

ORIGINAL ARTICLE

Executive functions predict weight loss in a medically supervised weight loss programme

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Summary

Background

Deficits in executive functions are related to poorer weight loss after bariatric surgery; however, less is known about the role that these deficits may play during participation in nonsurgical weight loss programmes. This study examined associations between objectively measured executive functions and weight loss during participation in a medically supervised weight loss programme.

Methods

Twenty-three adult patients (age 50.4 ± 15.1 , BMI 44.2 ± 8.8 , 68% female, 92% White) enrolled in a medically supervised weight loss programme, involving prescription of a very low calorie diet and strategies to change eating and activity behaviours, underwent comprehensive computerized testing of executive functions at baseline. Weight was obtained at baseline and 8 weeks. Demographic and clinical information were obtained through medical chart review.

Results

Participants lost an average of $9.8 \pm 3.4\%$ of their initial body weight at 8 weeks. Fewer correct responses on a set-shifting task and faster reaction time on a response inhibition task were associated with lower weight loss percentage at 8 weeks after adjusting for age, education and depressive symptoms. There were no associations between performance on tests of working memory or planning and weight loss.

Conclusions

This study shows that worse performance on a set-shifting task (indicative of poorer cognitive flexibility) and faster reaction times on a response inhibition test (indicative of higher impulsivity) are associated with lower weight loss among participants in a medically supervised weight loss programme. Pre-treatment assessment of executive functions may be useful in identifying individuals who may be at risk for suboptimal treatment outcomes. Future research is needed to replicate these findings in larger samples and identify underlying mechanisms.

Keywords: Behavioural weight loss, cognition, executive functions, neuropsychology.

Introduction

A growing body of evidence suggests that deficits in executive functions (i.e. higher-order cognitive abilities necessary for engaging in goal-oriented behaviours and self-regulation such as impulsivity and working memory) are common in obesity (1–3). Such impairments in

executive functions have been linked to maladaptive eating behaviours including uncontrolled/disinhibited eating (4–7) and weight gain (8). Executive dysfunction is also associated with poorer weight loss outcomes among bariatric surgery patients. Specifically, our work shows that lower scores on a composite variable consisting of multiple attention/executive function tests were associated

with smaller weight losses at 12 and 24 months post-operatively (9,10). Follow-up studies showed that the relationship between executive functions and weight loss among bariatric surgery patients may be mediated by reduced adherence to post-operative guidelines for physical activity (PA) and diet, including adherence to eating multiple 'mini-meals,' checking for fullness after each bite, achieving recommended levels of PA and building PA into daily routines (9).

The relationship between executive functions and weight loss achieved through nonsurgical interventions has received little study. Behavioural weight loss (BWL) involves strategies to increase PA and decrease caloric intake to produce weight loss (11,12). Standard BWL programmes typically result in weight reductions of 7–10% (13,14), with those using more extreme approaches such as medically supervised very low calorie diets (VLCD; defined as diets providing ~800 kcal/day (15)) producing greater weight loss (16), but many individuals fail to achieve optimal weight loss (17,18). As in bariatric surgery, it is possible that executive dysfunction could contribute to suboptimal weight loss outcomes through reduced adherence to recommended PA and diet behaviours. As such, many individuals demonstrate difficulties with restraint and inhibition, manifested in uncontrolled and impulsive eating (4–6).

Few studies have examined the association between executive functions and weight loss outcomes among participants of BWL programmes. In one study involving children, poorer weight loss following a behavioural treatment was related to greater impulsivity, assessed via a stop-signal task (19). In adults, one study found that better decision-making (performance on the Iowa Gambling Task) was associated with greater weight loss among female participants of a 12-week weight loss intervention (20). In contrast, another study in adults found that risk-taking, impulsivity and delay of gratification were not associated with weight loss following a 16-week BWL v. However, the findings did demonstrate that there was a significant effect of recency in distinguishing successful and unsuccessful participants such that individuals who tended to process time-distant information in decision making were more successful with weight loss than those who were high in recency (21). Taken together, these data raise the possibility that executive functions may be important predictors of BWL success. However, previous research is scarce and has largely employed only limited measures of executive functions, which is widely considered a multifaceted construct.

