Cognitive Interference From Food Cues in Weight Loss Maintainers, Normal Weight, and Obese Individuals

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Much attention has been paid to the behavioral characteristics of successful weight loss maintenance, but less is known about the cognitive processes that underlie this process. The purpose of this study was to investigate cognitive interference from food-related cues in long-term weight loss maintainers (WLM; *N* = 15) as compared with normal weight (NW; *N* = 19) and obese (OB; *N* = 14) controls. A Food Stroop paradigm was used to determine whether successful WLM differed from controls in both the speed and accuracy of color naming words for low-calorie and high-calorie foods. A significant group × condition interaction for reaction time was observed (*P* = 0.04). In *post hoc* analyses, no significant differences in reaction time across the three groups were observed for the low-calorie foods (*P* = 0.66). However, for the high-calorie foods, WLM showed a significantly slower reaction time than the NW (0.04) and OB (0.009) groups (885 ± 17.6, 834 ± 15.8, 816 ± 18.3 ms, respectively). No significant group differences were seen for number of correct trials in 45 s (*P* = 0.12). The differential interference among WLM did not appear to generalize to other types of distracters (i.e., nonfood). Overall, findings from this study suggest that WLM differ from OB and NW controls in their cognitive responses to high-calorie food cues. Future research is needed to better understand why this bias exists and whether and how interventions can change cognitive processes to better facilitate long-term weight control.

INTRODUCTION

Long-term weight loss maintenance involves ongoing behavioral vigilance, including continued consumption of a low-calorie, low-fat diet, high-physical activity, frequent self-monitoring, and infrequent loss of control over eating. Recent findings suggest that long-term weight loss maintainers (WLM) engage in these weight control behaviors to a greater extreme than their always-normal weight (NW) counterparts, performing more physical activity and adhering to more dietary restriction strategies (1,2).

Less attention has been paid to the cognitive processes that underlie weight loss maintenance. WLM consistently report high levels of cognitive restraint, suggesting cognitive efforts to resist eating in response to tempting food cues and maintain ongoing conscious control over food intake (3,4). These data, however, are largely based on self-reports, which are notoriously prone to contamination of demand characteristics.

The Stroop Color–Word Interference Test (5) has long been adopted from cognitive psychology to collect observable data on cognitive processes. In the traditional Stroop Color–Word Interference condition, participants are presented with a series of color words (i.e., "red," "blue," "green") printed in red, green, or blue text colors. They are asked to actively inhibit the more salient response of reading the word and to simply report the color in which each word is printed (6). A relatively longer reaction time for a target word is referred to as "interference." This task has been adapted to include other interference stimuli, including food words (Food Stroop or Stroop Food Interference Test) (7,8). Researchers using the Food Stroop have repeatedly demonstrated that eating disordered women are slower to name the color of body weight, shape, and food-related words than women without eating disorders or as compared with naming the colors of neutral words (9,10). Delayed color naming (i.e., "Stroop interference") for food-related words has also been observed in noneating disordered populations, including individuals with high dietary restraint (7,8,11,12) and obesity (13,14). Little is known, however, about the cognitive processes of individuals who are successfully maintaining weight losses.

The primary aim of this study was to investigate cognitive interference from food-related cues in long-term WLM as compared with normal-weight individuals (without a history of obesity) and obese (OB) control participants. A Food Stroop paradigm was used to determine whether successful WLM differed from NW and OB controls in both the speed and accuracy of color naming words for low-calorie and high-calorie foods. We hypothesized that WLM would have the slowest reaction time to color naming of high-calorie foods, perhaps due to heightened efforts to monitor and restrict these types of foods or an emotional response to the foods. We also compared these groups on the traditional Stroop Color–Word Interference test to determine whether any group differences were specific to food or reflected a more general pattern of susceptibility to cognitive interference.

