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Validation of a Laboratory Craving Assessment and Evaluation of 4 Different Interventions on Cravings Among Adults with Overweight or Obesity

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Abstract

Food cue reactivity (FCR) is an appetitive trait associated with overeating and weight gain. We developed a laboratory craving assessment to objectively evaluate cognitive aspects of FCR. This study examined the preliminary construct and criterion validity of this craving assessment and evaluated 4 different interventions, 2 of which incorporated cue-exposure treatment for food, on craving over treatment and follow-up. 271 treatment-seeking adults with overweight/obesity (body mass index=34.6[5.2]; age=46.5[11.8]; 81.2% female; 61.6% non-Latinx White) completed the Food Cue Responsivity Scale and the laboratory craving assessment, during which they alternated holding and smelling a highly craved food and provided craving ratings over 5 minutes. Participants were subsequently randomized to 26 treatment sessions over 12-months of ROC, Behavioral Weight Loss (BWL), a combined arm (ROC+) and an active comparator (AC), and repeated the craving assessment at post-treatment and 12-month follow-up. Linear

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All authors declare that they have no conflicts of interest.

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mixed-effects models assessed associations between trial type (holding vs. smelling), trial number, pre-treatment FCR, treatment arm, assessment time point, and craving. Cravings were greater when smelling vs. holding food (b=0.31, p<0.001), and cravings decreased over time (b=−0.02, p<0.001). Participants with higher pre-treatment FCR reported elevated cravings (b=0.29, p<0.001). Longitudinally, we observed a significant 3-way interaction in which treatment arm modified the relationship between pre-treatment FCR and craving over time (F(17,5122)=6.88, p<0.001). An attenuated FCR-craving relationship was observed in ROC+ and BWL from baseline to post-treatment but was only sustained in BWL at follow-up. This attenuation was also observed in ROC and AC from post-treatment to follow-up. The preliminary validity of this laboratory craving assessment was supported; however, greater craving reductions over time in ROC/ROC+ compared to BWL and AC were not consistently observed, and thus do not appear to fully account for the moderating effect of FCR on weight losses observed in the trial.

Keywords

food cue reactivity; overeating; craving; cue-exposure treatment

1. Introduction

Food cue reactivity (FCR) is an appetitive trait which refers to physiological, cognitive, and emotional responses to food cues that signal the availability of food, prepare the body for digestion, and increase the drive to eat.[1,2] FCR is highly heritable[3] and interacts with the obesogenic environment, contributing to overeating and weight gain.[4] Evidence suggests FCR is related to overweight and obesity (OW/OB) via overeating in response to environmental food cues.[5,6] Early changes in FCR have been found to be predictive of treatment response in weight management interventions[7] and enhanced neurobehavioral control over FCR has been observed among individuals able to maintain weight loss over time.[8] As weight loss maintenance has been a pervasive challenge in behavioral interventions for OW/OB, FCR could be a salient treatment target to increase durability of results.[9]

While FCR has demonstrated genetic underpinnings,[3] FCR is also the result of Pavlovian and operant conditioning,[2] in which individuals who overeat develop strong associations between food cues and eating, even when they are not physically hungry. Jansen and colleagues developed and tested the earliest interventions targeting FCR predicated on this theoretical mechanism, aiming to extinguish responses to food cues through cue-exposure treatment for food.[10,11] During cue-exposure treatment for food, individuals who are sated are exposed to food cues and learn to resist eating. Cue-exposure treatment for food has been tested and adapted for a variety of populations and demonstrated success in reducing body weight,[12,13] binge eating,[12,14,15] and eating in the absence of hunger[16,17] among individuals with OW/OB.

In addition to FCR, satiety responsiveness (SR), or sensitivity to internal cues to stop eating, is another important appetitive trait associated with weight[18] and a potential treatment target for overeating and OW/OB. Our group developed the Regulation of Cues (ROC)

program to target both FCR and SR concurrently by combining cue-exposure treatment for food to target decreasing FCR with appetite awareness training to target improving SR.[19] In ROC, experiential learning exercises are used to teach these concepts *in vivo*. In cue-exposure treatment for food, individuals who are sated complete guided exposures during treatment sessions in which they are exposed to a highly craved food unique to them, and hold, smell, and take 2 small bites of the food over a 5-minute exposure before throwing it away.[19] In addition to in-session exposures, participants are also encouraged to complete out-of-session exposures, in which they expose themselves to food cues in the environment and practice resisting their urges to eat (e.g., going to the movies without eating popcorn). These exposures are designed to decrease reactivity and responding to food cues and improve inhibitory control over urges to overeat.

