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ORIGINAL ARTICLE

Cognitive remediation-enabled cognitive behaviour therapy for obesity: a case series

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Abstract

Purpose Despite varied treatment effects, weight recidivism is common and typically associated with the abandonment of prescribed weight management strategies. Literature suggests that difficulty with weight management is associated with deficits in executive functioning, in particular cognitive flexibility and response inhibition, the neurocognitive processes that are involved in goal-directed behaviours, such as dietary adherence. These processes are overlooked by mainstream weight loss programmes. The aim of the study was to assess the effectiveness of a cognitive remediation-enabled cognitive behaviour therapy (CR-CBT) in addressing the neurocognitive, psychological and behavioural correlates of weight loss. It was hypothesised that CR-CBT would improve cognitive flexibility and response inhibition, reduce binge eating, aid weight loss and improve metabolic health.

Methods Four adults with obesity (body mass index > 30 kg/m^2) received 7 weeks of manualised CR-CBT and were assessed via a case series analysis at baseline, end of treatment and 3-month follow-up. Treatment included 3 weekly 90-min group-based behaviour weight loss sessions for 3 weeks, followed by twice-weekly 50-min individualised CR-CBT sessions for 4 weeks.

Results Cognitive remediation-enabled cognitive behaviour therapy produced improvements in response inhibition and cognitive flexibility, and reductions in binge eating frequency, weight, and metabolic health readings between baseline and 3-month follow-up.

Conclusions This is the first study to assess the effectiveness of CR-CBT in the treatment of obesity. Preliminary indications of treatment success are discussed with respect to study limitations. In light of these results, we recommend further investigation via a randomised control trial (RCT).

Level of evidence Level IV, case series.

Keywords Cognitive Remediation-enabled Cognitive Behaviour Therapy · Obesity · Executive function · Cognitive flexibility · Response inhibition · Weight loss

Introduction

Obesity is defined as the accumulation of excess body fat and a Body Mass Index (BMI) of 30 or above [1]. Its increasing prevalence, lifetime chronicity, and association with adverse health outcomes such as type 2 diabetes and cardiovascular disease have made it a major target for public health action [1, 2]. While health guidelines recommend lifestyle modification to reduce weight and improve metabolic health, many individuals with obesity struggle to enact long-term behaviour change [2–4]. Behavioural Weight Loss (BWL) programmes are considered the cornerstone of obesity treatment, targeting weight loss via lifestyle adaptations including healthy diet and regular exercise [5].

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Extensive research suggests that while BWL is associated with a 5–10% reduction in weight during treatment, 85% of participants return to or exceed their original weight in the months and years following treatment [6, 7]. Poor long-term treatment outcomes remain one of the most critical issues for this population, and researchers are calling for the trial of novel interventions in addressing this ongoing issue [8, 9].

Relapse in obesity is typically associated with the abandonment of prescribed weight management strategies, once the motivating effects of therapy are no longer available [10]. Commitment to dietary regimes is particularly challenging within contemporary "obesogenic" environments, where readily available energy-dense foods are easy triggers for the return to excessive and unhealthy eating habits [10, 11]. Furthermore, the psychological factors that underpin weight recidivism are becoming increasingly known. These include binge eating disorder (BED), loss of control eating, addictive eating behaviours and emotional eating [12, 13]. Trials of interventions targeting these issues have rendered unpromising results [14, 15]. Psychological theorists have associated relapse with clients' unrealistic weight loss expectations, which leads to perceived failure and abandonment of dietary strategies [10, 16]. Trials of Cognitive behaviour Therapy (CBT) that have encouraged the maintenance of modest weight loss have found that while participants lose weight during treatment, CBT is no more efficacious than BWL in preventing post-treatment relapse [10, 17].

Brain-directed approaches: a new direction

Challenges associated with sustained weight loss have led researchers to look beyond the physical and psychological mechanisms of obesity. Emerging evidence suggests that obesity is associated with impairments in executive functioning, that is, the top–down cognitive processes responsible for goal-directed behaviours [18, 19]. Key processes of executive functioning include response inhibition, cognitive flexibility, planning and problem solving, which have all been shown to play important roles in weight management [19–21].

Response inhibition, or inhibitory control, refers to the effortful suppression of impulses, which is implicated in the ability to overcome urges to eat foods that jeopardise weight loss [22]. Cognitive flexibility, or set-shifting, refers to the ability to switch between goals, rules or modes of thinking, which is a key requirement for modifying unhelpful eating patterns [18, 23, 24]. Finally, planning and problem solving are processes that are crucial for replacing old dietary habits with new ones [22, 25].

A number of studies suggest that adults with obesity perform more poorly on measures of executive functioning when compared to normative controls, including poorer response inhibition [23, 26–29], set-shifting [23, 30], and decision-making [31, 32], independent of differences in intelligence and level of education. A recent meta-analysis reported that individuals with obesity display impairments across a range of executive processes independent of differences in gender, obesity severity and age [22].

Additionally, neurocognitive research has adopted new ways of designing weight management interventions and delivered positive outcomes, for example, advanced set-shifting for stronger fulfilment of dietary goals [33], advanced response inhibition for more controlled eating and greater weight loss among BWL programmes [34–37], and strengthened executive functioning for healthier food choices [36]. Inhibitory deficits have also been associated with binge eating, i.e. excessive and uncontrolled food consumption, common among individuals with obesity [28, 38, 39].

The bidirectional relationship between executive impairments and obesity has also been recognised [40, 41]. On the other hand, obesity-related inflammation and hypertension have been shown to contribute to poorer executive functioning [42–45]. Supporting this interpretation, bariatric patients have been shown to exhibit prompt and sustained improvements in executive functioning following surgical weight loss [46]. The exact relationship between executive impairment and obesity remains unclear and further longitudinal research is needed.

Recently, it has been suggested that self-regulatory behaviour change entails not just motivation to control behaviours but also the capacity to overcome obstacles and temptations that compromise goals [47]. In line with this, there have been explorations of the impact of improving executive functioning in obesity via "brain-training", which may strengthen capacities for sustained behaviour change in the treatment of Obesity [48, 49].

Brain-training is derived from principles of neuroplasticity, that is the brain's capacity to strengthen neural pathways via task repetition, producing neurological changes that can disrupt and modify automatic behaviours [50–52]. Recent evidence suggests that brain-training has the potential to reverse executive impairments and promotes weight loss [49, 53–55]. A recent review of 32 studies found positive associations between various types of brain-training techniques, reduced food intake and weight loss, although studies were largely limited to laboratory settings and normal weight participants [56].

