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Empirical Articles

Characterization of Executive Functioning in a Portuguese Sample of Candidates for Bariatric Surgery

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Abstract

Aim: The prevalence of obesity has been steadily increasing and is a major worldwide public health problem. It is associated with multiple medical and psychological conditions and recent research supports a link to several cognitive deficit domains, including executive functioning. The aim of this article is to describe socio-demographic, clinical and neuropsychological characteristics of a sample of candidates for bariatric surgery (BS) and to compare their performance with normative values.

Method: Between May 2012 and May 2013 we evaluated the neuropsychological performance of 42 patient candidates for BS at the Morbid Obesity Consultation at Centro Hospitalar Lisboa Norte (CHLN).

Results: The population was predominantly female and education was equally distributed between basic, secondary and tertiary levels. The neuropsychological results showed a significant decrease on Recall ($p < .01$), Learning ($p < .10$), Nonverbal Memory ($p < .001$), Cognitive Flexibility ($p < .01$) and Resistance to Interference ($p < .05$).

Conclusion: Despite the limitations inherent to a small sample, the results obtained in the Portuguese population coincide with those of earlier studies; namely that obesity differentially effects instrumental functions.

Keywords: severe obesity, cognitive performance, executive functions, neuropsychology

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Introduction

The number of severely obese individuals has been increasing steadily worldwide and, although in Portugal the percentage is smaller when compared to other countries, it is estimated there are approximately 32,000 adult patients (Carmo, Santos, Camolas, & Vieira, 2008).

Obesity is one of the most frequent causes of death and is associated with many medical and psychological conditions including diabetes, hypertension, cancer, cardiovascular disease, sleep apnoea and depression. Recent studies also report the existence of deficits in multiple cognitive domains, particularly in areas such as attention, concentration, memory and executive functions (EF) (Cohen, Yates, Duong, & Convit, 2011; Gunstad et al., 2007;

Volkow et al., 2009), both in children and adults (Fergenbaum et al., 2009; Gunstad, Lhotsky, Wendell, Ferruci, & Zonderman, 2010).

In fact, a Body Mass Index (BMI - defined by the ratio of weight in kilograms by the square of height in meters) greater than 25kg/m^2 is positively associated with impaired decision-making and other cognitive deficits, leading some authors to conclude that there may exist a neurocognitive component to obesity regardless of other comorbidities (Boeka & Lokken, 2008; Gunstad et al., 2007). Severe obesity is defined as $BMI \geq 40$ kg/m^2, or $BMI \geq 35$ kg/m^2 when accompanied by comorbidities.

The evaluation of cognitive performance in a sample of adolescents with severe obesity showed deficits in various domains, including attention and EF, such as the ability to establish new behavioural patterns and new ways of thinking about themselves (Lokken, Boeka, Austin, Gunstad, & Harmon, 2009; Manning, 2005). Neuropsychological studies examining extreme body weight suggest changes in the inhibitory circuit regulating emotional control and EF may occur. In general, one common theme seems to be the executive dysfunction in three separate functions: decision making, response inhibition and cognitive flexibility (Fagundo et al., 2012; Gunstad et al., 2007).

Executive functions contribute to the self-regulation of behaviour and allow individuals to think before acting. Thus, inhibition reduction may be associated with compulsive or impulsive behaviours. In fact, some studies suggest that obese persons may be more impulsive and have greater difficulty in resisting the palatability of high calorie food (Cohen, Yates, Duong, & Convit, 2011). On the other hand, the reduced ability to inhibit feeding behaviour is, according with Boeka and Lokken (2008), a contributing factor to the high percentage of obese individuals unable to regulate their excess weight via conventional weight loss methods, and may be related to their difficulty in changing their obesogenic lifestyle even after bariatric surgery.

Furthermore, these patients have an increased risk for dementia and other brain disorders, such as cerebral atrophy, and exhibit structural changes in white matter (Gunstad et al., 2007; Verstynen et al., 2012). Recent work indicates that elderly women with high BMIs have greater temporal lobe atrophy - a fact that might explain the increased risk of Alzheimer's disease in this population (Gunstad et al., 2008). However, even in elderly males and females who do not have cognitive impairments, high fat tissue may have an adverse effect on brain structure leading to subsequent atrophy and dementia (Hassing et al., 2009; Raji et al., 2010).