The Providing Adults Collaborative Interventions for Ideal Changes (PACIFIC) study was a 4-arm randomized control trial designed to evaluate the efficacy of ROC, Behavioral Weight Loss (BWL), ROC combined with BWL (ROC+), and an active comparator (AC) on body weight reduction among adults with OW/OB over 24 months.[19] BWL, which consists of dietary, physical activity, and behavioral change recommendations, is the current gold-standard treatment for OW/OB.[20-22] The ROC+ program was designed to capitalize on the strengths of both ROC and BWL, and integrated experiential learning exercises from ROC with the skills for reducing energy intake and increasing energy expenditure from BWL. The AC was a series of structured health education informational sessions, focusing on mindfulness, social support and nutrition education, that was matched for time and duration of the other treatment arms. Results from the PACIFIC study suggested that while BWL and ROC+ demonstrated greater initial BMI reductions, these were not statistically different from those observed in ROC at post-treatment. Additionally, participants who received ROC did not experience the increase in BMI observed among those in BWL and ROC+ over the follow-up period, demonstrating improved weight maintenance in ROC after treatment.[13] Importantly, FCR was a moderator of treatment results, such that those who scored higher in FCR at baseline (measured via Food Cue Responsivity Scale; FCRS[23]) and received food exposure treatment (ROC or ROC+) demonstrated greater weights losses compared to those who received BWL or AC.[13]

Due to the limitations of self-report questionnaires and the momentary nature of thoughts and physiological urges that food exposure may evoke, we developed an experiential laboratory-based assessment to evaluate FCR *in vivo* as a treatment target in the PACIFIC study. As FCR is comprised of cognitive, physiological, and emotional components,[1] we operationalized the cognitive component of FCR as craving, which is defined as an intense desire to consume specific foods,[24] and can be quickly understood and reported by individuals during exposure to palatable foods. Thus, we administered this laboratory craving assessment at 3 timepoints over the course of the study during which individuals were exposed to a highly craved food of their choosing and provided craving ratings while alternating holding and smelling the food. As research suggests cravings are enhanced in response to olfactory cues,[25-27] we designed the assessment with this pattern to alternate between visual and olfactory food cues to enhance responding. The objective of the present study was to 1) examine the validity of this novel laboratory assessment of craving among a sample of treatment-seeking adults with OW/OB, by examining construct validity via

craving generation and habituation during the assessment, and criterion validity in relation to FCR measured via questionnaire (FCRS[23]), and 2) evaluate whether pre-treatment FCR contributed to differential changes in craving responsiveness during the assessment over time between treatment arms. We hypothesized that 1a) exposure to craved foods would generate cravings that would increase and then decrease over time, 1b) smelling the craved food would increase cravings more than holding the food, and 1c) individuals with high FCR would demonstrate increased acute craving levels during the assessment. We also hypothesized that 2) individuals with high pre-treatment FCR who received cue-exposure treatment for food (ROC or ROC+) would demonstrate lower overall cravings during the assessment at post-treatment and follow-up assessments compared to individuals who received BWL or AC.

2. Methods

2.1 Study Design

The PACIFIC trial (Clinical Trial NCT02516839) was a randomized controlled treatment trial for adults with OW/OB. Recruitment methods, measures, treatment arms, and main outcomes are detailed in full in previous publications.[13,19] Variables for the current study were collected during a food exposure paradigm at baseline (month 0), post-treatment (month 12), and 12-month follow-up (month 24) assessment visits. Questionnaires included in analyses were collected during baseline assessment visits (month 0). All assessments were completed in-person at the University of California San Diego (UC San Diego) Center for Healthy Eating and Activity Research. The study was approved by the Institutional Review Board at UC San Diego (151110) and written consent was obtained from all participants.

2.2 Participants

Participants were recruited from the San Diego, California area with the following inclusion criteria: age 18-65 years, body mass index (BMI) ≥ 25 and ≤ 45 kg/m2, English language skills of at least the 5th grade reading level, and willingness to participate in assessment and treatment visits over 2 years. Exclusion criteria included the following: history of diagnosis of a serious current physical disease (e.g., diabetes), any medical condition that would make unmonitored physical activity unsafe, current substance use disorder, current or upcoming pregnancy or lactation, and any medical or psychological problems that could make adherence to the study protocol difficult or dangerous (e.g., purging, suicidality).

