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Perseveration Augments the Effects of Cognitive Restraint on *ad libitum* Food Intake in Adults Seeking Weight Loss

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Abstract

OBJECTIVE—Differences in executive function have been associated with eating behaviors. Our aim was to determine whether measures of executive function predicted *ad libitum* food intake in subjects seeking weight loss.

METHODS—This cross-sectional study involved 78 obese, otherwise healthy, individuals (40 female /38 male; age 36±10y; BMI 37.8±7.2 kg/m^2) enrolled in weight loss studies, but prior to any intervention. Participants completed the Iowa Gambling Task to evaluate decision making, the Stroop Word Color Task to assess attention, the Wisconsin Card Sorting Task (WCST) to measure perseverative errors, and the Three Factor Eating Questionnaire (TFEQ) to measure disinhibition and cognitive restraint. *Ad libitum* energy intake over 3-days was then collected using a validated vending paradigm.

RESULTS—Only results from the WCST and the TFEQ correlated with mean daily energy intake. When expressed as a percentage of an individual's calculated weight maintaining energy needs (%WMEN; [mean daily energy consumed/WMEN]*100), intake correlated positively with number of perseverative errors ($r = 0.24$, $p = 0.03$) and negatively with cognitive restraint ($r^2 = -0.51$, $p<0.0001$). In a regression model of %WMEN ($r^2 = 0.59$, $p<0.0001$) including age, sex, race, disinhibition, restraint, and perseverative error T-score, an interaction between perseveration and restraint was observed ($p = 0.05$). Greater numbers of perseverative errors intensified the effect of restraint such that subjects with both high restraint and high perseveration, per manual-defined cut-offs, ate the least (median (IQR) = 70 (62, 94) % WMEN), while those with low restraint and high perseveration ate the most (130 (102, 153) %WMEN).

Subjects with low perseveration and high versus low restraint ate a median of 84 (70, 86) and 112 (98, 133) %WMEN, respectively.

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CONCLUSION—In obese subjects seeking weight loss, the effects of perseveration on food intake are conditional on the level of dietary restraint, and may contribute to increased intake exhibited by some subjects when self-control is undermined.

Keywords

Energy Intake; Obesity; Neuropsychological Tests; Executive Function; Appetite Regulation

INTRODUCTION

Obesity is a complex condition demonstrated by the poor success of dietary interventions and medications to produce long lasting weight loss in most individuals (1). The underlying psychological and behavioral mechanisms controlling food intake, particularly among subjects seeking weight loss, are still poorly understood. Executive function, the higher level cognitive processes that modulate human behavior including flexibility, trouble shooting, processing speed, planning and execution, has been implicated in the decision making process leading to food intake, in part, because obese populations have lower scores than lean populations on tests of memory, decision making, and cognitive flexibility (2, 3). However, it is not clear which aspects of executive function might affect *ad libitum* food intake.

Tests of executive function which have been reported to differ in obese populations, and therefore might regulate voluntary food intake, include the Iowa Gambling Task (IGT) (4,5), which is used to evaluate the ability to resist potential immediate rewards for smaller longer-term rewards, the Stroop Word Color Test (SWCT) (6,7), which assesses selective attention and processing speed, and the Wisconsin Card Sorting Task (WCST) (4,7,8), which measures cognitive flexibility. Increases in perseverative error, an outcome measure of the WCST that indicates difficulty in adapting new behaviors to a changing situation (set shifting), has been associated with eating disordered behavior (4,9–11), including binge eating (9). Although obesity has been associated with poorer performance on all three tests (4,6–8), the cause and effect relationship between obesity and these tests is unclear. Weight loss has been associated with improvements in IGT performance (3), whereas weight gain has been associated with worsening performance on the SWCT (6) implying that excess adiposity may lead to changes in executive function. It is not known whether executive function constructs predict subsequent *ad libitum* food intake, a causal factor in the regulation of body weight.