A more clinical approach to brain-training in obesity has been recently trialled via cognitive remediation therapy (CRT) [49]. CRT uses the repetition of simple mental exercises to improve executive skills that underpin behaviour change, such as the ability to plan ahead, inhibit automatic impulses and think flexibly [57]. CRT was initially developed to treat brain lesions and schizophrenia [58, 59] and has now been associated with improved cognition and health

behaviours in addiction and anorexia nervosa [60–62]. CRT is intended as an adjunct to other therapeutic modalities as a means of improving clients' cognitive capacities to independently apply the strategies provided in treatment [49]. A recent randomised control trial (RCT) demonstrated clinically significant weight loss and better set-shifting in a CRT intervention group, in comparison to the control, among 80 adults with obesity [49].

Cognitive remediation-enabled CBT (CR-CBT)

The rationale of the proposed CR-CBT approach was to enhance cognitive flexibility in our participants, so that they are better able to follow the guidelines of the cognitive behavioural therapy offered in this programme. To achieve both positive short-term effects on client motivation and weight loss, and advancements in the executive processes responsible for sustained behaviour change [6–8, 59], a manualised CR-CBT treatment for obesity that combines BWL, CBT and CRT was developed. Cognitive remediation-enabled CBT (CR-CBT) uses standardised BWL and customised CBT principles to introduce weight loss strategies and enhance client motivation to lose weight, combined with CRT training exercises that address the neurocognitive processes which facilitate sustained behaviour change. The inclusion of meta-cognitive training, that is, reflection on one's own thinking processes, is envisaged to promote individuals' awareness of how their habitual thinking styles, such as impulsive responding, relate to their everyday dietary behaviours. As standalone BWL and CBT are associated with high relapse rates, CR-CBT aims to enhance the self-regulatory skills required to maintain weight loss post-treatment.

Aim and hypotheses

The current study aimed to assess the effectiveness of CR-CBT as a viable treatment for obesity in its potential to achieve weight loss and reduce associated cardiometabolic health risks. This was executed via a case series, aiming to provide preliminary data for a future RCT.

Methods

A case-based time series analysis was used to assess the efficacy of CR-CBT in treating obesity. The expected outcomes were weight loss, improved executive functioning (set-shifting and response inhibition), improved cardiometabolic health (blood pressure, Triglycerides/High Density Lipoproteins-Cholesterol, C-Reactive protein), and reduced binge eating frequency. Outcome measures were taken at End of Treatment (EoT) and 3-month follow-up. Ethics approval was obtained through the University of Technology Sydney (UTS; Human Research Committee Number ETH17-1440).

Participants

Participants were three women and one man ($n=4$) recruited from the community via word of mouth and advertisements posted on social media, community and university notice boards. Participants were included if they were (a) between ages 18 and 55, (b) had a minimum BMI of 30, (c) could read and write in English; and (d) had a minimum of 10-year education. Exclusion criteria included: prior or planned bariatric surgery; history of psychosis, head injury or neurological disorder; current use of weight loss medication, excessive alcohol, illicit drugs, hypnotics, antipsychotics, anticholinergic and cholinergic medication.

Procedure

Assessment and treatment were delivered by a clinical psychologist. Following a phone-screener, participants attended a pre-treatment assessment where eligibility was further assessed via a face-to-face interview. Participants were given an information sheet outlining the study aims before providing written consent. Weight, height, demographic, executive functioning, cardiovascular health, and binge eating behaviour information were taken at baseline. Treatment included 8 sessions delivered over 7–9 weeks, depending on participant availability. Outcome measures were taken at EoT and 3-month follow-up. An emergency protocol was developed to manage risk associated with potential client distress. Participants were given a $50 shopping voucher to compensate for their commute and parking.

Measures

Weight

Participants' weight was measured using calibrated scales, and their height and waist circumference were measured using a tape measure. Participants' BMIs indicated obesity severity and were calculated by dividing weight by height squared (kg/m^2). Weight change outcomes included absolute weight loss from baseline (in kg), Total Body Weight Loss (TBWL) (in %), and reduction in waist circumference (in cm). Based on global and national health guidelines, successful weight loss was defined as a 5% reduction in weight from baseline, as this is associated with considerable health improvements [2–4].

Executive functioning

Participants' response inhibition and set-shifting ability were used as indicators of executive functioning, as these are the domains identified to be most implicated in obesity [25, 27]. Participants completed inhibitory control and set shifting subtests from the Cambridge Neuropsychological Test Automated Battery (CANTAB) [63], a computerised assessment of cognitive functioning [63, 64]. Tests were completed on an electronic tablet. Inhibitory control was measured with the stop signal task (SST), assessing response inhibition via the action of inhibiting an already initiated response [23]. The outcome measurements of SST included stop signal delay (SSD) and stop signal reaction time (SSRT). Set-shifting ability was measured using the attention switching task (AST), with outcome measurements expressed as switching cost (SC). Detailed explanation of SST and AST can be found in Supplementary File 1 with interpretation of measurements.

Cardiometabolic health outcomes

Obesity is associated with hypertension, elevated insulin levels and low-grade systemic inflammation, which are all risk factors for cardiometabolic diseases [65–68]. Cardiometabolic health measurements in the study included:

Blood pressure (BP): BP was measured in millimetres of mercury (mmHg), with hypertension identified via readings of > 140/90 mmHg [69]. Readings were taken in-session by the research clinician using an electronic BP monitor (OMRON™) at baseline, EoT and 3-month follow-up [67].

Triglycerides/high-density lipoprotein cholesterol (Tg/HDL-C): The Tg/HDL-C Ratio is a measure of hypertension and insulin resistance [65].

C-Reactive protein (CRP): CRP is a measure of low-grade systemic inflammation.CRP was measured in milligrams per litre (mg/L), with readings of > 2.4 mg/L identifying clinically significant levels [68].

Triglycerides, HDL and CRP were measured at baseline and 3-month follow-up via a single blood test. Participants were directed to their local pathology centre for this purpose.

Binge eating

Self-reported binge eating episodes provided an indicator of dysregulated and uncontrolled eating behaviour and were measured via the Eating Disorder Examination Questionnaire (EDE-Q) [70]. Binge eating is highly prevalent among individuals with obesity and is associated with poorer treatment outcomes [70–72].