2.3 Laboratory Craving Assessment

Participants selected a highly craved food from the following options: Lay's® classic potato chips, Fritos®, Cheez-Its®, a chocolate chip cookie, Hershey's Kisses®, M&M's®, gummy bears, or Entenmann's Little Bites® mini blueberry muffins. During the assessment, participants were exposed to their selected highly craved food for 5 minutes and were instructed not to eat it. Participants were provided with a definition of craving and a rating scale. and provided craving ratings on paper every 30 seconds while they alternated holding (6 trials) and smelling (6 trials) the food for the duration of each 30 second trial, as instructed by a trained research assistant. Cravings were rated on a scale of 1 (no craving at all) to 5 (strongest craving). A total of 12 craving ratings were made over the assessment.

The same food that the participant selected at baseline was used during the paradigm at each subsequent assessment (i.e., post-treatment and 12-month follow-up).

2.4 Intervention

Randomized participants attended up to 26 90-minute group treatment sessions over 12 months. Brief descriptions of the treatment groups are included below and further details regarding the intervention arms have been published.[19] Of the 26 treatment sessions, the average attendance was 16.59 (SD = 6.89) sessions.

Regulation of Cues (ROC).—The ROC program targeted reducing FCR through cue-exposure treatment for food and increasing SR through appetite awareness training using experiential learning exercises. Participants were taught about hunger and satiety dysregulation and were instructed to self-monitor their hunger before, during, and after each meal. Participants brought and ate dinner with the group to monitor their hunger levels in-session. Later in the treatment after building on this skill, participants learned to self-monitor cravings and urges to eat. Participants completed in-session exposures to craved foods in the group setting. During in-session group exposures, participants held, smelled, and tasted the food while rating their cravings over 5 minutes, and then threw the food away. Participants brought in craved foods unique to them for exposures and also completed exposures with rotating “surprise” foods from the list of foods offered during the laboratory craving assessment. Participants were also encouraged to complete out-of-session exposures, in which they exposed themselves to food cues in the environment and practiced resisting their urges to eat (e.g., going to the movies without eating popcorn). Participants were instructed to monitor their hunger and cravings on paper or using an app.

Behavioral Weight Loss (BWL).—The BWL program consisted of nutrition and physical activity education and behavior change skills. Participants were taught about a balanced deficit diet based on the US Department of Agriculture’s MyPlate guidelines.[28] Initial strategies for managing cravings were primarily avoidance-based, and included stimulus control (e.g., not bringing craved foods into the house, or placing them on a high shelf) and distraction techniques (e.g., focusing on conversation rather than food at a party). Later in treatment, participants were taught planning ahead strategies for “high-risk” situations (e.g., parties, meals out), and instructed to plan ahead to fit in potentially craved foods into their daily calorie goal (e.g., eat a lower calorie dinner if planned to get ice cream later). Participants were instructed to self-monitor their food intake, caloric intake, and physical activity on paper or using an app. Individualized calorie goals were given to promote a weight loss of 1 to 2 pounds per week.

Combined Program (ROC+).—The ROC+ program integrated all principles from the ROC program with the focus on diet and energy intake from BWL. Participants learned all of the ROC components, including psychoeducation and experiential learning exercises to manage cravings and SR. Participants were also taught behavioral skills for decreasing energy intake from BWL. Participants in this group were taught to self-monitor hunger, cravings, food intake, caloric intake, and physical activity on paper or using an app.

Active Comparator (AC).—The AC program was a series of structured health education informational sessions, focusing on mindfulness, social support and nutrition education, that was matched for time and duration of the other treatment arms. This group was designed to provide health information typically received in community care, with additional focus placed on relaxation and mindfulness. At each session, a mindfulness exercise was conducted, and participants were encouraged to practice mindfulness at home. Participants were not instructed to self-monitor.

2.5 Measures

2.5.1 Demographics and Anthropometrics—

Participants self-reported their age, gender, and race/ethnicity as part of baseline assessments. Height was measured in triplicate to the nearest 0.1 cm using a portable Schorr stadiometer (Schorr Inc., Olney, MD). Weight was measured in duplicate to the nearest 0.1 kg using a calibrated digital Tanita scale (model WB 110-A). The values obtained at the baseline assessment visit were averaged to calculate BMI (weight in kilograms divided by height in meters squared).

2.5.2 Food Cue Responsivity Scale (FCRS)—

The FCRS[23] is a 6-item validated questionnaire for assessing FCR. The FCRS employs a rigorous psychometric approach, incorporating items for various existing overeating-related questionnaires (i.e., Power of Food [PFS],[29] Food Craving Questionnaire-Trait [FCQ-T],[30] and Reward-Based Eating Drive Scale [RED][31]). These items were selected and validated against physiological measures, specifically heart rate variability changes during exposure to highly craved foods. The FCRS reflects cognitive and uncontrolled eating domains of FCR. Participants rated items using rating schemes from the original measures' scale from ("never/not applicable", "don't agree at all", "strongly disagree") to ("strongly agree") with scores on the PFS and FCQ-T ranging from 1-6 and scores on the RED ranging from 1-5. Scores were subsequently compiled and averaged to create mean FCRS scores, which ranged from 1 to 5.67, and higher scores indicated greater FCR. The FCRS demonstrated strong internal consistency ($\alpha = 0.86$, $H = 0.57$).