METHODS AND PROCEDURES

Participants

A convenience sample was recruited by placing advertisements in local newspapers and through letters to local participants in the National Weight Control Registry (15). To be eligible for the study, WLM had to be overweight or OB (BMI ≥30) at some point in their life, currently NW (BMI 18.5–25), and must have lost ≥30 pounds of maximum body weight. In addition, to identify individuals who were clearly succeeding at weight loss maintenance, they were required to have kept off a loss of ≥30 pounds for at least 3 years and be weight stable (±10 lb) within the past 2 years.

Participants in the always NW group had to be NW (BMI between 18.5 and 25) with no history of overweight or obesity (BMI ≥25). The criteria for participants in the always NW group also required that they be weight stable (±10 lb) for at least 2 years before enrollment. Participants in the OB group had to have an adult history of obesity, be currently OB (BMI ≥ 30), and weight stable (±15 lb) for at least 2 years before enrollment.

For all three groups, additional exclusion criteria included binge eating, food allergies, and vegetarianism. As participants in this study were also recruited for a study involving functional magnetic resonance imaging (16), additional exclusion criteria included standard magnetic resonance imaging contraindications (e.g., metal implants, claustrophobia, pregnancy), left-handedness, and neurological or psychiatric conditions, and weight loss and/or psychiatric medications. We also required that participants not have lost >5 pounds over the past month. Participants were paid $100 for completing the study assessments. The study was approved by the institutional review board at the Miriam Hospital (Providence, Rhode Island).

Stroop procedures

All participants arrived on the test day in a fasting state (4 h fast minimum) and were provided instruction and practice with the Stroop tasks before data collection. Both Stroop tasks were presented during an functional magnetic resonance imaging protocol using E-Prime software (Psychology Software Tools, Pittsburgh, PA). Words were shown one by one against a black background.

The Stroop Color–Word Interference Test and the Food Stroop were each administered three times, in alternating order. The Food Stroop was comprised of three 45-s subtests. During the first subtest, participants viewed the neutral, nonfood words; during the second subtest, participants viewed words of common low-calorie foods; and, during the third subtest, participants viewed words of common high-calorie foods. The food words were selected by investigators to identify common low-calorie and high-calorie foods and were matched on syllables and length to neutral words and to each other (see **Supplementary Table S1** online). For all subtests, the food and nonfood words were printed in three different text colors (either red, blue, or green), and participants were instructed to identify the color of the text and respond by pressing a designated response box button for each color.

The Stroop Color–Word Interference Test administration was based on the traditional Golden (17) paradigm. Briefly, during the first 45-s subtest, participants were asked to match the color word written in black text with the correct response button. During the second 45-s subtest, participants were asked to identify the text color of a series of X's. The final 45-s subtest required participants to identify the text color of non-matching color words (i.e., "red" printed in blue text).

For both the Food Stroop and the Stroop Color–Word Interference tests, reaction times, errors (e.g., wrong color or no response), and correct responses were recorded for each trial. The primary behavioral outcomes were averaged median reaction time during correct trials across the three administrations and the averaged number of correct trials in 45 s across the three administrations.

Eating inventory. The Eating Inventory (18) was also administered, which is a self-report instrument used to assess levels of dietary restraint and disinhibition. Items on the restraint subscale reflect behaviors used to control dietary intake (e.g., "consciously control my intake" and "count calories"). The dietary disinhibition subscale measures a person's reported loss of control while eating. Both scales have been found to have good test–retest reliability and internal consistency (18,19).

Statistics

Descriptive statistics are presented in the tables as either means ± s.d. for continuous measures or percentages for categorical responses. ANOVAs with *post hoc* contrasts and χ^2-tests were used to examine group differences in baseline demographic variables. Analyses of the reaction time during the Food Stroop were conducted using repeated measures ANOVA with type of food condition (low-calorie, high-calorie) as a within-subjects factor, group (WLM, NW, OB) as a between-subject factor, and nonfood interference as a covariate. Age and gender were also entered as covariates in all analyses given their potential influence on weight-related and cognitive processing variables. Median reaction times for words of each category were averaged over trials. Similar analyses were conducted for number of correct responses during the three Food Stroop conditions. As a validation measure, an interference ratio (20) for high-calorie food word reaction time was calculated for the Food Stroop by dividing the mean reaction times of the neutral and low calorie conditions by the high calorie condition. For the Stroop Color–Word Interference Test, reaction time and number correct in 45 s were analyzed using ANOVAs with group as the between-subjects factor, and response to the color and color matching conditions, age and gender entered as covariates. Similar to the Food Stroop, an interference ratio was calculated as a validation measure by dividing the number of correct color matching scores by the number of correct color word scores (20). To examine the association between food interference effects and self-report measures, regression analyses were conducted with the self-report measure as an independent variable, response to the food interference condition as a dependent measure, and age, gender and response to the neutral word interference entered as covariates.