Treatment

Treatment included 3 weekly 90-min group-based BWL sessions followed by 8 50-min individualised CR-CBT sessions, delivered approximately twice a week. Each treatment component was delivered in accordance with the CR-CBT manual developed for this study. BWL sessions were consistent with conventional programme content including goal setting, psycho-education surrounding healthy eating practices and exercise, and discussion of personal barriers to weight loss [7, 73]. Each CR-CBT session included 30 min of CRT and 20 min of CBT, and provided homework tasks to ensure that skills were practiced outside therapy. The treatment outline is provided in Appendix 1.

CBT component

Cognitive behaviour therapy consisted of customised cognitive and behavioural strategies designed to complement CRT by encouraging the regulation of habitual eating behaviours and more adaptive food-related thoughts. Cognitive restructuring techniques addressed habitual all-or-nothing mindsets associated with dietary practices, and behavioural techniques include urge surfing, coping intentions, response inhibition, "mindful" eating and behavioural experiments such as exposure and response prevention. The final session focused on relapse prevention strategies to help maintain weight loss.

CRT component

The CRT component included pen-to-paper exercises, puzzles and games to promote flexible thinking styles, inhibitory control, planning and problem solving. Upon the completion of each exercise, participants engaged in meta-cognitive practice by reflecting on how their task performance (e.g. automatic and impulsive responding or lack of attention to detail) related to the dietary practices addressed via CBT (e.g. automatic and habitual grazing behaviours or lack of attention to nutritional information and meal planning). This component was essential in encouraging understandings of how personal thinking styles underpinned approaches to food and how improvements in these areas could facilitate behaviour change. Sessions 1–4 introduced all CRT tasks and sessions 5–8 focused on practicing skills that individual participants found most challenging. All participants were encouraged to do word and number puzzles, try new behaviours at least once a week and also to attempt brain-training online games such as Lumosity.com from the time intervention was completed to their 3-month follow-up. No data were collected at the 3-month follow-up as to whether participants adhered to these suggestions.

Data analysis

Change in measurements was recorded from baseline, to EoT and 3-month follow-up. Data analysis followed the per-protocol approach. Continuous data were aggregated and presented as group mean and range (min–max), and measured individual data were also presented. Visual inspection of the data was used to assess trend and magnitude of change, as is traditionally applied in case series analysis [74]. Statistical tests were not conducted due to the small sample size (and the assumptions of normality not being met), as well as the lack of availability of normative data for the CANTAB electronic tablet tests.

Results

Participant characteristics

Baseline participant characteristics are displayed in Table 1. Three participants were Anglo-Saxon and one was Latino. Three had post-graduate qualifications and worked full time, and one was a current full-time university student. Three of the 4 participants were categorised as morbidly obese (BMI > 40 kg/m^2). All participants displayed clinically elevated levels of CRP. Two participants displayed clinically high level of BP.

Weight loss outcomes

All participants lost weight from baseline to EoT ($M = 4.0$ kg, TBWL 3.4%) and 3-month follow-up ($M = 4.8$ kg, TBWL 3.8%). Weight loss was also reflected in reductions in waist circumference measurements (Table 2). One participant reached the 5% TBWL threshold by EoT but failed to maintain the level by 3-month follow-up, whereas the other participants maintained or achieved further weight loss from EoT to 3-month follow-up.

Individual weight loss data are displayed in Table 2.

Executive functioning outcomes

Figure 1 demonstrates participants' SST performance. On average, participants' ability to inhibit inappropriate responses (i.e. SSRT score) improved from baseline ($M = 257$ ms, range 223–327 ms) to EoT ($M = 232.4$ ms, range: 221–245 ms) and 3-month follow-up ($M = 222.4$ ms, range 197.3–246.5 ms), indicating improved response inhibition performance.

Figure 2 demonstrates participants' AST performance. On average, participants' switching cost (SC) scores reduced from baseline ($M = 258$ ms, range 181–317 ms) to EoT ($M = 237$ ms, range 95–373 ms) and again at 3-month follow-up ($M = 198$ ms, range 137–229 ms).

This indicated that their average ability to switch between stimuli improved, indexing improved set-shifting.

Table 1 Baseline participant characteristics

	Age (years)	Weight (kg)	Waist (cm)	BMI (kg/m^2)	BP (mmHg)	Tg (mmol/L)	HDL (mmol/L)	CRP (mg/L)	Binge (episodes/28 days)
P1	34	143	135	40	157/103	1.2	1.7	2.5	5
P2	50	141	145	45	133/101	1.1	1.7	3.5	8
P3	44	73	98	30	181/126	1.2	1.7	2.5	14
P4	31	151	162	50	132/91	3.8	1.4	32.7	15

P participant, *BMI* body mass index, *BP* blood pressure, *Tg* triglycerides, *HDL* high density lipoprotein cholesterol, *CRP* C-reactive protein, *Binge* Binge eating

Table 2 Individual participant weight loss outcomes from baseline to End of Treatment (EoT) and 3-month follow-up

	EoT			Three-month follow-up		
	Absolute weight loss (kg)	TBWL (%)	Reduction in waist circumference (cm)	Absolute weight loss (kg)	TBWL (%)	Reduction in waist circumference (cm)
P1	6	4.2	10	7	4.9	9
P2	3	2.1	4	3	2.1	5
P3	4	5.5	3	3	4.1	3
P4	3	2	13	6	4	13

P participant, *TBWL* percentage of total body weight loss from baseline

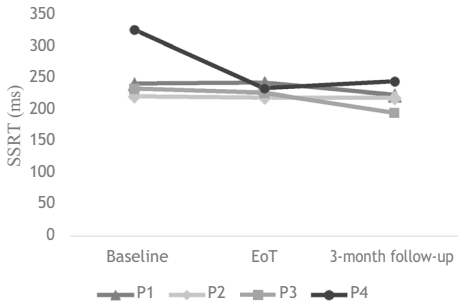

Fig. 1 Individual participant SST scores at baseline, end of treatment (EoT) and 3-month follow-up

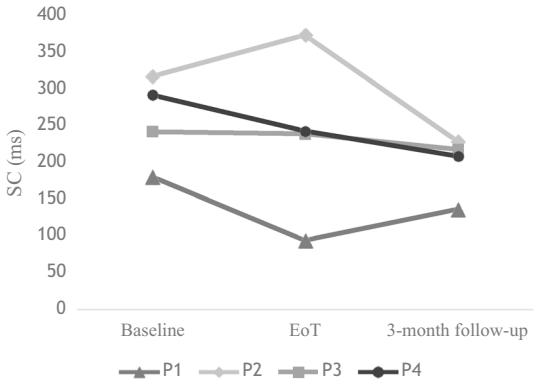

Fig. 2 Individual participant AST scores at baseline, end of treatment (EoT) and 3-month follow-up

Cardiometabolic health outcomes

An overall reduction was observed among all participants in blood pressure, CRP, and Tg, from baseline to 3-month follow-up (Table 3). On average, HDL levels remained the same. Individual participant results can be seen in Appendix 2.