2.6 Statistical Analyses

First, baseline data were examined to establish the construct (Hypotheses 1a and 1b) and criterion validity (Hypothesis 1c) of the craving assessment. Linear mixed-effects (LME) models assessed associations between trial type (i.e., holding vs. smelling the food), trial number (1-12, evaluated as a continuous variable), pre-treatment FCRS, and craving rating, adjusting for planned covariates of gender, age, race, ethnicity, and BMI. Trial number and trial type were evaluated as potential moderators of the relationship between pre-treatment FCRS and craving.

Subsequently, longitudinal evaluation included terms for assessment time point (baseline, post-treatment, or 12-month follow-up) and treatment arm (ROC, ROC+, BWL, or AC) that were added to the above LME models as categorical variables to evaluate the impact of treatment arm on cravings over treatment and follow-up. Treatment arm and assessment time point were evaluated as potential moderators of the relationship between pre-treatment FCRS and craving. A 3-way FCRS by treatment arm by assessment time point interaction

effect was also evaluated (Hypothesis 2). Model-predicted cravings from this model were computed at the 33rd and 67th percentiles of FCRS for the study sample. Simple slopes were calculated for each group at each assessment timepoint to provide estimates of the relation between FCRS and craving over time.

All study variables were analyzed using R version 4.3.0[32] using the "lmerTest,"[33] "lme4,"[34] "psych,"[35] "interactions,"[36] and "mokken"[37] packages. The "ggeffects"[38] package was used to plot predicted cravings based upon LME models and to calculate marginal means for craving. Internal consistency was assessed using Cronbach's alpha (α) and coefficient H from Mokken scale analysis (H),[39] with $0.3 \leq H < 0.4$ indicative of a weak scale, $0.4 \leq H < 0.5$ indicative of a moderate scale, and $H \geq 0.5$ indicative of a strong scale.[40] Multiple imputation was used for missing data with the "mice" package.[41] Multiple imputation with 40 replicate combinations were formed using all predictors (age, gender, race, ethnicity, pre-treatment FCRS, pre-treatment BMI) in the evaluative model predicting craving and pooled estimates were obtained using Rubin's rule. Complete data from the craving assessment at baseline, post-treatment and 12-month follow-up assessment time points was 99.6%, 74.9%, and 73.4%, respectively.

3. Results

3.1 Participant Characteristics

271 participants were randomized to ROC ($n = 69$), BWL ($n = 69$), ROC+ ($n = 67$), and AC ($n = 66$) and were included in the present analyses. 81.2% of the sample identified as female, the average age of participants was 46.5 years (SD = 11.8), average BMI was 34.6 kg/m^2 (SD = 5.2), and 61.6% were non-Latinx-White. See Table 1 for detailed demographic information by treatment arm.

3.2 Validation of Craving Assessment

Figure 1a displays model-predicted craving over the 12 trials of the assessment at baseline and Figure 1b displays model-predicted craving over the assessment by tertile of pre-treatment FCRS. Trial number, type of trial (hold vs. smell), and pre-treatment FCRS were significantly associated with cravings (ps < 0.001). Cravings decreased over the course of the assessment such that for each additional trial (30 seconds elapsed), cravings decreased by 0.02 points (95%CI: −0.03, −0.01; Hypothesis 1a). Cravings were higher by 0.31 points (95%CI: 0.27, 0.35) when participants smelled the food as compared to when they held the food (Hypothesis 1b). Cravings were higher with increasing level of pre-treatment FCRS ($b = 0.29$; Hypothesis 1c). Predicted cravings for participants at the 33rd percentile of FCRS (mean score of 2.33) were 2.18 (95%CI: 1.94, 2.42), and for those at the 67th percentile of FCRS (mean score of 3.17) were 2.42 (95%CI: 2.17, 2.67). The only significant covariate was BMI (b=−0.02, 95%CI: −0.04,−0.002). Neither trial number nor trial type was found to significantly moderate the relationship between baseline FCRS and craving (ps > 0.05).

