institute of Catalonia's classification of occupations (CCO-94 (ca), Decret 98/1995). This information was used to define the socioeconomic status of the sample. The socioeconomic status was then categorised as low, middle or high. The second part of the CBCL is a list of questions to assess the following scales of behavioural problems: anxious/depressed, withdrawn/depressed, somatic complaints, social problems, thought problems, attention problems, rule-breaking behaviour and aggressive behaviour. These scales are quantified using scores, with higher scores representing higher levels of behavioural problems levels. According to multicultural data used by the authors, test-retest reliability showed appropriate results (0.90) and multicultural data (0.77).

Self-perception of body image: The Figure Rating Scale (FRS) (13) contains seven schematic sketches of children that were used to examine the boys' and girls' perception of their current body size and the size they would like to be. Following Eckstein et al (13) this scale has shown good reliability. The children were first asked to choose the sketch from the FRS that they believed themselves to most resemble and then the sketch that they would most like to resemble. Body image dissatisfaction in the children was measured by the discrepancy between the two figures chosen. Children of normal weight who were dissatisfied with their body image because they wanted to be fatter were removed for the purposes of this statistical analysis.

Neuropsychological tests

The Symbol Digit Modalities Test (SDMT) (14). This test consists of relating symbols to numbers. Each child was asked to manually fill in the blank space under each symbol with the corresponding number. The SDMT assesses processing speed and visomotor ability (14) and has been validated in Spanish population (15). In the SDMT a higher score represents a better performance.

Five Digit Test (16). We used the validated Spanish version of the FDT as a test of cognitive functions that needs minimal linguistic knowledge. This is a test to assess the effect of interference in the reaction time to do a task. This task is low linguistic dependence and does not penalize participants with reading problems (17). Some studies indicate good construct and criterion validity for patients of different ages and educational and cultural backgrounds (18). Sedó et al (16, 17) reported significant correlations with other attention and executive function tests with moderate or high effect sizes and correlations with the Stroop test were between 0.65 and 0.71. The FDT has been validated in the Spanish population with good psychometric properties (17).

There are four sections in the test - reading, counting, selecting and switching - that provide information about processing speed, verbal fluency, and sustained attention. The inhibition function was obtained from performance of reading and selecting sections and the flexibility function was obtained from reading and switching sections. Inhibition is the ability to stop paying attention to some information and, or, to suppress prepotent responses and flexibility is the ability to switch between multiple representations or task sets. Both inhibition and flexibility are mental skills that require an additional cognitive effort. The outcome measures were the performance times for the four different parts of the test; therefore, the longer time required by the child to do the tasks, the worse performance.

The Children's Color Trails Test 1 & 2 (CCTT) (19). This is a neuropsychological instrument designed to measure inhibitory control, sustained visual attention, sequencing, psychomotor speed and cognitive flexibility. It consists of two parts: CCTT 1 and CCTT 2. CCTT uses numbered colour circles and universal sign language symbols. The temporal stability of CCTT was considered to be modest (rtt=0.46–0.68). We analysed our data in order to obtain the CCTT short-term, one-month retest reliability, which was modest for both the CCTT 1 and CCTT 2 parts (r=0.37; r=0.40). CCTT was administered in the first phase of this study. As in the FDT, the dependent measures were the performance times for tests one and two, so a higher test score would indicate worse in the test performance.

Statistical analyses

The statistical analyses were carried out using SPSS 20.0 software (IBM corp., Armonk, NY, USA). First, we performed chi-square analyses to compare percentages between and within anthropometrical groups by gender, age and socioeconomic status. Then an ANOVA, including post-hoc Bonferroni-corrected comparisons, and Student's t-test analyses were performed to find out differences in neuropsychological tests performance between the BMI groups normal weight, overweight and obese. Stepwise logistic regression models adjusting for age, gender, socioeconomic status, body image dissatisfaction and the CBCL scales were used to determine the associations between executive functions and BMI group - normal weight versus overweight, including obesity - as the dependent variable. Given that the Pearson correlation between the SDMT, FDT and CCTT variables showed that there was collinearity ($r \geq 0.6$), we performed logistic regression models for each single executive function. The eight CBCL scales outputted two categories: normal and clinical, which included borderline plus clinical. Statistical significance was accepted at the level $p<0.05$.