Behavioral attitudes toward food intake are known contributors to successful weight maintenance. Validated across gender, age, and BMI, the Three Factor Eating Questionnaire (TFEQ) is an effective indicator of dietary behaviors (12). The three factors (restraint, disinhibition, and hunger) of the TFEQ have all been positively correlated with BMI (12). Cognitive restraint has been validated as an indicator of dietary restraint. It has been hypothesized that high levels of restraint can develop in response to excess adiposity leading to the restriction of food consumption (13). A longitudinal weight loss study demonstrated that those with high restraint are most successful at maintaining weight loss if they also have low disinhibition (14). However, if restraint is disrupted by stress, exposure to palatable foods, or the perception of failure to maintain dietary restrictions, disinhibition and subsequent overeating may occur (15–19). Individuals who maintain weight loss not only score higher on measures of dietary restraint but also demonstrate increased neural activity in regions responsible for executive function (20). It is unknown if cognitive restraint and executive function interact to impact behavioral choices. Given observed differences in obese populations, it is possible that decision making abilities, selective attention and cognitive flexibility may impact amount of kilocalories consumed in healthy individuals interested in weight loss. We hypothesized that scores of executive function measures would be associated with objective measures of *ad libitum* food intake in an obese study population seeking weight loss and that any effects of executive function might interact with the effects of restraint.

METHODS

Subjects

Obese subjects, who participated in studies (Clinical Trial Identifier: NCT00856609, NCT00739362, NCT00342732) on our clinical research unit with complete data for TFEQ and tests of executive function including IGT, SWCT, and WCST data as well as *ad libitum* food intake, were selected for this analysis (n=78). All subjects were healthy as determined by history, physical examination, and basic laboratory measures, were on no medications, were weight stable for 3 months prior to admission (by self report), and had no evidence of active psychiatric illness, including eating disorders. Obesity was defined ≥25% body fat in men or ≥35% in women, according to World Health Organization guidelines (21). The majority of subjects (90%, n=70) were enrolled in weight loss studies with the remainder participating in an observational study of contributors to eating behavior; however, the first 8 days of all included studies were identical. Only baseline measures, prior to any weight loss intervention, are included in this analysis. The subjects resided on the clinical research unit during the study period. Prior to the *ad libitum* food intake assessment, subjects were given a weight maintaining diet, which contained a macronutrient composition of 20% protein, 50% carbohydrate, and 30% fat and was calculated for each individual as previously described (22). Subjects were instructed to consume the entirety of every weight maintaining meal. Body weight was measured each morning using a calibrated scale, and for the first 4 days, the provided kilocalories were adjusted as needed to stabilize body weight. The number of kilocalories at which an individual's body weight was stable represents the weight maintaining energy needs (WMEN). Percent fat mass and fat free mass of each subject was determined by Dual-Energy X-Ray Absorptiometry (DPX-L; Lunar Radiation, Madison, WI). All 78 subjects were non-diabetic as determined by a 75g oral glucose tolerance test (23) conducted after three days on the weight maintaining diet. All subjects provided written informed consent prior to beginning any study. All studies were approved by the Institutional Review Board of the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK).

Neuropsychological Measures

All performance tests and the TFEQ were administered within 48 hours of admission and prior to the *ad libitum* food intake assessment. The tests of executive function were administered within 30 minutes after completing breakfast in a dedicated, monitored testing room. Computerized versions of the WCST(24), IGT(25) and SWCT were used.

Wisconsin Card Sorting Task

The WCST provides an assessment of prefrontal cortical function, particularly dorsolateral prefrontal function, which controls executive processes such as feedback utilization, complex working memory, set-shifting, directed attention, and prioritizing information (26). Commonly used as a neuropsychological measure of cognitive flexibility (set-shifting), it requires the inhibition of a previously reinforced action to appropriately respond to a shift in paradigm. Subjects are instructed to match cards according to three possible dimensions (color, form, or number), receiving only a correct or incorrect signal after each trial as feedback. After the subject has achieved 10 consecutive correct matches, the matching principle is changed without warning. The test ends once 6 categories (10 correct card matches per category) have been achieved or 128 trials have been attempted. One of the main outcome variables is perseveration, which denotes an inability to modify the response to a stimulus despite the reinforcement of a different response (27). Perseverative errors are made when the subject continues to adhere to a previously-rewarded matching paradigm in the face of negative feedback or returns to a previous matching paradigm even though a new matching paradigm has been identified. Increasing levels of perseveration are denoted by higher raw perseverative error scores. However, each raw perseverative error score was normalized with respect to age and education, and assigned a T-score to allow comparison among subjects of differing ages and education. Lower T-scores indicate greater perseverative error.