Interventions in obesity, particularly in severe obesity, therefore require a multidisciplinary approach, since low cognitive performance, high impulsivity and reduced inhibitory control are plausible explanations for excessive food intake, loss of control and compulsive eating (Gunstad, Müller, Stanek, & Spitznagel, 2012). Nowadays, conventional treatments for obesity, as lifestyle modification, diet pharmacotherapy and psychotherapeutic interventions, have been shown to have low efficacy in both moderate and severe obesity. As a result, bariatric surgery (BS) is generally accepted as the most effective treatment for severe obesity (Adams et al., 2005, 2010; Berenguer et al., 2007) given that it leads to a substantial reduction in weight, improvement of associated diseases, increased self-esteem, reduced psychopathology, improvement in cognitive function, enhanced sexual function, decreased disturbed eating behaviour, and improved quality of life (Berenguer et al., 2007; Greenburg, Lettieri, & Eliasson, 2009; Miller et al., 2013; Silva, Pais-Ribeiro, & Cardoso, 2009).

Bariatric surgery has been a growing trend over the past few years. According with Lokken, Boeka, Yellumahanthi, Wesley, and Clements (2010), little research has been undertaken to describe the demographic, psychosocial and cognitive characteristics of candidates for this type of surgery. Moreover, these authors suggest there is a common belief that health professionals have negative opinions about individuals with severe obesity, such as their being less intelligent, less educated, having lower socio-economic status and experiencing more psychopathology.

In Portugal, BS has been performed since the mid 1990's and is divided into three types of techniques: restrictive, malabsorptive and mixed. The aim of these three techniques is, respectively, to reduce the amount of food intake, to produce a change in the process of digestion/absorption, and to simultaneously decrease food intake capacity and change the process of digestion/absorption (Ceneviva, Silva, Viegas, Sankarankutty, & Chueire, 2006).

In Portugal, patients seeking BS are generally referred to a multidisciplinary consultation that uses a protocol, which involves various interventions aimed at obtaining all the patient's clinical, laboratory and imaging data along with their psychological and nutritional profiles. From the patient's perspective, these procedures may seem time consuming and frustrating but they facilitate the acquisition of new habits, promote an understanding of the risks, limitations and benefits of treatment and, very importantly, can exclude candidates for surgery for whom the risks outweigh the benefits (Ribeiro et al., 2012).

Objective

The objective of this paper is to describe the socio-demographic and clinical variables of BS candidates and compare their performance with neuropsychological normative data for EF. The hypothesis is that severely obese patients demonstrate significantly lower cognitive performance.

Method

Participants

After obtaining approval from the Ethics Committee of the Centro Hospitalar de Lisboa Norte (CHLN) we evaluated 42 patients with severe obesity, who sought surgical treatment at the Morbid Obesity Consultation between May 2012 and May 2013.

Instruments

- Socio-demographic and Clinical questionnaire – to collect personal and social characteristics of participants (i.e. age, gender, marital status, number of children, employment status, level of education and monthly income), and relevant clinical data (i.e. anthropometric measures, comorbidities, highest/lowest lifetime weight, reasons for excessive weight, consumption of alcoholic beverages, smoking, exercise regime, eyesight/hearing status and blood pressure).
- Digit Span from the Wechsler Intelligence Scale for Adults (WAIS-III) – to assess short-term memory and working memory (Tulsky et al., 2003).
- Digit Symbol from the WAIS III – to evaluate fine motor control, learning speed, stress tolerance and sustained attention (Golden, Espe-Pfeifer, & Wachsler-Felder, 2002).
- Search Symbol from the WAIS III – to measure the processing speed of new data (Tulsky et al., 2003).
- Vocabulary from of the WAIS III - reflects level of education and culture, and is considered a measure of acquired knowledge (Tulsky et al., 2003).