RESULTS

Descriptive data

The distribution of sex, school grade and socioeconomic status by anthropometric group is shown in Table 1. In the sample from the first phase, 28.9% of the children were overweight and 7.2% were obese. In both the first and the second phases, there were no significant differences between BMI groups according to gender, school grade and socioeconomic status. When overweight and obesity were classified into the same group - overweight, including obesity - and compared with normal weight, no significant differences were found between BMI groups in terms of gender, age or socioeconomic status for neither phase. Likewise, no significant differences where found within each anthropometrical group by sociodemographic variables.

Relationship between BMI status and neuropsychological function

As can be seen in Table 2, there were no significant differences between BMI statuses in neuropsychological tests performance with the exception of FDT counting (p=0.03). In this respect, according to post hoc analysis, the overweight children performed worse than children with normal weight. When the performance of children in the overweight, including obesity group was compared to that from children in the normal weight group, these differences were maintained.

Logistic regression analysing the effect of executive functions on overweight, including obesity, adjusting for covariates (see Table 3), showed that overweight, including obesity, was significantly associated with inhibition (odds risk of 1.04, range 1.00-1.08, p=0.04) and flexibility (odds risk of 1.04, range 1.00-1.07, p=0.02) functions. Thus, overweight, including obese, children required more time for these processes to take place. A part of these executive function scales, we found a significant association of overweight, including obesity, with the selecting subscale (odds risk of 1.03, range 0.99-1.09, p=0.03) and switching subscale (odds risk of 1.03, range 1.01-1.06, p=0.04). The other executive functions did not show any significant effect on overweight, including obesity, in logistic regression models. In all the models with statistically significant results, body dissatisfaction and the presence of somatic complaints were related with overweight, including obesity.

DISCUSSION

The prevalence of overweight and obesity found in our study was similar to that found by other studies in Mediterranean areas (1). We did not find any gender differences along the lines of Sanchez-Cruz et al (20) or a relationship between obesity and lower socioeconomic status in contrast to other studies (21).

The main finding of our study was that children with overweight, including obesity, had a deficient inhibitory control. When we performed multivariate analyses, adjusting for variables that may be related with BMI, such as psychological problems (22), body image dissatisfaction (23), and socioeconomic status (21), we found an association in adolescents between overweight, including obesity, and lower performance in FDT inhibition and flexibility functions. Our findings were similar to those of Verdejo-García et al (5). This relationship was also found in the switching and selecting sections, which are related to the inhibition and flexibility function. These processes involve controlled and conscious behaviour that require cognitive processing speed, verbal fluency, sustained attention and an ability to mobilise the additional cognitive effort required to inhibit involuntary responses and switching between different mental operations. However, we found no relation between overweight, including obesity, and other tests measuring processing speed, visual attention, inhibitory control and cognitive flexibility from the SDMT and the CCTT. It is important to take into account that these tests were written forms whereas the FDT was performed verbally. These data support those from Guxens et al (8), who found significantly lower performance in verbal and executive function in overweight individuals but no relation to memory, motor skills or perceptual performance. Other studies that have used verbal tests (24) have also found that childhood obesity involved perseveration and attention problems. In contrast, Gunstad et al (25) found no relationship between BMI and any neuropsychological test in adults. Li et al (9) suggested that the adverse effects of increased body weight status on cognition functioning started as early as childhood. In this respect, although our results showed weak relationships, the fact that we did find differences in the more complex executive functioning tasks - because these were more sensitive when detecting a small deficit - could indicate an incipient association. We suggest that a possible prefrontal dysfunction could explain the alterations in executive function and a poor behavioural regulation leading to abnormal eating behaviours that increase the obesity risk. In this sense, Pauli-Pott et al (26) found that deficient inhibitory control was linked with obesity in children.