Iowa Gambling Test

The IGT is used to measure decision making (28) in an environment of uncertainty, reward, and penalties. Subjects made 100 sequential choices from four decks of cards, which resulted in either a net gain or loss of money. Two decks were disadvantageous, giving large immediate rewards followed by larger long-term penalties that resulted in overall net loss, while the remaining two decks were advantageous, giving small immediate rewards and positive long-term consequences with small penalties that resulted in overall net gain. Instructed to win as much money as possible, subjects had to resist the immediate payoff of disadvantageous decks to achieve the long-term rewards of the advantageous decks. The net IGT score is determined by the number of cards chosen from disadvantageous decks subtracted from the number of cards chosen from advantageous decks. A positive score indicates overall advantageous choices, and a negative score indicates overall disadvantageous choices (25).

Stroop Word Color Test

The SWCT is used to assess selective attention (29). Subjects completed three different timed trials. Two are control tasks that assess attention and processing speed in which subjects must either read words or identify colors. In the third task, the name of a color word is printed in an incongruent color of ink. The subject must name the color of ink for as many color words as he can within a set time limit. The difficulty each subject has in ignoring the meaning of the word in order to identify the ink color is reflected by the interference score.

This score is calculated by dividing the difference between the number of items completed in Trial 2 and Trial 3 by the number completed in Trial 2 and then multiplying by 100 [((Trial 2-Trial3)/Trial 2)*100]. The interference score reflects each individual's selective attention with higher scores indicating poorer performance.

Three Factor Eating Questionnaire

The TFEQ classifies eating behavior on the basis of three factors: cognitive restraint, disinhibition, and perceived hunger (30). It consists of 51 questions that assess food behaviors—36 true/false and 15 that use the 4-point Likert scale. Cognitive dietary restraint reflects the intent to restrict energy intake to control body weight. Disinhibition is the loss of control that oftentimes results in overconsumption of food in response to various stimuli.

Automated Food Selection System

After 5 days on the weight maintaining diet, three days of *ad libitum* food intake was assessed. Subjects self-selected their food using an automated vending machine as previously described (31). This method of measuring food intake is more accurate than self-reporting and highly reproducible with an intraclass correlation coefficient of 0.9 (32). Each subject had access to an assigned, refrigerated vending machine 23.5 hours per day, and was instructed to eat as desired. For each day of the vend, the same 40 foods were stocked for consumption and were chosen according to each subject's rating of 80 food items on a Food Preferences Questionnaire (33). Food items receiving an intermediate hedonic rating (between 4 and 8 on a scale of 1 to 9) were chosen and provided along with a selection of condiments, milk, juice, and soda. All uneaten food items and wrappers were returned to the vending machine to be weighed by the metabolic kitchen for precise assessment of consumed food. The Food Processor Professional Diet Analyzer Program (ESHA version 10.0.0, ESHA Research, Salem, OR) was used to calculate caloric and macronutrient intake (32). Because there were no significant differences in food intake between the 3 days by one-way ANOVA, all outcome variables were expressed as the average per day. Daily energy intake (DEI) was expressed as total kilocalories eaten per day as well as percent of weight maintaining energy needs consumed per day (%WMEN). The %WMEN was calculated as DEI divided by WMEN and expressed as a percent. Food items consumed by each subject were classified according to macronutrient content (34), and choices from three subcategories were recorded and expressed as a percentage of DEI: food high in simple sugar (>30%kcal of food item), food with high fat (>45%kcal), and food classified as healthier choices (low fat < 20% plus either high protein >13% or high in complex carbohydrate >30%).