Binge eating outcomes

Participant responses to question 18 of the EDE-Q across 3 time points can be seen in Fig. 3. On average, participants reported a reduction in binge eating frequency between baseline ($M = 11$, range 5–15) and EoT ($M = 3$, range 0–5), which was sustained at 3-month follow-up ($M = 3$, range 0–6).

Discussion

The findings of this study indicated promising results in weight management, cardiovascular, and cognitive outcomes with CR-CBT among people with obesity. Standalone BWL and CBT are associated with high relapse rates, and post-treatment weight regain remains one of the greatest challenges in the treatment of obesity [4, 5]. This preliminary study was the first to assess whether CR-CBT, a novel intervention, could produce sustained weight loss by targeting the behavioural and psychological components of weight management, as well as the neurocognitive processes that facilitate behaviour change, and that are known to be impaired in obesity. It was hypothesised that among four individuals with obesity, CR-CBT would reduce weight, improve cardiometabolic health readings, enhance cognitive flexibility and response inhibition and regulate eating behaviours by the end of treatment and 3-month follow-up. Preliminary visual inspection of the data confirmed each of these hypotheses, suggesting that CR-CBT may be a promising treatment solution for individuals with obesity.

Results indicated that CR-CBT was effective in producing weight loss, and that the greatest percentage of total body weight loss (TBWL) occurred during treatment. This trend is common to weight loss programmes and has been associated with the provision and reinforcement of treatment strategies and the motivating effects of therapist support [7, 9, 15]. The average percentage of TBWL during treatment was 3.4%, and only 1 participant reached the 5% weight loss guideline [2, 3]. As standalone BWL and CBT programmes produce 5–10% TBWL within 6–24 months of treatment [5, 7, 9, 15, 72, 73], 3.4% TBWL during the current study's brief 7–9-week intervention may be a promising start.

Excluding participant 3, who gained a kilogram between end of treatment and 3-month follow-up, all other participants either continued to lose weight post-treatment or maintained the weight they had lost. This may suggest that CR-CBT was effective in providing individuals with the tools

Table 3 Mean cardiometabolic reading at baseline, End of Treatment (EoT) and 3-month follow-up

	Baseline		EoT		Three-month follow-up	
	Group mean	Range	Group mean	Range	Group mean	Range
BP (mmHg)	146/103	132–181/	130/93	124–138/	129/90	111–137/
CRP	10.3	2.5–32.7			8.1	0.9–27.4
Tg (mg/L)	1.8	1.1–3.8			1.4	0.9–2.6
HDL (mmol/L)	1.6	1.2–1.6			1.5	1.2–1.6

BP blood pressure, *CRP* C-reactive protein, *Tg* triglycerides, *HDL* high density lipoprotein cholesterol

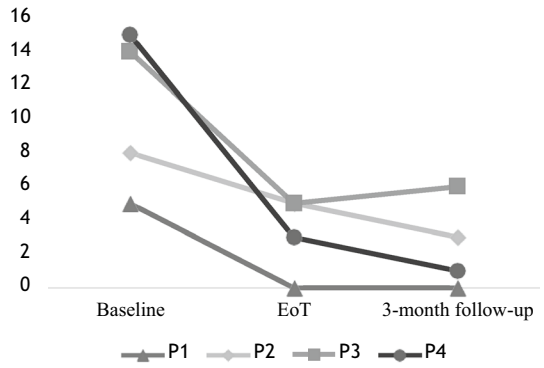

Fig. 3 Individual participant self-reported binge eating occurrences in the previous 28 days at baseline, end of treatment (EoT) and 3-month follow-up

to maintain weight loss independent of therapist contact—a preliminary indication of the long-term effectiveness of CR-CBT. As standalone BWL and CBT intervention studies have identified that post-treatment weight regain typically begins 6 months after programme completion, the current study's 3-month follow-up could not assess whether the addition of CRT as an adjunct to CBT and BWL was advantageous in preventing typical patterns of weight regain [75]. As a longer follow-up period was beyond the scope of this project, future research should employ follow-up periods up to 12 months, in keeping with the Institute of Medicine criteria [76].

Consistent with predictions, participants' average response inhibition and set-shifting performances improved between baseline and end of treatment and continued to improve by 3-month follow-up. The magnitude and trajectories of change differed between tasks and participants. Participant 1's SST scores improved between baseline and end of treatment but weakened between end of treatment and 3-month follow-up, while the opposite trend was noted for this participant's AST performance. Participant 2 displayed close to no change on the SST and the greatest improvement of all participants on the AST between baseline and 3-month follow-up, although performance initially weakened between baseline and end of treatment. Participant 3 displayed progressive improvements on the SST and AST at both follow-up points. Participant 4 displayed the greatest improvements on the SST by the end of treatment and the most linear and continuous improvement on the AST at all time points. It is not uncommon for participant performance to vary across distinct measures of executive functioning, which may reflect both the diversity and complexity of executive processes, and the varying sensitivity of tasks [77]. While the magnitude and significance of improvement are inconclusive in the absence of population norms and statistical analysis, the observed trend in average improvement at each follow-up point builds upon a recent study to suggest that the repetition of CRT exercises strengthens executive processes [49]. We propose that further investigation within a large sample is warranted.

Our findings also indicated that by aiding in weight reduction, CR-CBT may help other important health outcomes in the treatment of obesity [1–4, 66]. While HDL readings remained the same, the general pattern of improvement across all other metabolic health readings was promising. Steep reductions in binge eating behaviours were reported between baseline and end of treatment, with participant 3 reporting the elimination of binge eating. By 3-month follow-up, these reductions were either sustained or reduced further (excluding participant 3 who reported an increase by 1 episode at 3-month follow-up). Raman et al. [49] reported that CRT produced similar reductions in binge eating during treatment that were maintained at 3-month follow-up. In the current study, CRT exercises encouraged the inhibition of automatic and ineffective task-based responses; while the addition of CBT homework tasks (for example, exposure and response prevention to energy-dense foods), encouraged the inhibition of real-world automatic and ineffective eating behaviours (for example, binge eating). Hence, CR-CBT targets binge eating more comprehensively than standalone CRT by facilitating the behavioural generalisation of neurocognitive skills to everyday eating. In the current study, this connection was identified by participants during metacognitive task reflection, thus reinforcing learning.