RESULTS

Subject characteristics are displayed in **Table 1**. In total, 19 NW, 14 OB, and 15 WLM completed the study. Significant group differences in current BMI were observed ($F(2,46) = 107.4$; $P < 0.001$). By definition, both NW and WLM differed significantly from OB ($P < 0.001$) in BMI; also, a trend ($P = 0.07$) was observed for a greater current BMI among WLM, relative to NW. Significant differences were also observed in lifetime maximum BMI ($F(2,46) = 86.6$; $P < 0.001$). Both the OB and WLM reported lifetime maximum BMI in the OB range, differing significantly from the NW who reported a

Table 1 Demographic and weight characteristics

	Weight loss maintainer	Normal weight	Obese	
	N = 15	*N* = 19	*N* = 14	*P* value
Age, M (s.d.)	48.5 (11.4)	43.6 (8.2)	48.3 (7.6)	0.20
% Female	88.2 (*n* = 13)	89.5 (*n* = 17)	88.2 (*n* =12)	0.991
% White	92.5	100	82.4	0.361
% Employed	94.1	94.4	100	0.603
% College educated	70.5	68.4	52.9	0.228
Current BMI, M (s.d.)	23.7 (1.6)[a]	21.6 (2.0)[a]	34.3 (6.7)[b]	0.0001
Lifetime maximum BMI, mean (s.d.)	33.1 (3.0)[a]	22.7 (2.2)[b]	35.8 (3.7)[c]	0.0001
Restraint	15.1 (4.8)[a]	10.1 (5.2)[b]	7.6 (4.9)[b]	0.001
Disinhibition	4.9 (3.3)[a]	4.0 (2.8)[a]	8.3 (3.9)[b]	0.002

Across rows, superscripts that differ indicate significant differences $P < 0.05$.

Table 2 Reaction time (ms) and number of valid reactions on a 45-s modified Stroop task for low-calorie food words, high-calorie food words, and neutral words among individuals in the weight loss maintainer, normal weight, and obese groups

	Weight loss maintainer	Normal weight	Obese
	N = 15	*N* = 19	*N* = 14
*Low-calorie food words**			
Reaction time M (s.d.)	853 (15.7)	833 (14.1)	843 (16.3)
Number of valid M (s.d.)	46.2 (1.8)	49.8 (1.6)	47.3 (1.9)
*High-calorie food words**			
Reaction time M (s.d.)	885 (17.6)[a]	834 (15.8)[b]	816 (18.3)[b]
Number of valid M (s.d.)	45.3 (2.0)	49.5 (1.8)	49.0 (2.1)
Neutral words			
Reaction time M (s.d.)	783 (80)	743 (108)	807 (174)
Number of valid M (s.d.)	51.7 (4.8)	55.5 (8.9)	52.4 (9.8)

Across rows, different superscripts represent significant differences in *post hoc* tests adjusted for age, gender, and neutral word response. *Post hoc* significant *P* values for high-calorie food reaction times were: $P = 0.04$ for the comparison of WLM vs. NW, and $P = 0.009$ for the comparison of WLM vs. OB.
NW, normal weight; OB, obese; WLM, weight loss maintainers.
*Marginal means adjusted for neutral word response, gender, and age.