A selective review of neuroimaging findings in obese adults reveals structural brain alterations including global atrophy and regional reduction of grey matter density, primarily in the frontal regions (27). Consistent with these findings, some studies have found a negative association between BMI and prefrontal metabolism (28). Thus, obese children who begin to present a lower performance in tests related to prefrontal functions, as we have seen in our study, could develop structural brain alterations in adulthood. In this respect, Sabia et al (10) reported that the neuropsychological impairment in adults was a consequence of the chronic pathophysiological processes associated with obesity.

Although there is compelling evidence to indicate that executive processes are present early in life and improve throughout childhood, the developmental profile of these skills is still unclear. There is sufficient evidence to suggest that specific executive processes come on-line at different ages and exhibit variable developmental trajectories (29). In line with this data, Best et al (30) suggested that there were different developmental trajectories for each executive function during middle childhood – from nine to 12-years-of-age - and adolescence. Furthermore, there may be sleeper effects in which experiences or individual differences in early childhood - from six to eight-years-of-age - do not show observable effects until middle childhood. Given this variable development, it is difficult to indicate whether or not our results are the beginning of problems in adulthood. The mere fact that we have found initial evidence of some impairment would require longitudinal studies in children.

The weaknesses of this study may be the possible selection bias, since only the 31% of the families agreed to participate. We cannot discard a possible influence of different socio-economic levels, or childhood obesity, children's neuropsychological problems on families decision to participate, However, the random inclusion in the study of the schools from different socio-economic levels, the similar participation rates in all the schools and the similar overweight and obesity found in our study as compared to the general population (1), make us believe that our results are consistent. Another limitation of our study is its cross-sectional design, which does not allow establishing a cause-effect relationship. Longitudinal analyses should be adequately addressed in future studies. On the other hand, a possible weakness is that behaviour scales from CBCL were reported by parents rather than assessed by a psychologist. However, this method is accepted in epidemiological studies (12).

Despite these limitations, we consider that our data are relevant, because they suggest an association between executive function and overweight, including obesity, in non-clinical children with an average age of eight. The relation found between more complex executive function tasks and high BMI at this early age, suggest the beginning of a process, which may have consequences at adolescence and adulthood. Preventing childhood obesity may have a positive effect not only on the negative consequences for several aspects of physical and emotional health but also on neuropsychological functions throughout life. On the other hand, to intervene in executive dysfunction such as deficient inhibitory control, high reward sensibility and impulsivity may prevent abnormal eating behaviours linked with obesity. Additional work is needed to determine directionality, and a longitudinal follow up of these study populations would provide important insights into the relationship between high BMI and executive dysfunction in the long term.

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Table 1. Sociodemographic characteristics of the sample by anthropometric group and study phase

	Normal Weight	Overweight	Obesity	Overweight including obesity
First Phase				
Gender; n(%)				
Girls	159(60)	79(29.8)	19(7.2)	98(38.1)
Boys	157(62.8)	70(28)	18(7.2)	88(35.9)
School grade; n(%)				
2nd	97(30.7)	38(25.5)	10(6.7)	48(33.1)
3rd	152(48.1)	85(57)	21(8)	106(41.1)
4th	67(21.2)	26(17.4)	6(5.8)	32(32.3)
Socioeconomic status; n(%)				
Low	86(27.2)	35(23.5)	13(35.1)	48(35.8)
Middle	134(42.2)	71(47.7)	15(40.5)	86(39.1)
High	81(25.6)	27(18.1)	3(8.1)	30(27)
Second phase				
Gender; n(%)				
Girls	36(37.5)	42(43.75)	18(18.75)	60(62.5)
Boys	54(43.2)	53(42.4)	18(14.4)	71(56.8)
School grade; n(%)				
2nd	33(36.7)	29(30.5)	10(27.8)	39(54.2)
3rd	41(45.6)	52(54.7)	21(58.3)	73(64)
4th	16(17.8)	14(14.7)	5(13.9)	19(54.3)
Socioeconomic status; n(%)				

Low	29(32.2)	25(26.3)	13(36.1)	38(56.7)
Middle	38(42.2)	51(53.7)	14(38.9)	65(63.1)
High	19(21.1)	12(12.6)	3(8.3)	15(44.1)

No significant differences intergroup (neither between 3 groups nor between normal and overweight including obesity) and no significant differences intragroup (between first and second phases) were found for sociodemographic variables.