Most promising were the consistent trends observed across all measures, identifying that on average, cognition, binge eating, weight loss and the majority of metabolic readings all improved between baseline and 3-month follow-up. This may suggest that the combined neurocognitive, psychological and behavioural approach was successful in facilitating improved executive functioning, which in turn contributed to improved eating behaviours and associated weight loss and metabolic health. There is also the possibility that weight loss contributed to improvement in cognitive flexibility and response inhibition measures, reflecting the hypothesised bidirectional relationship between obesity and executive dysfunction [78]. While conclusions surrounding the causal relationship between factors in the current case series are speculative, these preliminary observations are promising and warrant further investigation via a correlation analysis in a large sample.

Limitations and future research

The current findings need to be interpreted with caution as data from single case series are preliminary and cannot be

generalised to the wider clinical population [79]. Other general limitations of case series studies also applied, including lack of control and potential measurement error. An additional limitation was the use of single tasks to measure inhibitory control and set-shifting. Specific brain regions are difficult to localise via single measures that reflect varying processes [77, 80]. Additionally, CRT strengthens cognitive skills beyond response inhibition and cognitive flexibility, such as planning and decision-making that are also implicated in obesity and weight management [28, 39, 58]. Future research should assess these mechanisms via additional testing tools.

Despite these limitations, the preliminary suggestion that CR-CBT is advantageous in addressing the physical, metabolic and neurocognitive features of obesity during and after treatment provides reason for further statistical investigation via an RCT. The short-term CR-CBT may be a beneficial alternative to longer-term weight loss programmes in terms of cost and time efficiencies for both clients and practitioners [18, 58].

Future RCTs should compare the effects of CR-CBT with those of standalone CRT, BWL and CBT, at multiple follow-up points, to determine whether the combined treatment approach is more efficacious in contributing to long-term weight loss maintenance. More research is also needed to understand how executive function plays out long term and their exact relationship with weight regain. Concurrent advancements in this knowledge may help to refine interventions such as CR-CBT to target specific executive processes and related eating behaviours both during and after treatment. Multiple and extensive follow-up points should endeavour to assess whether clinical improvement is sustainable, and whether CR-CBT provides a viable solution to longer-term weight management, which remains the central issue in obesity treatment. Finally, future trials should also include a diagnostic assessment of binge eating disorder to assess whether CR-CBT is also influential in treating psychopathology associated with obesity [8, 9].

Conclusion

Mainstream BWL and CBT interventional approaches to obesity have failed to show long-term behaviour change. Recent evidence suggests that relapse may be due to executive deficits associated with obesity that are known to be implicated in the self-regulation of eating behaviours. This study was the first to assess the efficacy of CR-CBT, a novel intervention, in treating the behavioural and psychological mechanisms of obesity, as well as the cognitive flexibility and response inhibition capacities that facilitate sustained behaviour change. Results suggested that 8 sessions of CR-CBT rendered average improvements in weight, metabolic health, executive functioning and eating behaviours among 4 individuals with obesity. The preliminary indication that these improvements were sustained in the absence of therapist contact suggests that CR-CBT may be influential in facilitating the maintenance of adaptive health behaviours post-treatment. These preliminary findings should be verified via RCTs with more extensive follow-up periods.

What is already known on this subject?

Emerging evidence suggests that obesity is associated with impairments in executive functioning. Cognitive remediation therapy has been shown to help reduce eating pathology, and enhance set shifting abilities.

What does this study add?

This study utilised cognitive remediation as an adjunct therapy to cognitive behavioural therapy (CR-CBT), simultaneously treating the cognitive, behavioural and psychological aspects of eating behaviours in obesity to facilitate sustained behaviour change. A brief 8-session intervention of CR-CBT rendered improvements in weight, metabolic health, executive functioning and eating behaviours among 4 individuals with obesity. The findings from this study have implications for clinical practice and for future trials using cognitive remediation as an adjunct therapy.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in this study involving human participants were in accordance with the Human Research Ethics Committee of the University of Technology Sydney (UTS) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethics approval was obtained from the UTS Human Research Ethics Committee prior to conducting this research.

Informed consent Informed consent was obtained from all individual participants included in the study.

Appendix 1: CR-CBT Treatment Plan

Cognitive remediation-enabled cognitive behavioural therapy (CR-CBT) manualised format		
Session 1	CRT	1. Introduction to the programme 2. Psycho-education of CRT in weight management 3. Tasks relating to cognitive flexibility
	CBT	1. Psychoeducation of CBT in weight management 2. Self-efficacy training 3. SMART goals
Session 2	CRT	1. Review home work 2. Recap 3. More tasks on cognitive flexibility 4. New ways of thinking—in-session training 5. Home work—self-monitoring
	CBT	1. Review home work 2. Recap 3. Eating focused CBT—discussion 4. Behavioural experiments 5. Homework—beh experiment + continue self-monitoring
Session 3	CRT	1. Review home work 2. Recap 3. Tasks on cognitive flexibility, response inhibition and planning 4. Home work
	CBT	1. CBT on impulse control 2. CBT on health behaviour change 3. In-session training 4. Homework—beh experiment and continue self-monitoring
Session 4	CRT	1. Review home work 2. Cognitive flexibility and response inhibition tasks—continued 3. Estimation tasks—in-session training 4. Planning and organisation—in-session training 5. Home work: estimation tasks in shopping behaviours
	CBT	1. Review home work 2. Mindfulness in eating behaviours 3. Exposure and response prevention—Psycho-ed 4. Home work: on 2 and 3
Session 5	CRT	1. Review home work 2. Attention switching and Attention to detail tasks 3. Planning and organisation tasks 4. Cognitive flexibility tasks 5. New ways of thinking tasks
	CBT	1. Review home work 2. Resisting and managing temptation—in-session training 3. Structured problem solving in eating behaviours—in-session training 4. Home work: on 2 and 3
Session 6	CRT	1. Review home work 2. Cognitive flexibility tasks 3. Response inhibition tasks 4. Advise participant to start preparing a letter to the therapist
	CBT	1. Review home work 2. Overcoming unhelpful habits 3. Temptation management Cont'd 4. Homework tasks: on 1 and 2
Session 7	CRT	1. Goals—moving forward and strategies
	CBT	1. Review home work 2. Recap on all CBT strategies taught so far with an emphasis on linking them with the CRT exercises taught so far: content and process
Session 8	CRT	1. Mind map 2. Read letter to the therapist 3. Recap programme content 4. Relapse prevention
	CBT	1. Relapse prevention 2. Motivational therapy building self-efficacy—Guided discovery techniques 3. CBT goals—moving forward and strategies