Statistical Analysis

All statistical analyses were performed using SAS software, version 9.2 (SAS Institute, Cary, NC). Alpha was set at 0.05 for most analyses, however, a $p<0.1$ was considered significant for interaction terms. Normally distributed data is presented as mean ± standard deviation, while non-Gaussian data is presented as median (interquartile range (IQR)). Pearson correlation coefficients were determined for normally distributed variables, and Spearman correlation coefficients were used for skewed data including for the correlations between neurocognitive variables and measures of energy intake (DEI, %WMEN, %kilocalories consumed from foods high in simple sugar, %kilocalories consumed from foods high in fat, and %kilocalories consumed from the healthy choices). Categorical differences were evaluated using the Wilcoxon Rank Sum Test for non-parametric data and a Student's t-test for normally distributed data. Differences between ethnic groups were assessed using 1-way ANOVA. If the simple correlations demonstrated a potential relationship with measures of food intake, then multivariate linear regression models were used to further explore potential contributors to energy intake. These models included age, sex, race, restraint, and disinhibition as covariates. Interactions between neuropsychological variables that related to energy intake were also assessed in a full model. To better understand significant interactions and effects of the neurocognitive measures, restraint and perseveration were categorized into low and high categories based on the scoring manuals. Individuals were categorized as having high restraint if they had a score of 11 or higher on the cognitive restraint portion of the TFEQ (30). The WCST manual (24) defines a perseverative error T-score ≤39 as impaired and a score ≤44 as below average for the general US population. Individuals receiving a score ≤39 were categorized as perseverating and individuals with a score >39 were categorized as non-perseverating. The results were similar even if the perseverating group was defined as <44 instead of <39. One-way ANOVA was used to confirm differences between categories representing the interactions of low and high restraint with low and high perseveration, respectively.

RESULTS

Demographics

Subject characteristics are shown in Table 1. Men ate more than women both in total DEI (Δ= 1478 kcal) and as %WMEN (Δ=36.3%; $p<0.0001$) (Table 1). Although men consumed more total calories as simple sugar, high fat, and healthy choices than women, this difference was solely due to the overall greater food intake of men such that the percentage of each subcategory eaten was similar between men and women. On average, subjects consumed 109% of their weight maintaining needs, although this was not unexpected as the tendency to overeat during *ad libitum* food intake has been previously observed (32).

Relationships between Energy Intake and Neurocognitive Measures

Restraint, disinhibition and perseverative error were associated with the measures of energy intake (Table 2, Figure 1). The restrained group ate less than the unrestrained group (median (IQR): 76.1% (64.4, 86.2%) v 116.0% (99.3, 139.8%); $p<0.0001$). When the association between disinhibition and energy intake was adjusted for restraint, the relationship was no longer present ($\rho = -0.1$, $p=0.4$). Lower perseverative error T-scores, which indicate increasing amount of perseverative error, were associated with an increase in both total energy ($\rho = -0.26$; $p = 0.02$) and %WMEN consumed ($\rho = -0.22$; $p = 0.04$). The perseverating group consumed, on average, 409±847 kcal more than the non-perseverating group ($p = 0.046$). Neither daily kilocalories consumed nor %WMEN correlated with decision making as measured by the IGT ($r = -0.13$; $p = 0.27$ and $r = -0.14$; $p = 0.22$, respectively), or attention as measured by the SWCT ($r = 0.05$; $p = 0.65$ and $r = 0.06$; $p = 0.62$, respectively). When these correlations were assessed separately by sex, the strength of

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the correlation was similar for both genders as for the whole group. There were no correlations between the tests of executive function indicating that these tests are likely assessing different components of executive function.

(A) Energy consumed as a percentage of weight maintaining needs (%WMEN) is negatively correlated with cognitive restraint score. (B) Energy consumed as a percentage of weight maintaining needs (%WMEN) is negatively correlated with perseverative error T-score. A higher T-score indicates less perseveration.

Perseveration Modifies the Effects of Restraint on Energy Intake

The observed correlations were further explored using multivariate models for the various measures of energy intake including the covariates age, sex, race, restraint, disinhibition, and the perseverative error T-score. A significant interaction between restraint and perseverative error was noted in the models for both %WMEN ($p = 0.05$) and total energy intake ($p = 0.04$) (Table 3). The model explained 59% of the variance in %WMEN ($F=11.01$, $p<0.0001$) and 68% of the variance in absolute total energy intake ($F=16.07$, $p<0.0001$). An interaction between disinhibition and the perseverative error T-score was not observed in the full model. The results were similar in men and women in sensitivity analyses with models done separately by sex. The results were also similar when the eight subjects not enrolled in a weight loss study were excluded.