To our knowledge, no studies have conducted a comprehensive assessment of executive functions in the context of a medically supervised weight loss programme. This is potentially problematic given that pre-treatment

detection of executive deficits may have important implications for intervention strategies for those who may be at risk for poor outcomes. Given the limitations of prior research in this area, this study obtained a detailed assessment of executive functions among participants of a medically supervised weight loss programme and examined the association between multiple aspects of executive functioning on weight loss after 8 weeks of treatment. The 8-week time point was chosen as the primary end-point given that length of treatment is variable; however, all participants receive at least 8 weeks of treatment. We hypothesized that worse performance on executive function measures at the start of treatment would predict poorer weight loss outcomes at 8 weeks.

Methods

Participants

Participants were 23 adult participants of a medically supervised weight loss programme. Inclusion/exclusion criteria were: (i) ≥ 18 years old; (ii) body mass index ≥ 30 kg/m²; (iii) English-speaking; (iv) no history of neurological disorder or injury (e.g. stroke, moderate-severe brain injury); (v) no past or current severe psychiatric illness (e.g. schizophrenia, bipolar disorder; defined by DSM 5 (22) criteria) or substance use; (vi) no history of a learning or developmental disability, and (vii) no significantly impaired sensory function. These criteria were initially assessed via telephone screener and confirmed via chart review.

Measures

Executive functions

The *NIH EXAMINER* battery (23) was used to obtain a detailed assessment of executive functions and is a computerized battery of experimental tests that assesses multiple executive functions. It has demonstrated good reliability and validity. The following subtests of the *NIH EXAMINER* battery were administered (Table 1 provides a description of the Tasks):

Working memory

The *Dot Counting* task asks participants to count and remember the number of blue circles in a display of other shapes. The number of displays presented in each trial increases from two to seven over six trials, and the participant is asked to recall, in order, the total number of blue circles on each display. The dependent variable is total correctly recalled numbers over six trials. The *N-back test*

Table 1 NIH-EXAMINER subtests, domains assessed and dependent variables

Test	Domain	Dependent variables
Dot counting	Working memory	Total correct
N-back (1 and 2 back)	Working memory	1-back – total correct, reaction time 2-back – total correct, reaction time
Flanker	Inhibition	Congruent trials – total correct, reaction time Incongruent trials – total correct, reaction time
Set-shifting	Cognitive flexibility/set-shifting	Total correct, reaction time
Unstructured task	Planning	Total points, percentage of high value items completed

is a widely used measure of working memory. This particular test includes a spatial 0-back and 1-back task to assess spatial working memory. The dependent variables are correct responses and reaction time for the 0-back and 1-back tests.

Inhibition

The *Flanker* test requires participants make rapid decisions about the direction of central stimuli when surrounding items are pointed in the same direction (congruent) or opposite direction (incongruent). The dependent variables are number correct and reaction time for the congruent and incongruent conditions.

Set shifting

The *Set Shifting* task requires participants to match a stimulus on the top of the screen to one of two stimuli in the corner of the screen on one of two types of characteristics (colour and shape). The characteristic upon which the participant is asked to match the stimuli alternates in a pseudorandom fashion. This test assesses ability to shift mental set or cognitive flexibility. The dependent variables are number correct and reaction time.

Planning

The *Unstructured Task* asks subjects to complete simple puzzles with various assigned point values in order to obtain as many points as they can in 6 min. The puzzles vary in their cost–benefit ration; better planning is reflected in completion of a greater percentage of low cost–benefit ratio puzzles. The dependent variables are total points and percentage of high-value puzzles completed.

Mood

The Patient Health Questionnaire – 9 (PHQ-9 (24)) was used to assess depressive symptoms. The PHQ-9 is a nine-item measure, which assesses the nine DMS-IV-TR

criteria for depression (25). Scores range from 0 to 27 with higher scores reflecting greater depressive symptoms.

Clinical/demographic information

Clinical and demographic information was obtained both through participant self-report at the time of the assessment, and through comprehensive medical review at baseline and 8 weeks. Participants completed a questionnaire assessing age, gender, race/ethnicity and education. Medical chart review provided information on medical comorbidities (e.g. hypertension, type 2 diabetes, hyperlipidemia, sleep apnea) and intervention type (modified or full fast). Weight was measured by clinical staff at each weekly visit. For this study, weight at the initial medical visit and 8-week visit weight were used.