Appendix 2: Individual participant cardiometabolic results

Individual C-reactive protein (CRP), triglycerides and high density lipoproteins—cholesterol readings at baseline, end of treatment (EoT) and 3-month follow-up

	CRP (mg/L)		Tg (mmol/L)		HDL (mmol/L)	
	Baseline	Three-month follow-up	Baseline	Three-month follow-up	Baseline	Three-month follow-up
P1	2.5	1.5	1.2	1	1.7	1.2
P2	3.5	2.6	1.1	0.9	1.7	1.5
P3	2.5	0.9	1.2	0.9	1.7	1.6
P4	32.7	27.4	3.8	2.6	1.4	1.5

P participant, *BMI* body mass index, *BP* blood pressure, *Tg* triglycerides, *HDL* high density lipoprotein cholesterol, *CRP* C-reactive protein, *Binge* Binge eatingIndividual participant blood pressure (BP) readings at baseline end of treatment (EoT) and 3-month follow-up

	BP (mmHg)		
	Baseline	EoT	Three-month follow-up
P1	157/103	138/90	134/82
P2	133/101	124/88	133/98
P3	181/126	127/100	137/101
P4	132/91	129/94	111/78

P participant

References

1. World Health Organisation (2018) Obesity and overweight, fact sheet 311. http://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight. Accessed 13 Oct 2018
2. National Health & Medical Research Council (Australia) (2003) Clinical practice guidelines for the management of overweight and obesity in adults. National Health & Medical Research Council, Canberra
3. Institute of Medicine (1995) Weighing the options: criteria for evaluating weight-management programs. National Academy Press, Washington, DC
4. Wing RR, Hill JO (2001) Successful weight loss maintenance. Annu Rev Nutr 21:323–341. https://doi.org/10.1146/annurev.nutr.21.1.323
5. Olson K (2017) Behavioral approaches to the treatment of obesity. Rhode Island Med J 100(3):21
6. Avenell A, Broom JI, Brown TJ, Poobalan A, Aucott LS, Stearns SC, Grant AM (2004) Systematic review of the long-term effects and economic consequences of treatments for obesity and implications for health improvement. Health Technol Assess. https://doi.org/10.3310/hta8210
7. Wadden TA, Butryn ML, Wilson C (2007) Lifestyle modification for the management of obesity. Gastroenterology 132(6):2226–2238. https://doi.org/10.1053/j.gastro.2007.03.051
8. MacLean PS, Wing RR, Davidson T, Epstein L, Goodpaster B, Hall KD et al (2015) NIH working group report: innovative research to improve maintenance of weight loss. Obesity 23(1):7–15. https://doi.org/10.1002/oby.20967
9. Cooper Z, Doll HA, Hawker DM, Byrne S, Bonner G, Eeley E et al (2010) Testing a new cognitive behavioural treatment for obesity: a randomized controlled trial with three-year follow-up. Behav Res Ther 48(8):706–713. https://doi.org/10.1016/j.brat.2010.03.008
10. Cooper Z, Fairburn CG (2001) A new cognitive behavioural approach to the treatment of obesity. Behav Res Ther 39(5):499–511. https://doi.org/10.1016/S0005-7967(00)00065-6
11. Melchionda N, Besteghi L, Di Domizio S, Pasqui F, Nuccitelli C, Migliorini S et al (2003) Cognitive behavioural therapy for obesity: one-year follow-up in a clinical setting. Eat Weight Disord 8(3):188–193
12. Bourdier L, Orri M, Carre A, Gearhardt AN, Romo L, Dantzer C, Berthoz S (2018) Are emotionally driven and addictive-like eating behaviors the missing links between psychological distress and greater body weight? Appetite 120:536–546. https://doi.org/10.1016/j.appet.2017.10.013
13. Schulte EM, Gearhardt AN (2018) Associations of food addiction in a sample recruited to be nationally representative of the United States. Eur Eat Disord Rev 26(2):112–119
14. Perri MG (1998) The maintenance of treatment effects in the long-term management of obesity. Clin Psychol Sci Pract 5(4):526–543. https://doi.org/10.1111/j.1468-2850.1998.tb00172.x
15. Middleton KM, Patidar SM, Perri MG (2012) The impact of extended care on the long-term maintenance of weight loss: a systematic review and meta-analysis. Obes Rev 13(6):509–517. https://doi.org/10.1111/j.1467-789X.2011.00972.x
16. Foster GD, Wadden TA, Phelan S, Sarwer DB, Sanderson RS (2001) Obese patients' perceptions of treatment outcomes and the factors that influence them. Arch Internal Med 161:2133–2139
17. Ames GE, Perri MG, Fox LD, Fallon EA, De Braganza N, Murawski ME et al (2005) Changing weight-loss expectations: a randomized pilot study. Eat Behav 6(3):259–269
18. Hayes JF, Eichen DM, Barch DM, Wilfley DE (2018) Executive function in childhood obesity: promising intervention strategies to optimize treatment outcomes. Appetite 124:10–23. https://doi.org/10.1016/j.appet.2017.05.040
19. Jansen A, Houben K, Roefs A (2015) A cognitive profile of obesity and its translation into new interventions. Front Psychol 6:1807
20. Appelhans BM, French SA, Pagoto SL, Sherwood NE (2016) Managing temptation in obesity treatment: a neurobehavioral model of intervention strategies. Appetite 96:268–279. https://doi.org/10.1016/j.appet.2015.09.03
21. Gettens KM, Gorin AA (2017) Executive function in weight loss and weight loss maintenance: a conceptual review and novel neuropsychological model of weight control. J Behav Med 40(4):687–701. https://doi.org/10.1007/s10865-017-9831-5
22. Yang Y, Shields GS, Guo C, Liu Y (2017) Executive function performance in obesity and overweight individuals: a meta-analysis and review. Neurosci Biobehav Rev 84:225–244. https://doi.org/10.1016/j.neubiorev.2017.11.020
23. Perpiñá C, Segura M, Sánchez-Reales S (2017) Cognitive flexibility and decision-making in eating disorders and obesity. Eat