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- Rey-Osterrieth Complex Figure (RCF) – to evaluate perceptual activity and visual memory (Rey, 1959).
- Rey Auditory Verbal Learning Test (RAVLT) – to assess the ability to retain, consolidate, store and retrieve verbal information (Cavaco et al., 2008).
- Stroop Colour and Word Test (Stroop) – to measure cognitive flexibility and resistance to interference from external stimuli (Fernandes, 2013).
- Trail Making Test (TMT) – to provide information on attention, visual exploration, hand-eye coordination, processing speed, sequencing and cognitive flexibility (Cavaco et al., 2008).
- Wisconsin Card Sorting Test (WCST) – to evaluate EF, particularly abstract thinking and the ability to shift cognitive strategies in response to changing environmental contingencies (Heaton, Chelune, Talley, Kay, & Curtiss, 2001).
- Hopkins Symptom Checklist Revised (SCL-90-R) – to assess symptoms of emotional adjustment/maladjustment in psychiatric/psychological patients in comparison to the general population (Baptista, 1993).
- Hospital Anxiety Depression Scale (HADS) – to measure levels of anxiety and depression (Pais-Ribeiro, Silva, Ferreira, Martins, Meneses, & Baltar, 2007).

Procedures

At the end of the required Endocrinology consultation, patients candidate to BS were invited to participate in the present study. The purpose of the study was explained to each patient and his/her voluntary and confidential participation was obtained, through an informed consent form that all patients were asked to read and complete.

Anthropometric measurements were taken including weight, height, neck circumference, waist and hip circumference and blood pressure. Hypertension was defined as a systolic blood pressure ≥ 140 mm Hg and/or diastolic blood pressure ≥ 90 mm Hg, as per the European Society of Cardiology's (ESC) criteria (Mancia et al., 2007), and was measured by the interviewing nurse. Body Mass Index (BMI) was calculated as weight in kilograms divided by height in meters squared.

Each patient was evaluated by a psychologist who had additional training in neuropsychology and the application of the test battery had a mean duration of 40 minutes.

Statistical Analysis

The Student's *t*-test was used to compare normative values with continuous variables (one-sample *t*-test). The Wilcoxon test was used for comparisons with ordinal variables.

Statistical analyses were performed using SPSS (Statistical Package for the Social Sciences) version 20.0 for Windows. The significance level was set at $p \leq 0.10$.

Sample Characterization

The 42 patients with severe obesity who participated in the study were mostly female (79%), aged between 21 and 63 years, and mostly integrating the 50 or older (50+) age group. In this sample, 52% of participants were married, 29% had a primary school education, 26% had a secondary school education and 29% had a post-secondary education.

The mean BMI of participants was 46.94 kg/m^2. The mean neck circumference was 41.96 cm, the mean waist circumference was 126.42 cm and the mean hip circumference was 136.38 cm (Table 1).

Table 1

Descriptive Statistics for Weight, Height, Cervical Perimeter, Waist, Hip and BMI (N = 42)

Characteristic	*Min*	*Max*	*M*	*SD*
Weight (kg)	90.00	160.80	124.35	17.68
Height (cm)	148.00	187.00	162.80	9.87
Neck circumference (cm)	35.00	50.00	41.96	3.88
Waist (cm)	105.00	150.00	126.42	12.56
Hip (cm)	114.00	150.00	136.38	10.08
BMI	40.00	63.29	46.94	6.37

From self-reported data, 57.1% of participants referred suffering from hypertension but 81% denied having diabetes mellitus, dyslipidaemia or other diseases. The mean systolic blood pressure was 145 mmHg, (classified as Grade I hypertension) and diastolic pressure of 87 mmHg (classified as normal blood pressure). Only 19% of patients endorsed smoking and another 19% reported participating in regular physical activity.

Results

Patients were eligible for participation in the study, regardless of gender, if they were aged between 18 and 65 years, severely obese (BMI ≥ 40 kg/m^2), proposed for BS, had no known diagnosis of psychiatric disorders (such as major depression, schizophrenia, bipolar disorder, alcohol or drug use/abuse), had no known diagnosis of neurological disorders (i.e. degenerative diseases of the CNS, epilepsy, history of moderate to severe head trauma with loss of consciousness greater than 10 minutes) and had non-corrected hearing or vision.

In comparison to standard scores (μ = 50.0), the patients in this sample performed significantly lower on neuro-psychological variables as evidenced by their results from the RAVLT including Immediate Recall, Learning and Deferred Recognition (Table 2).

The visuoperceptual structuring calculated in the *RCF* (in terms of the copy as accurate reproduction) and the interference in Stroop performance was significantly lower when compared to normative performance (Table 2).

The TMT showed no significant changes in the performance of patients with respect to normative values in both Form A and Form B (Table 2).