Procedure

All study procedures were approved by the local Institutional Review Board, and informed consent was obtained prior to participation in the study. Participants were informed of the opportunity to participate in this study by medical staff of the weight loss programme at one of the enrollment evaluations (medical or lifestyle evaluation). Interested participants were screened by telephone for inclusion/exclusion criteria and were then scheduled for an in-office assessment. Participants completed computerized assessment of executive functions within one week of starting the medical weight loss programme.

Weight loss intervention

The intervention was a medically supervised weight loss programme consisting of four components: (i) a VLCD that utilized modified or full fast utilizing meal replacement shakes; (ii) group behaviour therapy; (iii) exercise plan; and (iv) education. Weight loss success varies on a number of factors including: eating extra food on the modified fast, which can have serious medical consequences such as an increased risk of stomach upset, possible gallbladder problems, increase in fluid retention and weight gain.

Skipping shakes may slow down weight loss because of inadequate protein and nutrition. Deviating from the prescribed protocol increases hunger level and results in fluid retention especially with carbohydrate foods. Alcohol consumption during the programme can cause liver function irregularities and also provides extra calories and may have behavioural consequences. The programme and its components are implemented as follows:

- a. Enrollment Evaluation: Upon enrollment, all participants undergo a comprehensive evaluation including laboratory workup, lifestyle evaluation, medical evaluation and exercise assessment.
- b. Dietary Plans and Guidelines: Meal plans and level of calorie restriction are determined upon enrollment based on starting weight and weight loss goals. Individuals can participate in full or modified fast programmes. The full fast meal plan provides approximately 800 calories, 100 g of carbohydrates, 70-g protein and 15 g of fat by drinking 5 Optifast® shakes per day; weight loss typically ranges from 2 to 5 pounds per week. The modified fast meal plan provides approximately 900 calories, 100 g of carbohydrates, 90-g protein and 30 g of fat. The modified fast consists of 3 Optifast® shakes, three servings of vegetables, one small fruit (4–6 oz. scale weight) and 5–6 oz. of low fat meat/protein; weight loss typically ranges from 2 to 4 pounds per week. Participants may also consume an extra 50 calories per day (e.g. chewing gum, salad dressing, coffee whiteners). In addition, participants are instructed to drink 64 fl oz of calorie free beverages per day. No alcoholic beverages are allowed.
- c. Group Meetings: Individuals attend weekly group behavioural therapy sessions led by a team of registered dietitians, exercise physiologists, nurses and psychologists. Topics include nutrition education, exercise instruction, diabetes education and strategies to manage unhealthy eating behaviours (e.g. emotional eating) and develop more helpful thoughts and behaviours related to a healthy lifestyle.

Statistical analysis

Descriptive statistics and independent samples *t*-tests were conducted to characterize the sample and investigate whether baseline characteristics and weight loss varied by type of diet (modified, full-fast) prescribed. Bivariate correlations were conducted to examine the associations among demographic and clinical characteristics and NIH-EXAMINER subtest scores in order to determine covariates for subsequent analyses. Separate hierarchical linear regressions were conducted to

examine the contribution of executive functions to percent weight loss at 8 weeks after controlling for clinical and demographic variables. Specifically, for each executive function variable, separate regression models in which age, education and PHQ-9 scores were entered into the first block and NIH-EXAMINER subtest scores were each entered into the second block were conducted.

Results

Sample characteristics

Participants averaged 50.35 years (SD = 15.11) and had 15.4 years of education (SD = 5.40). A large majority (92%) of participants was white and 68% were female. On average, participants lost 9.8% (SD = 3.35) of their initial body weight at 8 weeks (range = 1.50 – 14.88%). Table 2 presents demographic/clinical characteristics of the sample. The sample was nearly equal in terms of individuals who were participating in the modified (*n* = 11) and full (*n* = 12) fast programmes. Demographic characteristics, baseline BMI or percentage of weight loss, or performance on executive function tests (*p*'s > .13) did not vary according to type of diet prescribed.