3.3 Longitudinal Evaluation of the Craving Assessment by Treatment Arm

Upon examining data longitudinally, trial number, type of trial, and pre-treatment FCRS maintained significant main effects on craving across the baseline, post-treatment and 12-

month follow-up assessments ($p < 0.001$). At post treatment, cravings were 0.33 points (95%CI: −0.37, −0.29) lower and at the 12-month follow-up, cravings were 0.43 points (95%CI: −0.47, −0.39) lower than during baseline assessment. The main effect of treatment arm on craving was not significant for any arm compared to AC (ps > 0.50). However, treatment arm was found to significantly moderate the relationship between pre-treatment FCRS and craving over assessments (3-way interaction: treatment arm x FCRS x time; $F[17,5122] = 6.88$, $p < 0.001$), indicating a change in the strength of relationships between pre-treatment FCRS and craving over time depending on treatment arm. Predicted craving with 95% confidence intervals by assessment time point, treatment arm, and at the 33rd and 67th percentiles of pre-treatment FCRS are presented in Table 2.

Relationships between pre-treatment FCRS and craving by assessment time point and treatment arm are presented in Figure 2 (Hypothesis 2) and simple slopes are presented in Table 3. The strength of the FCRS-craving relationships after treatment and at follow-up differed both within and across treatment arms. Within treatment arms, ROC+ and BWL demonstrated a weakening of the pre-treatment FCRS-craving relationship from baseline to post-treatment. At 12-month follow-up, this relationship was further weakened in BWL, but not in the ROC+ arm. The FCRS-craving relationship was maintained in the ROC arm from baseline to post-treatment but was weakened at the 12-month follow-up. A strengthening of the FCRS-craving relationship was observed in the AC arm at post-treatment but not at 12-month follow-up. A comparison of the pre-treatment FCRS-craving relationship by treatment arm at post-treatment is displayed in Figure 3. The ROC+ arm seems to have produced the strongest initial effects on the FCRS-craving relationship over the treatment period, as high pre-treatment FCRS was less predictive of elevated cravings during the craving assessment at post-treatment for those who received ROC+. Across treatment arms and at both lower and higher levels of FCRS (Table 2), our model predicted reduced cravings during subsequent administrations of the craving assessment.

4. Discussion

This study sought to evaluate the construct and criterion validity of a laboratory craving assessment among treatment-seeking adults with OW/OB by evaluating changes in cravings during the assessment and the relationship between cravings generated during the assessment and FCR measured via questionnaire. This study also evaluated the presence of differential relationships between FCR and craving after treatment and a 12-month follow-up period in the 4 arms of a randomized controlled treatment trial for adults with OW/OB, 2 of which received cue-exposure treatment for food. Examining data collected pre-treatment, our laboratory craving assessment was successful in generating cravings as well as habituation (cravings increased and then decreased over time). We observed increased cravings when participants smelled the food, and a significant relationship between cravings and pre-treatment levels of FCR, such that individuals with higher FCR experienced elevated cravings throughout the assessment. These findings supported our hypotheses and are consistent with literature that cravings increase in response to olfactory cues[25-27] and that individuals with higher FCR experience greater cravings.[42] This evidence supports the preliminary construct and criterion validity of this craving assessment, which

aimed to measure cognitive components of FCR, among treatment-seeking adults with OW/OB.

When we evaluated data longitudinally, cravings decreased after the treatment and follow-up periods independent of treatment effects. Treatment arm modified the relationship between FCR and craving over time, which included reductions in the FCR-craving relationship from baseline to post-treatment in ROC+ and BWL. The FCR-craving relationship was most significantly attenuated in the ROC+ arm from baseline to post-treatment, indicating pre-treatment FCR was no longer as predictive of elevated cravings for individuals who received ROC+; however, effects were not maintained at the follow-up assessment in this arm, and while initial reductions were more modest, greater maintenance was observed in BWL. The hypothesized differential reduction in the strength of the pre-treatment FCR-craving relationship at post-treatment for those in the ROC arm compared to BWL and AC was not observed, although this relationship did weaken in ROC at the 12-month follow-up.

This study's longitudinal hypothesis was generated from the moderating effect of the FCRS scale observed in the PACIFIC study.[13] However, as we did not consistently observe a weakened FCR-craving relationship following treatment in ROC/ROC+ compared to BWL and AC, it is possible the FCRS scale may become less predictive of craving responsiveness after weight management treatment, indicated by the general weakening of the FCR-craving relationship we observed across all treatment arms over time. This may be in part due to treatment effects, as all treatment arms delivered content that may have impacted craving management (ROC and ROC+ provided cue-exposure treatment for food; BWL provided strategies including stimulus control, distraction, and planning ahead; AC provided social support, relaxation, and mindfulness skills that may have increased tolerance of cravings). Based upon theory from anxiety disorder research that avoidance maintains anxiety,[43] we hypothesized that primarily avoidance based-strategies for managing cravings in BWL would not be effective for dealing with cravings long term, especially among individuals with high FCR, as food cues are omni-present in today's environment. However, our results did not support this hypothesis. While we are unaware of evidence that BWL decreases FCR, one study reported reduced cravings after a BWL intervention,[44] and research suggests BWL may be associated with increased liking of lower calorie foods,[45] possibly by way of changed taste preferences. It is possible that changed taste preferences in BWL may have contributed to the reduction in strength of the pre-treatment FCR-craving relationship over time that we observed.