To better understand the effect of the interaction between restraint and perseverative error, we calculated the median (IQR) %WMEN consumed by the categorical groups of individuals with high and low restraint combined with either high or low perseveration. The effects of restraint on energy consumption were magnified in the perseverating group such that the restrained and perseverating group ate the least (1879 (1815, 2420) kcal; 70.3 (62.4, 94.0) %WMEN) while the unrestrained and perseverating group ate the most (3910 (2891, 4452) kcal; $p=0.001$) (130.3 (101.6, 152.7) %WMEN; $p=0.002$) (Figure 2, Table 4). The results were similar if the predicted values from the final model were used (78.3% v 127.2%WMEN, respectively) (Figure 2).

The models of energy consumed as simple sugar, high fat and healthy choices were not significant when the macronutrient categories were expressed as percentages of total calories consumed, indicating that any differences were driven by differences in total energy consumption.

Black Circles, Solid trend line: Perseverating Group. Open Diamonds, Dashed trend line: Non-Perseverating Group. The horizontal line represents the cut-off for high versus low restraint. (A) Energy consumed as a percentage of weight maintaining needs (%WMEN) with respect to restraint in perseverating and non-perseverating groups (raw values). (B) Predicted energy consumed as %WMEN with respect to restraint in perseverating and non-perseverating groups. The parameter estimates and p-values for the model used to create these predicted values are shown in Table 3.

DISCUSSION

We examined the relationships between measures of executive function and objectively measured food intake in an obese population, most of whom were seeking weight loss. As expected, individuals with greater restraint had less *ad libitum* food intake. We also noted a positive correlation between perseveration and food intake. However, we found an interaction between perseverative error and cognitive dietary restraint in determining *ad libitum* food intake, such that, perseverative error magnified the effect of restraint on caloric intake. Subjects with greater perseverative error and higher restraint restricted food intake the most, to as little as 60% of WMEN, while those with high perseveration but lack of restraint had the highest levels of food intake, up to 167% of WMEN.

Decreased prefrontal cortical activity may lead to impulsive, inappropriate, or overly rigid eating behaviors (4). Restraint, as measured by the TFEQ, has been correlated to signaling in the dorsolateral prefrontal cortex (DLPFC) and the striatum. In particular, subjects with higher restraint scores showed a stronger hemodynamic response in the DLPFC when asked to consciously suppress the desire for palatable foods than those with lower scores (35). These same brain regions have been implicated in executive function (35), particularly cognitive flexibility and set-shifting as tested by the WCST (26). Both cognitive restraint to reduce desire for highly palatable foods and the WCST resulted in bilateral activation of the DLPFC; the brain regions most strongly activated by desire suppression were the left DLPFC, dorsal striatum, and prefrontal-striatal circuitry, while the regions most strongly activated by the WCST were the right DLPFC and the dorsal striatum. The authors theorized that although cognitive control may be able to override the pleasurable aspects of food stimuli, this method of compensation may be insufficient in obese individuals (35). Some rigidly restrained individuals exhibit alternating periods of restriction followed by bingeing if loss of control occurs (36, 37). This restriction/binge cycle may result from competing cognitive and homeostatic functions that become unregulated in obese individuals. We would hypothesize that because the brain regions responsible for cognitive flexibility overlap with those of restraint, perseveration may indicate altered DLPFC function, which could lead to amplification of cognitive restraint during both restrained and unrestrained periods creating more dramatic restriction/binge cycles.