Univariate associations among demographics, executive functions and weight loss

Bivariate correlations examined relationships between executive functions and baseline demographic and clinical variables. Results indicated that older age was

Table 2 Characteristics of the sample

	Mean (SD)	Range/%
Age (years)	50.35 (15.11)	22–78
Female	—	68%
White	—	92%
Education (years)	15.40(2.27)	11–20
Baseline BMI (kg/m ²)	44.21 (8.82)	30.17–61.60
Baseline weight (kg)	127.15 (28.16)	83.73–176.18
Medical comorbidities		
Hypertension	—	52%
Type 2 diabetes	—	16%
Hyperlipidemia	—	44%
Sleep apnea	—	28%
Diet type		
Modified fast	—	47.8%
Full fast	—	52.2%
PHQ-9 score	8.22 (5.69)	0–20
8-week weight (kg)	113.55 (26.98)	76.57–166.74
8-week weight loss percent	9.81 (3.35)	1.5–14.88%

Note: PHQ-9, Patient Health Questionnaire – 9.

associated with both lower dot counting score ($r = -.41$, $p = .04$) and unstructured task points ($r = -.52$, $p < .01$), and slower reaction time on the shift task ($r = .42$, $p = .04$). Higher education was significantly associated with greater unstructured task points ($r = .44$, $p = .03$), and faster flanker task congruent ($r = -.42$, $p = .04$), and incongruent ($r = -.55$, $p < .01$) reaction times. More severe depressive symptoms were significantly associated with lower 8-week weight loss percentage ($r = -.43$, $p = .04$); depressive symptoms were not associated with performance on the NIH EXAMINER tests. Consequently, age, education and depression were included as covariates in the following analyses.

Relationship of executive functions with BWL programme outcomes

We next examined whether executive function difficulties on the NIH-EXAMINER battery tests were associated with lower percentage of weight loss at 8 weeks. As shown in Table 3, fewer correct responses on the set-shifting task and faster reaction times for the congruent and incongruent trials of the flanker task at baseline were associated with lower percentage of weight loss at 8 weeks, after adjustment for age, education and depression (p 's $< .05$). Analyses for the other executive function variables tasks were not significant (p 's $> .05$).

Discussion

The present study examined whether aspects of executive functions, using a comprehensive assessment of

objectively measured executive functions, were associated with 8-week weight loss outcomes of a medically supervised weight loss programme. The primary findings are that worse performance on a set-shifting task (indicative of poorer cognitive flexibility) and faster reaction times on a response inhibition test (indicative of higher impulsivity) were associated with lower 8-week weight loss. The current study advances previous research in this area (8,20,21) by examining the relationship of executive functions and weight loss in the context of a medically supervised weight loss programme using a comprehensive battery of executive function tests. Additionally, this study examined weight loss outcomes *during* active weight loss which better captures the participants ongoing efforts at weight control. Results of this study suggest that executive functions may contribute to outcomes of BWL programmes and highlight the importance of pre-treatment cognitive assessment in this context.

The finding that poorer cognitive flexibility was associated with lower weight loss is not surprising given previous observational and experimental research indicating an inflexible and/or rigid approach to control of food intake is related to poorer weight control (26–28). The current study advances previous research that relied on self-report measures of flexibility related to eating by using objective measures of cognitive flexibility and examining these associations during active weight loss in the context of a BWL programme.

Perhaps surprisingly, we found that faster reaction time on a response inhibition task was associated with lower weight loss. This was contrary to our hypotheses as faster reaction times on this task are commonly considered to be markers of better performance. However, it is possible that the slower reaction times reflect a more careful approach or less impulsivity on this task. This pattern emerged in past work showing that successful weight loss maintainers demonstrated slower reaction times of a food-related Stroop paradigm (29). A large body of literature suggests that greater impulsivity is related to weight control difficulties (30,31) and would be expected to lead to poorer weight loss in this population. Clarification of the possible contribution of objectively measured impulsivity on weight loss outcomes is much needed, as it may identify new therapeutic approaches.