Table 2. Comparison of neuropsychological test performance across BMI status

		Normal Weight[a]	Overweight[b]	Obesity[c]	ANOVA for normal weight, overweight and obesity F	ANOVA for normal weight, overweight and obesity p-value	Overweight obesity	t-test normal weight versus Overweight including obesity t	t-test normal weight versus Overweight including obesity p-value
SDMT	Written Form	31.17 (7.5)	30.35 (7.3)	30.54 (6.6)	0.48	0.62	30.55 (7.4)	0.78	0.44
FDT	Reading	28.65 (5.2)	28.84 (4.3)	28.14 (5.1)	2.06	0.13	28.85 (5.2)	1.04	0.30
	Counting	39.01 (7.3)	41.00 (10.8)	39.70 (7.4)	3.55	0.03*	40.46 (8.7)	2.08	0.03
	Selecting	67.18 (13.6)	68.58 (17.6)	68.00 (14.5)	2.03	0.13	69.12 (16.3)	1.82	0.07
	Switching	78.10 (16.9)	77.39 (17.7)	78.21 (18.9)	0.65	0.52	78.93 (18.4)	0.93	0.35
	Inhibition	38.53 (11.5)	39.74 (15.6)	39.86 (12.8)	1.46	0.23	40.27 (14)	1.70	0.09
	Flexibility	49.46 (15.0)	48.55 (15.8)	50.07 (16.7)	0.27	0.76	50.08 (15.9)	0.72	0.47
CCTT	Performance Time Test 1	30.22 (11.1)	32.74 (12.9)	32.29 (10.7)	0.56	0.57	59.98 (15.3)	0.05	0.96
	Performance Time Test 2	59.75 (17.9)	62.31 (15.8)	60.33 (13.9)	0.01	0.99	31.37 (11.28)	1.01	0.31

CCTT: Phase 1 participants; Normal weight: n=288, Overweight: n=133, Obesity: n=3
FDT: Phase 2 participants; Normal weight: n=90, Overweight: n=94, Obesity: n=36.
SDMT: Phase 2 participants; Normal weight: n=90, Overweight: n=92, Obesity: n=36.
*Post hoc comparison between normal weight and overweight was q=2.98, p=0.03.

Table 3. Logistic regression models to analyse the effect of executive functions on being overweight, including obese.

	Odds ratio (95% CI)	p
Model 1		
Somatic complaints (borderline and clinic)	1.31 (1.06 to 1.63)	< 0.05
Body image dissatisfaction (YES)	2.43 (1.45 to 4.07)	< 0.05
Inhibition function (time, seconds)	1.04 (1.00 to 1.08)	< 0.05

Model parameters: p=0.001; $x^2$3,134=39.23; r^2Nagelkerke100=35%.
Variables entered into the model: Inhibition function, age, gender, socioeconomic status and body image dissatisfaction, eight CBCL scales.

	Odds ratio (95% CI)	p
Model 2		
Somatic complaints (borderline and clinic)	1.34 (1.08 to 1.66)	< 0.05
Body image dissatisfaction (YES)	2.68 (1.58 to 4.55)	< 0.05
Flexibility function (time, seconds)	1.04 (1.00 to 1.07)	< 0.05

Model parameters: p=0.001; $x^2$3,134=40.03; r^2Nagelkerke100=36%.
Variables entered into the model: Flexibility function, age, gender, socioeconomic status and body image dissatisfaction, eight CBCL scales.