While high restraint has been associated with successful maintenance of weight loss, it is also associated with dietary relapse. If it is disrupted and disinhibited, unrestrained behavior results (14, 36). Higher levels of restraint may develop in response to weight gain caused by previously excessive food intake (13). In our obese study population, high restraint may reflect the intent and ability to diet, consistent with findings in other restrained and unrestrained groups (13). While the restrained group in our study reduced their energy intake below their weight maintaining needs, those who also displayed cognitive inflexibility with high perseverative error demonstrated the greatest ability to reduce average energy intake over the 3 days, possibly indicating a more absolute (all-or-nothing) approach to dieting. Studies investigating the successful maintenance of restrained eating in weight loss have described two subcategories of restraint, rigid versus flexible (36). Rigid restraint describes an all-or-nothing method of dieting while flexible restraint reflects a more relaxed lifestyle approach including reductions of portions and unhealthful foods (38). Rigid restraint may reflect a similar concept to those restrained individuals who perseverate and are able to more severely restrict food intake, while non-perseverating, restrained individuals may parallel flexible restraint. Flexible restraint, which is considered more adaptable, is associated with better long-term weight control and a decrease in the cognitive burden of food related information versus rigid restraint (38). The bingeing behavior induced by prolonged dietary restriction may be magnified by cognitive inflexibility as demonstrated by periods of disinhibited eating when rigid, but not flexible, restraint is disrupted (36) in subjects without known bingeing disorders (38, 39).

Some components of executive dysfunction, such as high perseverative error, may exacerbate energy intake in those highly motivated by food. High perseverative error scores on the WCST have been associated with both extremes of the eating disorder spectrum, including anorexia nervosa (4), binge eating disorder (9), and bulimia nervosa (10). The association of perseveration with both extremes of energy intake indicates a likely role for cognitive flexibility in formulating and executing dietary strategy in those with eating disorders. We now demonstrate that similar roles for flexibility in modifying restrained versus unrestrained eating may be present in people with non-pathological eating behaviors.

To successfully lose weight, individuals must restrict intake to a level below their weight maintaining needs. While restricted individuals appear ready to observe the rules of this paradigm to achieve their weight loss goals and perseveration seems to help maintain this goal in the short term, perseverating individuals may be less able to factor in new stimuli such as hunger, fatigue, or exposure to palatable foods that must be successfully navigated to maintain the restraint needed in the weight loss paradigm. While both perseverating and non-perseverating groups may experience the same cycles of restriction and overconsumption, our results indicate that perseveration may play a role in determining the severity of each stage. In our study, unrestrained subjects consumed more than their weight maintaining needs. Cognitive inflexibility, indicated by high perseverative error, appeared to further increase overconsumption in the unrestrained group by 649 kcal. Although our unrestrained subjects reported an interest in obtaining a healthy weight, they ate more than their weight maintaining needs during *ad libitum* food intake.

Limitations of our study include a relatively small sample size, and specifically, that our unrestrained group was larger than our restrained group. However, the statistical strength of our results as well as the robustness of our sensitivity analyses supports the validity of our findings. In addition, we used a cross-sectional design, although neurocognitive measures were administered prior to the assessment of energy intake. To confirm the interaction of restraint and perseveration in dietary intake for subjects seeking weight loss, this study should be replicated in a larger study population with longitudinal follow-up to determine the effects of perseveration on successful weight loss. It would also be of interest to know if executive function improves with weight loss as previous studies have noted a decrease in perseverative error with remission of maladaptive eating behaviors (4,11). It has been previously shown that the majority of subjects in non-weight loss studies overeat during the *ad libitum* vending paradigm (32). However, the degree of overconsumption is reproducible (intraclass correlation coefficient = 0.9) lending confidence to our findings. Also, we did not have measures of rigid and flexible subscales of restraint, although it would be a beneficial addition to future studies to further understand the role of perseveration in modifying restraint. In addition, we did not directly assess other components of executive function such as working memory. The greatest strengths of this study were the unique ethnic diversity of the study population and the objective measure of *ad libitum* food intake over a three-day period.

CONCLUSIONS

Our results support our hypothesis that some components of executive function are associated with objective measures of food intake and modify the impact of dietary restraint. In particular, the observed interaction between cognitive restraint and perseverative error may help explain the lack of success of extreme dietary restriction in long-term weight loss. If cognitive dietary restraint is undermined and disrupted, a return to or magnification of unrestrained behavior may occur in individuals with high levels of perseveration. Non-perseverating individuals may exhibit a more flexible attitude toward dietary restraint and exhibit less extreme behavior during periods of restrained versus unrestrained eating. Cognitive flexibility may play an important role in long-term weight maintenance. Cognitive behavioral therapy to increase cognitive flexibility may be of use in the ability to maintain long-term restriction of food intake. Further understanding of the effects of the interaction between perseverative error and restraint on food intake will allow the development of better, more tailored obesity treatments.