The performance of patients on the WCST was significantly lower than expected on all evaluated parameters (Table 3).

Table 2

Descriptive Statistics and Comparison with Normative Values for Percentile Values of RAVLT, RCF, Stroop and TMT (N = 42)

Instrument and Subscale	*Min*	*Max*	*M*	*SD*	t^a	*p*
RAVLT						
Immediate Recall	1	99	36.14	29.43	-3.051	0.004
Learning	2	100	41.50	27.58	-1.997	0.052
Retention Index	9	99	61.38	30.71	2.401	0.021
Deferred Recognition	5	55	29.88	17.47	-7.460	< 0.001
RCF						
Copy	10	75	41.79	24.59	-2.165	0.036
Memory	1	80	33.86	26.43	-3.957	0.001
Stroop						
Interference	27	80	46.52	9.31	-2.419	0.020
TMT						
Percentile A	1	99	49.90	28.88	-0.021	0.983
Percentile B	1	99	44.69	28.32	-1.215	0.231

[a]One-sample *t*-test ($\mu = 50.0$), $df = 41$.

Table 3

Descriptive Statistics and Comparison with Normative Values for Percentile Values of WCST (N = 42)

Variable	*Min*	*Max*	*M* or *Md*	*SD*	t^a or Z^b	*p*
% Errors	1	87	*M* = 28.74	27.32	*t* = -5.043	< 0.001
% Perseverative Responses	1	99	*M* = 35.60	31.39	*t* = -2.973	0.005
% Perseverative Errors	1	99	*M* = 34.07	30.74	*t* = -3.358	0.002
% Non-perseverative	1	99	*M* = 34.81	29.84	*t* = 3.299	0.002
% Conceptual Level Responses	1	91	*M* = 29.31	27.84	*t* = -4.816	< 0.001
Number Categories Completed			*Md* = 4		*Z* = -4.418	< 0.001
Trials to Complete First Category			*Md* = 5		*Z* = 5.701	< 0.001
Failure to Maintain Set			*Md* = 5		*Z* = -2.821	< 0.001
Learning to Learn			*Md* = 4		*Z* = -2.428	< 0.001

[a]One-sample *t*-test ($\mu = 50.0$), $df = 41$. [b]One sample Wilcoxon Signed Rank Test.

On the WAIS III's Symbol Search and Vocabulary subtests (Table 4) and on *RAVLT's* Retention Index (Long Term Retention percentage) (Table 2) participants' results were significantly higher than normative values.

HADS' mean global scores revealed participants' experienced mild symptoms of anxiety (8-10) and normative values of depression (0-7) (Table 5).

The General Symptom Index (GSI), obtained from the SCL-90-R, was significantly higher in patients with severe obesity than in the normal population (Table 6).

Table 4

Descriptive Statistics and Comparison with Normative Values for Standard Results of WAIS III (N = 42)

Subscale	***Min***	***Max***	***M***	***SD***	***t*[a]**	***p***
Digit Symbol	2	17	9.67	3.49	-0.618	0.540
Search Symbol	4.00	18.00	10.80	2.95	1.774	0.083
Digit Span	6.00	18.00	9.73	2.91	-0.583	0.563
Vocabulary	7.00	18.00	11.50	2.39	4.065	< 0.001

[a]One-sample *t*-test (μ = 10.0), *df* = 41.

Table 5

Descriptive Statistics of HADS (N = 42)

Subscale	**Min**	**Max**	**M**	**SD**
Anxiety	0	18	9.43	4.446
Depression	1	18	7.12	3.710

Table 6

Descriptive Statistics and Comparison with Normative Values for SCL90

Subscale	***Min***	***Max***	***M***	***SD***	***t*[a]**	***p***
GSI	0.16	2.54	1.04	0.63	-	
Percentile GSI	10.00	99.00	74.85	27.40	5.879	< 0.001
PSDI	0.64	3.03	1.76	0.48	-	
Percentile PSDI	5.00	99.00	49.85	26.51	-0.035	0.972

Note. GSI = General Symptom Index; PSDI = Positive Symptom of Distress Index.

[a]One-sample *t*-test (μ = 50.0), *df* = 41.