As our longitudinal hypothesis was not supported, the relationship between pre-treatment FCRS and craving does not appear to fully account for the moderation effect of FCR on weight losses observed in the PACIFIC study.[13] This may have been impacted by limitations of the timing of the assessment, as cravings measured at a single point in time are not necessarily reflective of the individual's response to food cues in their natural environment. The post-treatment assessment window lasted approximately 3 months after the end of treatment; thus, it is possible that some effects of treatment may have been less detectable among those who completed the craving assessment towards the end of the follow-up window. Further, the FCRS captures the multi-faceted nature of FCR, including both cognitive processes relating to food cues and uncontrolled eating. It is possible that the

facet of uncontrolled eating, which was not captured by our craving assessment, may have been more significantly impacted by cue-exposure treatment for food than the cognitive (i.e., craving) component, which we aimed to assess with our laboratory assessment. Ultimately, the goal of cue-exposure treatment within ROC/ROC+ is not to extinguish cravings, but rather to change learned interpretations and responses to cravings. It is possible individuals with high FCR who received ROC and ROC+ did not experience reduced cravings over treatment, but rather learned to respond to cravings differently, which we did not capture with our craving assessment.

It is also important to consider that the general reductions we observed in both cravings over time and the strength of the pre-treatment FCR-craving relationship over time could be reflective of habituation to the craving assessment and craved food itself over the 2-year study. The effect may reflect a natural decrease in novelty of the craving assessment with repetition and therefore responsiveness to the craved food across all treatment arms and levels of FCR. Further, the same highly craved food that was initially selected was used in the assessment at all study time points for consistency; however, as taste preferences may have changed or been impacted by treatment, it is possible the palatable food initially selected was no longer as highly craved. Additionally, it is possible that social desirability bias after completing treatment may have been high and contributed to lower reported cravings at post-treatment and follow-up, or other third variables that we did not measure in this analysis, including weight change during treatment, could have influenced our results.

The present study has several strengths. The study sample was large and incorporated racial/ethnic diversity. Participants completed an experiential behavioral task which was validated against a self-report questionnaire that was based upon psychophysiological responses to food cues. Repeated measures of the paradigm were also completed over treatment and follow-up. Additionally, participants were given a choice at baseline between multiple highly craved foods ensuring craving generation during the assessment. Several limitations are important in interpreting study findings. The study included a sample that was treatment-seeking and predominantly female; thus, results should be interpreted with caution for men and cannot be generalized to the population of all individuals with OW/OB. Even though a selection of highly craved foods was provided, it is also possible that none of the options were highly craved for some participants. Further, while the assessment was experiential, it relied upon self-report measures of craving.

Due to these limitations and to further evaluate potential explanations for findings that did not fully support our hypotheses, future research is needed to increase understanding of the mechanisms of the ROC and ROC+ treatments and their impacts on FCR and craving. Future studies may benefit from investigations with psychophysiological measures craving. Further, an investigation of craving response throughout the treatment period, as well as using momentary evaluations such as ecological momentary assessment, may provide additional utility in understanding the role of craving in weight-loss trajectories among adults who received different interventions, as well as facets of FCR that may have contributed to the observed differential weight loss for those high in FCR who received ROC/ROC+. Lastly, this craving assessment should be evaluated among different populations, including adults with healthy weight, and among adults with OW/OB in non-

intervention studies, as results may differ. As social desirability bias is high in follow-up assessments for weight management interventions, the utility of repeated measurement with this assessment should be explored in non-intervention studies to rule out social desirability contributing to reduced cravings over time.

5. Conclusion

In summary, our data supported the construct and criterion validity of this craving assessment during exposure to highly craved foods among treatment-seeking adults with OW/OB. Our craving assessment was successful in generating and measuring cravings, which were elevated in response to smell, and differential levels of cravings were observed based upon pre-treatment levels of FCR. Our data demonstrated a weakened pre-treatment FCR-craving relationship among individuals who received ROC+ and BWL at post-treatment; however, reductions were not maintained in ROC+ and the hypothesized weakened relationship at post-treatment among individuals who received ROC compared to BWL and AC was not observed. Our data support the preliminary validity of this laboratory craving assessment that addresses limitations of self-report questionnaires by capturing cognitive FCR in response to *in vivo* exposure to craved foods; however, craving measured with this assessment does not appear to fully account for the moderating effect of FCR on weight losses. There may be limitations to repeated assessment within treatment studies due to social desirability bias and other factors influenced by treatment such as taste preferences and weight.