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Abbreviations

ANOVA	analysis of variance
BMI	Body Mass Index
DEI	Daily energy intake
IGT	Iowa Gambling Task
IQR	interquartile range
SWCT	Stroop Word Color Test
TFEQ	Three Factor Eating Questionnaire
WCST	Wisconsin Card Sorting Task
WMEN	weight maintaining energy needs

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Highlights

- Effects of executive functioning on *ad libitum* food intake in adults were assessed.
- These were adults seeking weight loss with varying amounts of cognitive restraint.
- An interaction between perseveration and restraint was observed on 24h food intake.
- Those subjects with high perseveration and high restraint ate the least.
- However, unrestrained subjects with high perseveration ate the most.

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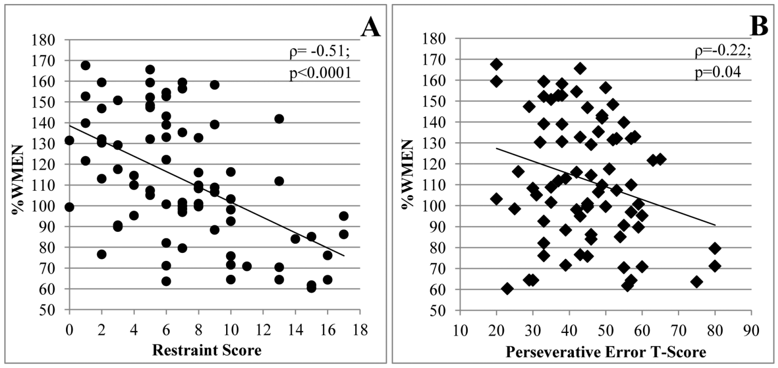

Figure 1.
Relationship of Main Neuropsychological Measures to Energy Intake

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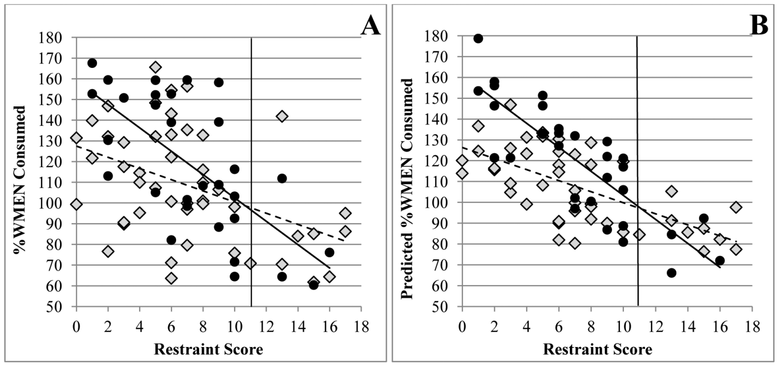

Figure 2.