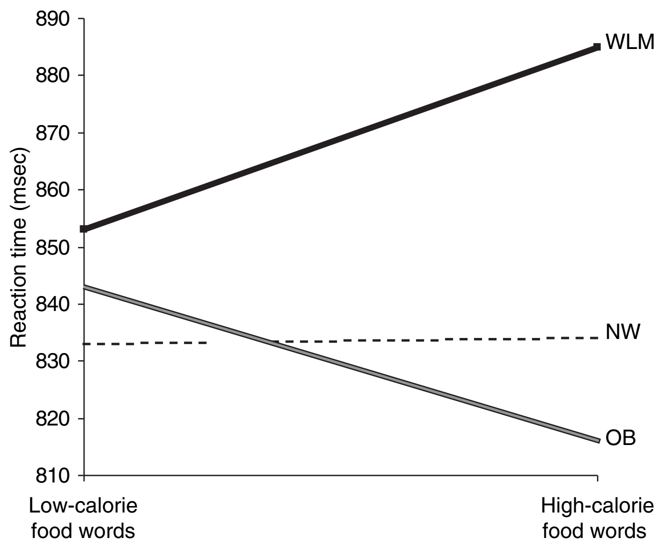

Figure 1 Reaction time among weight loss maintainer (*n* = 15), normal weight (*n* = 19), and obese (*n* =14) groups during the Food Stroop. NW, normal weight; OB, obese; WLM, weight loss maintainers.

lifetime maximum BMI in the normal range ($P < 0.001$). The OB participants, on average, reported a lifetime maximum BMI that was significantly greater than that reported by the WLM group ($P = 0.03$). No statistically significant group differences were observed for age, gender, or race.

Reaction times for each Food Stroop word category among WLM, NW, and OB participants are presented in Table 2 and displayed in Figure 1. A significant group × condition interaction for reaction time was observed ($F(2,42) = 3.6$; $P = 0.04$; partial $\eta^2 = 0.15$). In *post hoc* analyses, no significant differences in reaction time across the three groups were observed for the low-calorie foods ($P = 0.66$). However, for the high-calorie foods, WLM showed a significantly slower reaction time than NW ($P = 0.04$) and OB ($P = 0.009$) (Table 2). Results were similar when using interference ratio scores; there was a significant effect of group ($F(2,42) = 4.34$; $P = 0.019$), and WLM exhibited more reaction time interference than OB ($P = 0.006$) and NW ($P = 0.050$). These results suggest that high-calorie words interfered more with processing among WLM relative to NW and, particularly, OB participants. No significant effect was seen for number of correct trials in 45 s (group × condition $P = 0.12$).

Next, we determined whether these behavioral differences were specific to food distracters or also applied to other types of interference using the Stroop Color–Word interference task. No significant group differences in reaction times were observed during correct trials ($P = 0.20$) or number of correct trials in 45 s ($P = 0.13$). Results were similar when using interference ratio scores for reaction times ($P = 0.17$) or number of correct trials ($P = 0.19$), suggesting that the differential interference seen among WLM was specific to food distracters and did not generalize to other types of distracters.

Associations with individual difference variables

We examined the association of interference for food words with questionnaire data on restraint and disinhibition, with response to the neutral word interference entered as a covariate. Neither restraint nor disinhibition was significantly associated with food interference before or after controlling for group status ($P > 0.19$).

DISCUSSION

This study is the first to compare cognitive processing biases of food words among WLM and NW and OB controls. On a computerized version of the Food Stroop, WLM were slower in naming the color of high-calorie foods than either the NW or OB individuals. Prior research has highlighted the behavioral characteristics that distinguish WLM (15). These data add to the literature by suggesting that WLM also differ from NW and OB individuals in their cognitive responses to food stimuli.