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Abbreviations:

FCR	food cue reactivity
OW/OB	overweight or obesity
SR	satiety responsiveness
ROC	regulation of cues
BWL	behavioral weight loss
ROC+	regulation of cues + behavioral weight loss combined
AC	active comparator
PACIFIC	Providing Adults Collaborative Interventions for Ideal Changes

UC San Diego	University of California, San Diego
BMI	body mass index
FCRS	Food Cue Responsivity Scale
PFS	Power of Food Scale
FCQ-T	Food Craving Questionnaire—Trait
RED	Reward-Based Eating Drive Scale
LME	linear mixed effects models

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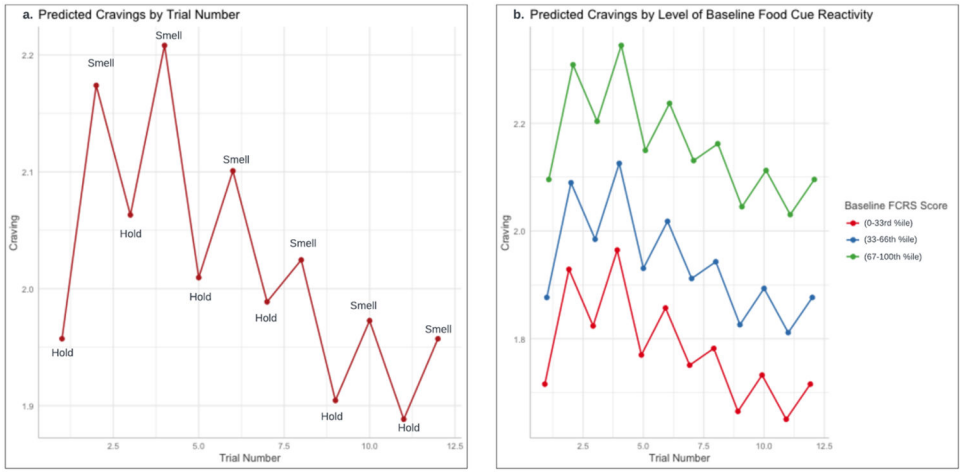

Figure 1. Model-based predicted cravings assessed over the 12 trials and by level of food cue reactivity.

Abbreviations: FCRS, Food Cue Responsivity Scale

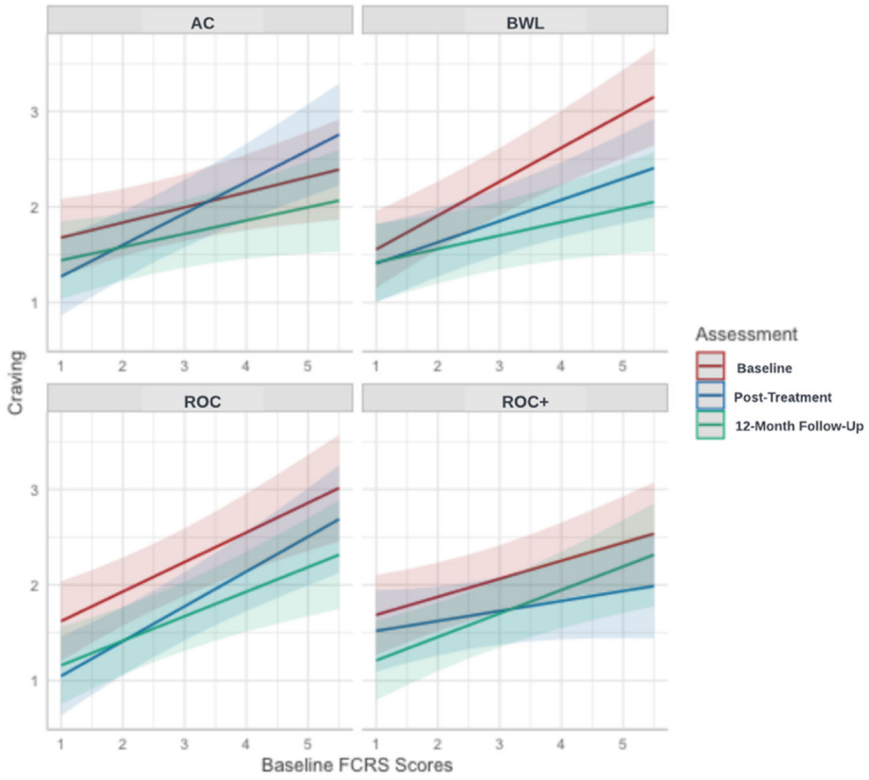

Figure 2. Treatment arm moderates the relationship between pre-treatment food cue reactivity, assessment time point, and model-based predicted craving.