Predicted and Actual Energy Intake with Respect to Perseveration Group

Table 1

Subject Characteristics

Variable[1]	**All (n=78)**	**Men (n=38)**	**Women (n=40)**
Race[2]	12 AA, 9 H, 26 C, 31 NA	5 AA, 6 H, 10 C, 17 NA	7AA, 3 H, 16 C, 14 NA
Age (yrs)	36.2±10.1 (19.0,55.0)	38.1±9.7 (20.0,55.0)	34.4±10.3 (19.0,52.0)
% Body Fat[3]	43.0±7.6 (26.8,59.9)	36.8±5.1 (26.8,47.9)	49.0±3.6 (41.9,59.9)
Total Energy Intake (kcal)[3]	3222 (2397, 3997)	3954 (3421, 4447)	2476 (2102, 3009)
%WMEN[3]	109.3 (89.8, 139.0)	132.4 (114.5, 152.7)	96.1 (76.0, 107.5)
%Simple Sugar	32.4 (25.7, 37.9)	32.3 (25.9, 36.9)	32.4 (25.0, 38.2)
%Healthy Choice	21.6 (17.4, 28.8)	19.4 (16.9, 28.7)	23.4 (18.0, 30.5)
%High Fat	40.6 (32.3, 46.6)	41.9 (33.3, 47.0)	39.4 (30.8, 44.4)
Restraint Score[3]	6.5 (4.0,10.0)	6.0 (4.0,8.0)	7.5 (4.5,10.5)
Disinhibition Score	5.5 (3.0,9.0)	4.5 (3.0,8.0)	6.0 (3.0,9.5)
Perseverative Error T-Score[3],[4]	45.0 (35.0,53.0)	40.0 (33.0,49.0)	47.0 (39.0,55.5)
IGT Raw Score	−2.0 (−10.0,12.0)	−4.0 (−12.0,8.0)	3.0 (−9.0,17.0)
Stroop Interference Score	25.3 (18.6,31.3)	25.7 (18.7,32.8)	25.1 (18.3,31.0)

[1]Mean ± Standard Deviation (Minimum, Maximum) or 164 Median (25% IQR, 75% IQR)

[2]165 AA=African American; H=Hispanic; C=Caucasian; NA=Native American

[3]166 Gender differences with $p<0.05$

[4]167 Perseverative error t-scores are normalized for age and education.

Table 2

Unadjusted Correlations of Energy Intake to Neuropsychological Measures

Measure of Energy Intake	Spearman Correlation Coefficient (p)		
	WCST	TFEQ	
	Perseverative Error[1]	Disinhibition	Restraint
Daily Energy Intake (kcal/d)	−0.26[3]	−0.19	−0.50[3]
%WMEN	−0.22[3]	−0.25[3]	−0.51[3]
%Simple Sugar[2]	−0.13	−0.23[3]	−0.17
%Healthy Choice[2]	0.08	0.30[3]	0.27[3]
%High Fat[2]	−0.07	0.05	−0.06

[1]T-scores were normalized for age and education with higher scores indicating fewer perseverative errors

[2]Percent of total kilocalories consumed

[3]p value <0.05

Table 3

Multivariate Models for the Determinants of Daily Energy Intake

	%WMEN	Total Energy Intake (kcal)
Explained variance (global p value)	r^2=0.59; p<0.0001	r^2=0.68; p<0.0001
Constant	176.2 (136, 216); p<0.0001	5040 (3898, 6181); p<0.0001
Age (years)	−0.1 (−0.6, 0.5); p=0.8	−2 (−17, 13); p=0.8
Sex (male = 1, female = 2)	26.1 (15.8, 36.5); p<0.0001	1043 (750, 1336); p<0.0001
Ethnicity	p=0.5	p=0.7
Restraint	−7.4 (−12.0, −2.9); p=0.002	−223 (−352, −94); p=0.0009
Disinhibition	−1.2 (−2.6, 0.3); p=0.1	−18 (−59, 23); p=0.4
Perseverative error T-score	−1.1 (−1.8, −0.3); p=0.006	−34 (−56, −13); p=0.002
Restraint*Perseverative error T-score Interaction	0.1 (0, 0.2); p=0.05	3 (0, 6); p=0.04

β-Coefficients are reported with 95% CIs in parentheses, and p-values.

Table 4

Energy Intake By Interaction Category

Neuropsychological Profile[1]	%WMEN[2,3]	Total Energy Intake (kcal)[2]
Restrained		
Perseverating	70.3 (62.4,94.0)	1879 (1815, 2420)
Not Perseverating	84.0 (70.4,86.2)	2213 (1830, 2352)
Unrestrained		
Perseverating	130.3 (101.6,152.7)	3910 (2891, 4452)
Not Perseverating	112.3 (98.1,132.8)	3261 (2782, 3893)

[1]Neuropsychological profile of study participants divided into four groups to describe the observed interaction: 1) Restrained and Perseverating, 2) Restrained and Not Perseverating, 3) Unrestrained and Perseverating, 4) Unrestrained and Not Perseverating

[2]Values reported as Median (IQR)

[3]%WMEN = percent weight maintaining energy needs