Weight Disord 22(3):435–444. https://doi.org/10.1007/s40519-016-0331-3
24. Raman J, Hay P, Smith E (2014) Manualised Cognitive Remediation Therapy for adult obesity: study protocol for a randomised controlled trial. Trials 15(1):426. https://doi.org/10.1186/1745-6215-15-426
25. Fitzpatrick S, Gilbert S, Serpell L (2013) Systematic review: are overweight and obese individuals impaired on behavioural tasks of executive functioning? Neuropsychol Rev 23(2):138–156
26. Danner UN, Ouwehand C, Haastert NL, Hornsveld H, Ridder DT (2012) Decision-making impairments in women with binge eating disorder in comparison with obese and normal weight women. Eur Eat Disord Rev 20(1):56–62. https://doi.org/10.1002/erv.1098
27. Lavagnino L, Arnone D, Cao B, Soares JC, Selvaraj S (2016) Inhibitory control in obesity and binge eating disorder: a systematic review and meta-analysis of neurocognitive and neuroimaging studies. Neurosci Biobehav Rev 68:714–726. https://doi.org/10.1016/j.neubiorev.2016.06.041
28. Mobbs O, Iglesias K, Golay A, Van der Linden M (2011) Cognitive deficits in obese persons with and without binge eating disorder: investigation using a mental flexibility task. Appetite 57:263–271. https://doi.org/10.1016/j.appet.2011.04.023
29. Gunstad J, Paul RH, Cohen RA, Tate DF, Spitznagel MB, Gordon E (2007) Elevated body mass index is associated with executive dysfunction in otherwise healthy adults. Compr Psychiatry 48(1):57–61. https://doi.org/10.1016/j.comppsych.2006.05.001
30. Lokken KL, Boeka AG, Austin HM, Gunstad J, Harmon CM (2009) Evidence of executive dysfunction in extremely obese adolescents: a pilot study. Surg Obes Relat Dis 5(5):547–552. https://doi.org/10.1016/j.soard.2009.05.008
31. Brogan A, Hevey D, Pignatti R (2010) Anorexia, bulimia, and obesity: shared decision-making deficits on the Iowa Gambling Task (IGT). J Int Neuropsychol Soc 16(4):711–715. https://doi.org/10.1017/S1355617710000354
32. Pignatti R, Bertella L, Albani G, Mauro A, Molinari E, Semenza C (2006) Decision-making in obesity: a study using the gambling task. Eat Weight Disord 11(3):126–132
33. Allan JL, Johnston M, Campbell N (2011) Missed by an inch or a mile? Predicting the size of intention behaviour gap from measures of executive control. Psychol Health 26(6):635–650. https://doi.org/10.1080/08870441003681307
34. Allom V, Mullan B (2014) Individual differences in executive function predict distinct eating behaviours. Appetite 80:123–130. https://doi.org/10.1016/j.appet.2014.05.007
35. Appelhans BM, Woolf K, Pagoto SL, Schneider KL, Whited MC, Liebman R (2011) Inhibiting food reward: delay discounting, food reward sensitivity, and palatable food intake in overweight and obese women. Obesity (Silver Spring) 19:2175–2182. https://doi.org/10.1038/oby.2011.57
36. Hall PA, Fong GT, Epp LJ (2008) Executive function moderates the intention–behavior link for physical activity and dietary behavior. Psychol Health 23:309–326. https://doi.org/10.1080/14768320701212099
37. Kulendran M, Vlaev I, Sugden C, King D, Ashrafian H, Gately P, Darzi A (2014) Neuropsychological assessment as a predictor of weight loss in obese adolescents. Int J Obes 38(4):507
38. Duchesne M, Mattos P, Appolinário J, de Freitas S, Coutinho G, Santos C et al (2010) Assessment of executive functions in obese individuals with binge eating disorder. Revista Brasileira de Psiquiatria 32:381–388
39. Svaldi J, Brand M, Tuschen-Caffier B (2010) Decision-making impairments in women with binge eating disorder. Appetite 54:84–92. https://doi.org/10.1016/j.appet.2009.09.010
40. Reinert KRS, Po'e EK, Barkin SL (2013) The relationship between executive function and obesity in children and adolescents: a systematic literature review. J Obes. https://doi.org/10.1155/2013/820956
41. Graziano PA, Calkins SD, Keane SP (2010) Toddler self-regulation skills predict risk for paediatric obesity. Int J Obes 34(4):633
42. Gonzales M, Tarumi T, Miles S, Tanaka H, Shah F, Haley A (2010) Insulin sensitivity as a mediator of the relationship between BMI and working memory-related brain activation. Obesity 18:2131–2137
43. Lasselin J, Magne E, Beau C et al (2016) Low-grade inflammation is a major contributor of impaired attentional set shifting in obese subjects. Brain Behav Immun 58:63–68. https://doi.org/10.1016/j.bbi.2016.05.013
44. Miller AA, Spencer SJ (2014) Obesity and neuroinflammation: a pathway to cognitive impairment. Brain Behav Immun 42:10–21. https://doi.org/10.1016/j.bbi.2014.04.001
45. Volkow N, Wang G, Telang F, Fowler J, Goldstein R, Alia-Klein N et al (2008) Inverse association between BMI and prefrontal metabolic activity in healthy adults. Obesity 17(1):60–65. https://doi.org/10.1038/oby.2008.469
46. Handley JD, Williams DM, Caplin S, Stephens JW, Barry J (2016) Changes in cognitive function following bariatric surgery: a systematic review. Obes Surg 26(10):2530–2537
47. Hofmann W, Schmeichel BJ, Baddeley AD (2012) Executive functions and self-regulation. Trends Cogn Sci 16(3):174–180. https://doi.org/10.1016/j.tics.2012.01.006
48. Hilbert A, Blume M, Petroff D, Neuhaus P, Smith E, Hay PJ, Hübner C (2018) Group cognitive remediation therapy for adults with obesity prior to behavioural weight loss treatment: study protocol for a randomised controlled superiority study (CRT study). BMJ Open 8(9):e022616. https://doi.org/10.1136/bmjopen-2018-022616
49. Raman J, Hay P, Tchanturia K, Smith E (2018) A randomised controlled trial of manualized cognitive remediation therapy in adult obesity. Appetite 123:269–279. https://doi.org/10.1016/j.appet.2017.12.023
50. Doidge N (2007) The brain that changes itself: stories of personal triumph from the frontiers of brain science. Penguin, New York
51. Rabipour S, Raz A (2012) Training the brain: fact and fad in cognitive and behavioral remediation. Brain Cogn 79(2):159–179. https://doi.org/10.1016/j.bandc.2012.02.006
52. Allom V, Mullan B, Smith E, Hay P, Raman J (2018) Breaking bad habits by improving executive function in individuals with obesity. BMC Public Health 18:505. https://doi.org/10.1186/s12889-018-5392-y
53. Houben K, Jansen A (2015) Chocolate equals stop: chocolate-specific inhibition training reduces chocolate intake and go associations with chocolate. Appetite 87:318–323. https://doi.org/10.1016/j.appet.2015.01.005
54. Lawrence NS, O'Sullivan J, Parslow D, Javaid M, Adams RC, Chambers CD et al (2015) Training response inhibition to food is associated with weight loss and reduced energy intake. Appetite 95:17–28. https://doi.org/10.1016/j.appet.2015.06.009
55. Veling H, van Koningsbruggen GM, Aarts H, Stroebe W (2014) Targeting impulsive processes of eating behavior via the internet. Effects on body weight. Appetite 78:102–109. https://doi.org/10.1016/j.appet.2014.03.014
56. Jones A, Hardman CA, Lawrence N, Field M (2018) Cognitive training as a potential treatment for overweight and obesity: a critical review of the evidence. Appetite 124:50–60. https://doi.org/10.1016/j.appet.2017.05.032
57. Tchanturia K, Lloyd S, Lang K (2013) Cognitive remediation therapy for anorexia nervosa: current evidence and future research directions. Int J Eat Disord 46(5):492–495. https://doi.org/10.1002/eat.22106