Slower color-naming of specific word categories is considered a clear indicator of information-processing bias; however, the precise source of color-naming interference remains unclear, and several interpretations have been proposed (21–23). The delayed reaction may reflect emotional distraction stemming from stimuli that are strongly desired (24), craved (7), and perceived as "threatening," and/or anxiety-provoking (25–28). Thus, the emotional salience of the high-calorie food words may have served to attract attention and/or impair WLM's ability to shift attention away from the cue, thereby disrupting their task performance (29). The delayed reaction could also reflect avoidance of cognitive dissonance stemming from emotional and cognitive conflict between ongoing desires for high-calorie foods vs. conscious control efforts (30) or avoidance of stimuli that could potentially encourage dissonant behavior (31).

It has also been suggested that information-processing bias may be characteristic of any motivational state and does not necessarily reflect negative emotion per se (32). For example, Klinger (33) argued that individuals striving for a goal become sensitized to information and cues relevant to that goal. This sensitization may take the form of emotional reactivity to goal-relevant cues. In the case of successful WLM, it is possible that information-processing bias may reflect a sensitization and reactivity to goal-relevant cues.

Slower reaction times to food cues may also reflect increased attention to high-calorie foods related to hunger resulting from food restriction (34) or dietary restraint (7,12,35). However, in the present study, differences in short-term hunger were controlled by having participants in all three groups fast for at least 4 h. Although the average duration of fasting was not assessed, specifying a minimal fasting duration across groups makes hunger a less likely explanation for these findings.

WLM in the present study had the highest restraint and the slowest response latency to high-calorie food words. From a cognitive load standpoint, maintenance of dietary restraint could place additional demands on cognitive processing resources, and thereby slow reaction times of the WLMs (36). However, surprisingly, restraint was not significantly related to food interference scores. By contrast, studies of eating disordered and NW participants have generally found positive associations between restraint and latencies for recognizing food words (7,12,35). Similarly, in one of the few studies to compare OB and NW individuals, OB restrained dieters had longer latencies than NW controls in naming food words (13), but no differences in these groups were observed in the present study. The mixed findings may be due to differences in Stroop methodologies used (e.g., card. vs. computer), outcomes under investigation (general foods vs. low- and high-calorie foods in the present study), the specific populations under investigation (e.g., dieting OB vs. nondieting OB in the present study), and/or power and sample size issues. We intend to correlate our behavioral findings with neural responses using functional magnetic resonance imaging, which may help to clarify the underlying neural sources of delayed responses.

This study is the first to evaluate processing biases for high- and low-calorie food words among WLM and NW and OB control groups. The study's experimental design was developed to control for several potential confounds, including level of hunger at the time of testing, and used a variety of food and nonfood stimuli to minimize the impact of any one food. This study also controlled for individual differences in psychomotor speed (by controlling for response to nonfood pictures) and examined whether effects were specific to food or a more general "distractability" trait. These elements likely strengthen the validity of the study's findings, but the study also has a few weaknesses. The Stroop task presented the food words in blocks (e.g., low-calorie words, high-calorie words, neutral words), which has been found to result in a larger attentional bias than presenting the words of each category intermixed (6). Also, the study's small sample size and sample composition, which included some members of the National Weight Control Registry, may limit its generalizability. In addition, the Stroop paradigm did not enable examination of the different mechanisms involved in attentional bias for threat (e.g., facilitation/hypervigilance vs. cost/disengagement (29)).

Overall, findings from this study suggest that WLM differ from OB and NW controls in their cognitive responses to high-calorie food cues. The slower latency in naming the color of high-calorie foods among WLM may reflect a cognitive processing bias that assists in successfully monitoring and inhibiting food intake and maintaining a healthy weight. The lack of significant group differences in naming the color of low-calorie food words suggest that cognitive responses to low-calorie foods may not be a defining feature of successful weight control. Future research using additional measures of attentional processing (e.g., the dot probe) is needed to disentangle why WLM experience delayed processing of high-calorie food words. Additional research is also needed to examine whether and how interventions can change underlying cognitive processes to better facilitate long-term weight control, perhaps by conditioning avoidance behaviors such as an "automatic delay" when tempted by high-calorie foods.

SUPPLEMENTARY MATERIAL

Supplementary material is linked to the online version of the paper at http://www.nature.com/oby

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DISCLOSURE

The authors declared no conflict of interest.

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