If confirmed in larger samples, the findings from this study carry significant clinical implications. These results suggest that pre-BWL treatment evaluation of executive functions may be useful in identifying individuals who may be at risk for suboptimal outcomes and could lead to targeted interventions to improve treatment outcomes. Specifically, individuals with executive function deficits may benefit from more frequent contact with treatment providers or treatment plans that are tailored to the

Table 3 Contribution of executive functions to mid-treatment weight loss percentage

Variable	Standardized β	t	p
Age	-.48	-2.83	.01
Education	.25	1.45	.17
PHQ-9	-.68	-4.07	.001
Flanker C-RT	.69	3.71	.002
Model $R^2 = 0.59$, $F(4, 18) = 6.12$, $p < .01$			
Age	-.36	-2.03	.06
Education	.06	.34	.74
PHQ-9	-.61	-3.41	.003
Flanker I-RT	.53	2.99	.008
Model $R^2 = 0.51$, $F(4, 18) = 4.49$, $p = .01$			
Age	-.17	-.88	.39
Education	-.08	-.40	.69
PHQ-9	-.48	-2.56	.02
Shift correct	.43	2.24	.04
Model $R^2 = 0.43$, $F(4, 18) = 3.17$, $p = .04$			

Note: PHQ-9, Patient Health Questionnaire – 9; C, congruent; I, incongruent; RT, reaction time. Bold data refers to significant findings.

individual's cognitive needs. For example, individuals with executive difficulties may benefit from highly structured plans and/or the use of assistive aids that allow for built-in reminders and/or organizational assistance such as smartphone applications. Alternatively, individuals with executive function difficulties may benefit from learning strategies to increase their cognitive skills. This could be accomplished through a structured skills class, or through computerized training of executive functions. Previous research demonstrates positive effects of executive function training on weight loss outcomes. Specifically, inhibitory control training has been shown to improve eating behaviours including reduced energy intake or choosing fewer unhealthy foods (32–36) and can lead to reduced body weight (32,37). A recent study also showed that training inhibition and working memory in children led to lower weight regain 8 weeks after participation in a BWL programme (38). Reductions in impulsivity during a lifestyle intervention in children were also associated with greater weight loss (39). Therefore, executive function training appears to be a promising target for improving weight loss outcomes among BWL participants. Future research should examine these interventions and determine whether pre-treatment assessment of executive functions may be useful for identifying at-risk individuals who may derive the most benefit from such programmes.

Although there are clear implications for assessment of executive functions prior to weight loss treatment, there are a number of barriers to standard neuropsychological assessment including time and cost. Few studies have examined whether self-report measures of executive functions can predict BWL treatment outcomes such as one previous study from our group which found that greater self-reported disinhibition was associated with weight regain among patients who had lost at least 10% of their initial body weight by non-surgical means and maintained their weight loss for at least one year (40). However, the executive function measure was specifically related to eating and did not assess the active weight loss period. Additional research is needed to further examine whether self-report measures of executive functions can also predict BWL programme outcomes.

This study is not without limitations. Of particular importance is understanding the mechanisms underlying the observed associations. A likely candidate is adherence to recommendations for diet and physical activity, as demonstrated in previous research we have conducted in bariatric surgery patients (41). Moreover, other groups have shown that poorer executive function are associated with less frequent engagement in healthy diet and exercise behaviours (e.g. consuming higher fat foods and fewer fruits and vegetables (42)) in young adults and

in the context of exercise interventions (43). Unfortunately, this study did not include objective measures of adherence to prescribed weight control behaviours and therefore cannot analyse the potential mechanisms underlying this association. Future research involving larger sample sizes and formal mediation analyses should examine whether physical activity and diet adherence underlie the association between executive functions and weight loss. Additionally, the small and mostly White sample limit the generalizability of the current findings. Future research should seek to replicate these findings in a larger and more diverse sample. Additionally, the medically supervised weight loss programme used in this study is considered a very intensive treatment, and future research should examine whether these results generalize to standard BWL treatments.

In brief summary, results of this study demonstrate that executive functions predicted mid-treatment weight loss outcomes of a BWL programme. These results highlight the importance of pre-treatment cognitive assessment and encourage future research to determine whether treatments tailored toward individuals with cognitive difficulties or executive function training could improve treatment outcomes.

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