58. Luria AR (1972) The man with a shattered world: the history of a brain wound. Harvard University Press, Cambridge
59. Harvey P, Bowie C (2012) Cognitive enhancement in schizophrenia: pharmacological and cognitive remediation approaches. Psychiatr Clin N Am 35:683–698. https://doi.org/10.1016/j.psc.2012.06.008
60. Genders R, Tchanturia K (2010) Cognitive remediation therapy (CRT) for anorexia in group format: a pilot study. Eat Weight Disord 15(4):234–239
61. Rupp CI, Kemmler G, Kurz M, Hinterhuber H, Wolfgang Fleischhacker W (2012) Cognitive remediation therapy during treatment for alcohol dependence. J Stud Alcohol Drugs 73(4):625–634. https://doi.org/10.15288/jsad.2012.73.625
62. Giombini L et al (2018) Young people's experience of individual cognitive remediation therapy (CRT) in an inpatient eating disorder service: a qualitative study. Eat Weight Disord 23(4):499–505. https://doi.org/10.1007/s40519-017-0369-x
63. Cambridge Cognition (2017) CANTAB® [Cognitive assessment software]. All rights reserved. http://www.cantab.com. Accessed 14 Aug 2018
64. Cormack FK, Taptiklis N, Abbott RA, Anatürk M, Cartland I, Coppieters L et al (2016) Changes to validity of online cognitive assessment in young and older adults: a comparison to supervised testing using the Cantab battery. Alzheimer's Dementia J Alzheimer's Assoc 12(7):286–287
65. Quijada Z, Paoli M, Zerpa Y, Camacho N, Cichetti R, Villarroel V et al (2008) The triglyceride/HDL-cholesterol ratio as a marker of cardiovascular risk in obese children; association with traditional and emergent risk factors. Pediatric Diabetes 9(5):464–471. https://doi.org/10.1111/j.1399-5448.2008.00406.x
66. Mertens IL, Van Gaal LF (2000) Overweight, obesity, and blood pressure: the effects of modest weight reduction. Obes Res 8(3):270–278. https://doi.org/10.1038/oby.2000.32
67. McGowan N, Padfield PL (2010) Self blood pressure monitoring: a worthy substitute for ambulatory blood pressure[quest]. J Hum Hypertens 24(12):801–806
68. Seo HS (2012) The role and clinical significance of high-sensitivity C-reactive protein in cardiovascular disease. Korean Circ J 42(3):151–153. https://doi.org/10.4070/kcj.2012.42.3.151
69. Muntner P, Shimbo D, Carey R, Charleston J, Gaillard T, Misra S, Myers M, Ogedegbe G, Schwartz J, Townsend R, Urbina E, Viera A, White W, Wright J (2019) Measurement of blood pressure in humans: a scientific statement from the American heart association. Hypertension 73(5):e35–e66
70. Berg KC, Peterson CB, Frazier P, Crow SJ (2012) Psychometric evaluation of the eating disorder examination and eating disorder examination-questionnaire: a systematic review of the literature. Int J Eat Disord 45(3):428–438. https://doi.org/10.1002/eat.20931
71. McCuen-Wurst C, Ruggieri M, Allison KC (2018) Disordered eating and obesity: associations between binge-eating disorder, night-eating syndrome, and weight-related comorbidities. Ann N Y Acad Sci 1411(1):96–105. https://doi.org/10.1111/nyas.13467
72. Texeira P, Going S, Houtkooper L, Cussler E, Metcalfe L, Blew R, Sardinha L, Lohman T (2004) Pretreatment predictors of attrition and successful weight management in women. Int J Obes Relat Metab Disord 28:1124–1133
73. Foster GD, Makris AP, Bailer BA (2005) Behavioral treatment of obesity. Am J Clin Nutr 82(1):230–235. https://doi.org/10.1093/ajcn/82.1.230S
74. Lane JD, Gast DL (2014) Visual analysis in single case experimental design studies: brief review and guidelines. Neuropsychol Rehabil 24:445–463. https://doi.org/10.1080/09602011.2013.815636
75. Franz MJ, VanWormer JJ, Crain AL, Boucher JL, Histon T, Caplan W, Pronk N (2007) Weight-loss outcomes: A systematic review and meta-analysis of weight-loss clinical trials with a minimum 1-year follow-up. Journal of the American Dietetic Association 107(10):1755–1767
76. Institute of Medicine (1995) Weighing the options: criteria for evaluating weight management programs. Government Printing Office, Washington, DC
77. Miyake A, Friedman NP, Emerson MJ, Witzki AH, Howerter A, Wager TD (2000) The unity and diversity of executive functions and their contributions to complex ''Frontal lobe'' tasks: a latent variable analysis. Cogn Psychol 41:49–100. https://doi.org/10.1006/cogp.1999.0734
78. Smith E, Hay P, Campbell L, Trollor JN (2011) A review of the association between obesity and cognitive function across the lifespan: implications for novel approaches to prevention and treatment. Obes Rev 12(9):740–755. https://doi.org/10.1111/j.1467-789X.2011.00920.x
79. Campbell J, Herzinger CV (2010) Statistics and single subject research methods. In: Gast DL (ed) Single subject research methodology in behavioral sciences. Routledge, New York, pp 417–453
80. Morgan A, Lilienfeld S (2000) A meta-analytic review of the relationship between antisocial behaviour and neuropsychological measures of executive function. Clin Psychol Rev 20(1):113–136. https://doi.org/10.1016/S0272-7358(98)00096-8

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