Discussion

The goal of this study was to describe the socio-demographic and clinical characteristics of candidates for BS in a Portuguese referral centre and compare their performance with neuropsychological normative values for EF, with the assumption that said values would be below the standard. This sample is representative of most candidates for BS in Portugal: predominantly female, with a mean age of 42 years, and low income.

The mean BMI was above the established for severe obesity, which likely contributes to the existence of specific cognitive difficulties and a decrease in EF.

Despite the fact that our study does not include imaging techniques, we will review the neuropsychological results by taking into account the available literature. The results of this study raise the possibility that obesity differentially affects various instrumental functions including attention and EF – a conclusion that was previously forwarded by

Gunstad and colleagues' longitudinal study of healthy subjects that found high BMI was associated with the loss of EF but not with decreased attention (Gunstad et al., 2010).

Our results also showed a mean BMI well above 40 kg/m^2 which points to the results by Volkow et al. (2009) that showed the existence of a significant negative correlation between BMI and basal glucose metabolism in healthy brains (mostly in the prefrontal regions and the anterior cingulate gyrus) and a negative association between prefrontal metabolism and performance on tasks of verbal learning and EF. Recently, it was also demonstrated that elevated BMI is associated with a reduction or disruption of the integrity of white matter in places such as the corpus callosum or fornix fibres (the main inter-hemispheric connections to cortical areas) (Stanek et al., 2011).

The mean neck of our sample was 41.96cm (above 40 cm) incrising the risk for respiratory distress syndrome and obstructive sleep apnoea/hypopnea (OSAS); OSAS is, by itself, a further risk for cognitive dysfunction due, mostly, to intra-thoracic excess fat, excessive daytime sleepiness, nocturnal hypoxemia, fragmented sleep and cerebral anoxia affecting the functionality of the prefrontal cortex (Alchanatis et al., 2004; Fritscher, 2006; Gonçalves, Lago, Godoy, Fregonezi, & Bruno, 2011; Teixeira, 2006).

A high waist/hip ratio (mean 0.92 cm obtained in our sample) represents increased body fat composition and has a high predictive value for the onset of Type II diabetes and cardiovascular disease, and, in turn, is associated with a progressive decrease in cognitive performance (Carmo, Santos, Camolas, & Vieira, 2008; Elias, Elias, Sullivan, Wolf, & D'Agostino, 2005).

Patients in this study acknowledged an unhealthy sedentary lifestyle along with poor diet and absence of exercise. This fact is important given that moderately active people have a lower risk of developing mental disorders than sedentary people and that participation in exercise programs improves cognitive functioning (Antunes et al., 2006; Raman, Smith, & Hay, 2013). Lean individuals performed better than obese individuals on measures of attention/executive function as measured by the International Physical Activity Questionnaire (Galioto Wiedemann, Calvo, Meister, & Spitznagel, 2014). Moreover, during a yearlong longitudinal study, Hötting, Schauenburg, and Röder (2012), demonstrated that even six months of supervised exercise produced positive effects on physical activity and cognition in sedentary adults including subsequent benefits in memory.

In comparison to normative data, our sample's neuropsychological performance was significantly lower in the *RAVLT* (Immediate Recall, Learning and Deferred Recognition), *RCF, Stroop Test* and *WCST.* The sample's performance in the *TMT, Digit Symbol* and *Digit Span*, however, was within the normal range. Performance was significantly higher than normative values on the *Retention Index of RAVLT, Search Symbol* and V*ocabulary.* The *HADS'* mean global scores revealed moderate anxiety symptoms and the SCL-90-R's General Symptom Index (GSI) scores were significantly higher, thereby revealing greater global psychological distress.

These results confirm conclusions previously obtained by Gunstad and colleagues, (2010) and by Gunstad, Paul, and Cohen (2006), where increased BMI, waist circumference and waist-hip ratio were significantly related to a reduction in learning and memory. They reinforce the specific impact of adiposity in EF (Fergenbaum et al., 2009) and selective attention (Cournot et al., 2006), and reinforce the possibility that obesity is a risk factor for neurodegenerative diseases, such as Alzheimer's disease (a disorder characterized by learning and memory deficits).

According to Lezak, Howieson, and Loring (2004), subjects with frontal lobe lesions, when compared with controls, have much lower performance in recall attempts of *RAVLT*. However, when tested using the shape recognition format they demonstrated a normal learning curve.

Our sample exhibited lower performance on the *RAVLT* immediate recall, likely due to changes in frontal functioning and not to amnesic disturbance. In fact, according to Marques-Teixeira (2012), upon hearing the list for the first time, normal controls demonstrate the effects of novelty (by more often recalling the first and the last words and rarely recalling the middle words). As tests are repeated, normal subjects begin to organize the words according to a set of associations, as evidenced by the groups of words they recall. That is, subjects developed strategies that improve their performance. Failure to use adequate strategies to manipulate and organize information limits the ability to adequately recall and consolidate information.

This same study (Marques-Teixeira, 2012) concluded that the cerebral region most involved in recall is the pre-frontal cortex in both hemispheres. In addition, the anterior-temporal region, the limbic structures and the medial temporal lobe help recall emotionally-laden information whilst the posterior hippocampus is activated.

For Golden, Espe-Pfeifer, and Wachsler-Felder (2002), in cases where recall is better than recognition (retrieval process when stimuli are presented between distractors), we can attribute this phenomenon to impulsivity or perseveration, since subjects can keep the Yes or No response while looking at the recognition list.

Another variable that may help to explain our sample's poor performance on *RAVLT* is the reduced density of grey matter in brain areas that mediate cognitive function, namely, the hippocampus (associated with memory performance) and the cerebellum/posterior lateral lobes (associated with executive, spatial and linguistic processing) as previously found by Mueller et al. (2012) using Volumetric Magnetic Resonance Imaging in 43 overweight/obese patients.

Regarding the *WCST*, a significant percentage of perseverative responses and a significant number of errors in this sample suggest a sharp decline in the patients' cognitive flexibility, demonstrating that they are able to acquire the first rule but unable to adjust their behaviour when rules change. Our sample exhibited difficulties in problem-solving tasks and a lower capacity to generate alternative behaviours in response to ambiguous information, a pattern suggestive of changes in dorsolateral prefrontal circuitry (Val-Laillet, Layec, Guérin, Meurice, & Malbert, 2011).

According to results obtained by Lokken, Boeka, Austin, Gunstad, and Harmon (2009), this may mean that patients with severe obesity, when faced with stressful situations, might have difficulty generating alternative coping strategies, especially those related to food. They also might have difficulty implementing healthy eating and exercise habits, especially when no specific instructions are given.

Significantly lower values in sustained attention, verbal fluency and cognitive efficacy during the Stroop test suggest impulsivity and difficulty resisting to interference – skills that depend largely on cingulate areas and regions of the lateral prefrontal cortex (Fagundo et al., 2012). Accordding with these authors this reinforces the theory, already forwarded in other studies, that obese persons have difficulty inhibiting intrusive thoughts and suppressing automatic or dominant behaviours. Impulsivity and disinhibition in the context of food are defined as a tendency to opportunistically consume food in response to environmental stimuli and this, in turn, plays an important role in the development and maintenance of obesity (Cohen, Yates, Duong, & Convit, 2011).

Our sample also exhibited significantly lower performance than normal controls in visuoperceptual structuring calculated via the RCF. Results indicate visuoperceptual difficulties in their ability to organize, plan and obtain non-verbal memory data and do not exclude the possibility of changes in visuomotor coordination (Golden, Espe-Pfeifer, & Wachsler-Felder, 2002).

These results indicate difficulty in task-planning, decreased use of strategies to achieve a given goal and reduced non-verbal memory which, in the context of obesity, may translate in a reduced ability to plan access to healthy meals and to organize one's day to include physical exercise (Lokken, Boeka, Austin, Gunstad, & Harmon, 2009).

The TMT measures visuomotor tracking, divided attention and cognitive flexibility, and require mental processing speed. This test is particularly useful in measuring cognitive deficits in patients with dorsolateral prefrontal dysfunction while, at the same time, taking into account the fact that poor education and low intelligence quotients are associated with worse performances (Cavaco et al., 2008; Lezak, Howieson, & Loring, 2004). Our non-significant results are similar to those obtained by Gunstad et al.'s (2010) where, in a comparative study of healthy subjects who were normal weight, overweight or obese, researchers found no significant differences for Part A due to the fact that medical and psychiatric illnesses were excluded from their sample – a methodology we too followed. These results are also consistent with the relatively high level of education of our sample (29% had 9 years of education and 26% had 12 years of education) and significantly elevated values in *Vocabulary,* indicating a good cognitive reserve that serves as a protective factor against cognitive impairment.

Results for *Digit Symbol* are in line with the results for *Digit Span* and the *TMT* and share in common the fact that they predict the relative integrity of the attention system. They may also be correlated to educational level, and to increased scores in *Vocabulary*, since Lezak, Howieson, and Loring (2004) found that, in a sample of elderly volunteers, level of education contributed significantly to performance on this test.

Scores in Search Symbol were significantly above average, and reflect a significantly faster regulatory speed of mental processing of information and significantly superior visuomotor coordination and are, again, in agreement with scores indicating a significantly higher vocabulary. These values are a relatively reliable index of the quality of education and point to the existence of an above-average pre-morbid intelligence in this population that works as a protective factor in the cognitive performances assessed.

Recent research suggests the existence of a correlation between premorbid intelligence, EF and health risk; namely that EF acts as a mediator in the relationship between premorbid intelligence and certain health risk behaviours. Understanding the relationship between these variables is important when making health recommendations that will improve patients' adherence to healthy behaviours (Menon, Jahn, Mauer, & O'Bryant, 2013).

Assuming that anxiety and depression are variables that can affect performance on neuropsychological tests including EF (Cserjési, Luminet, Poncelet, & Lénárd, 2009), these variables seem to have had little influence on the samples' performance in neuropsychological tests considering the presence of only moderate indicators of anxiety and the absence of indicators of depression (HADS). Although the *GSI* of the *SCL-90-R* is significantly elevated, indicating psychological distress within the total sample, this result might be mitigated when viewed together with the Positive Symptom of Distress Index (*PSDI*), which corresponds to the normative value, thus lessening the intensity and depth of reported distress.

A limitation of this study, beyond the small sample, is that the participants' medical diagnoses were self-reported, not allowing access to confirm information about their medical condition. Another limitation is the absence of a normal weight control sample that could give us more precise indications of existing cognitive alterations.

Conclusion

This study endeavoured to outline the socio-demographic and clinical variables of BS candidates in a Portuguese bariatric centre and to compare their performance with neuropsychological normative data with respect to EF. We hypothesized that severely obese patients would have significantly lower cognitive performance on neuropsychological tasks.

Our results are in line with the growing body of literature that proposes that severely obese individuals do, indeed, have lower performances on some neuropsychological measures such as the *RAVLT* (Immediate Recall, Learning and Deferred Recognition), *RCF, Stroop Test* and *WCST.*

These tests measure memory and EF, particularly the ability to plan, to control impulsive responses, to think abstractly and to change cognitive strategies in response to changing environmental contingencies.

On the other hand, our sample does not differ from normative values on *Digit Symbol, Digit Span* and *TMT,* measures that can predict the relative integrity of the attention system.

Scores on *Search Symbol, Vocabulary and RAVLT* (Long Term Retention percentage) are significantly higher than the normative values, suggesting selective cognitive changes in severely obese individuals.

Although the exact mechanism for the relationship between high BMI, reduction in EF and cognitive performance remains unknown, it is worth noting it is associated with multiple pathophysiological changes including vascular changes, decreased insulin regulation and systemic inflammation (Boeka & Lokken, 2008; Cohen, Yates, Duong, & Convit, 2011; Gunstad et al., 2007; Volkow et al., 2009) and with possible repercussions in prefrontal metabolism.

The different performance results between tests may be attributable to our small sample size, which despite being representative, does not allow for generalization of the data and, thus, limits the generalizability of our study.

However, our results suggest that severely obese people experience decreased cognitive flexibility, increased impulsive responses, lower resistance to interference and less ability to plan and use a strategy to achieve a given goal. These variables are part of executive functioning and can play an important role in the development and maintenance of obesity and in hindering the implementation of new behaviour patterns around eating and physical activity.

As Nilsson and Nilsson (2009) point out, there is the possibility that fat tissue affects homeostatic parameters in such a way that is insufficient to cause mild, medium or severe disease but is enough to cause a reduction in cognitive performance.

Finally, our study appears to reinforce that severe obesity is linked to a decline in some cognition specific areas, which means that screening for cognitive dysfunction, could prevent loss adherence and loss outcomes following BS.

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Competing Interests

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