Abbreviations: FCRS, Food Cue Responsivity Scale; ROC, Regulation of Cues; ROC+, Regulation of Cues + Behavioral Weight Loss combined arm; BWL, Behavioral Weight Loss; AC, active comparator

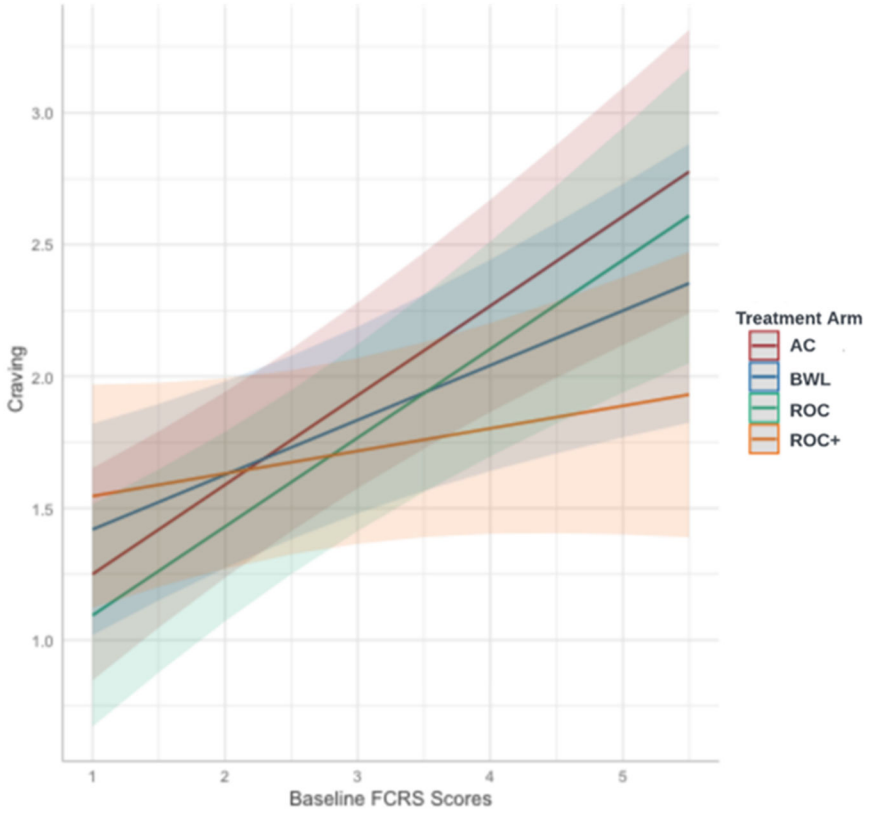

Figure 3. Relationships between pre-treatment food cue reactivity and model-based predicted craving at post-treatment.

Abbreviations: FCRS, Food Cue Responsivity Scale; ROC, Regulation of Cues; ROC+, Regulation of Cues + Behavioral Weight Loss combined arm; BWL, Behavioral Weight Loss; AC, active comparator

Table 1.

Sample characteristics.

Demographics, *N* (%) unless stated otherwise *	**Full Sample (*N*=271)**	**ROC (*N*=69)**	**BWL (*N*=69)**	**ROC+ (*N*=67)**	**AC (*N*=66)**
Age (years), Mean (SD)	46.5 (11.8)	45.7 (12.4)	47.2 (11.2)	47.7 (11.1)	45.1 (12.5)
Gender (Female)	220 (81.2%)	56 (81.2%)	56 (81.2%)	54 (80.6%)	54 (81.8%)
Race/Ethnicity					
Latinx	54 (19.9%)	13 (18.8%)	11 (15.9%)	14 (20.9%)	16 (24.2%)
Non-Latinx, White	167 (61.6%)	40 (58.0%)	46 (66.7%)	42 (62.7%)	39 (59.1%)
Black	15 (5.5%)	3 (4.3%)	5 (7.2%)	1 (1.5%)	6 (9.1%)
Asian/Pacific Islander	23 (8.5%)	6 (8.7&)	4 (5.8%)	8 (11.9%)	5 (7.8%)
American Indian	3 (1.1%)	0 (0.0%)	0 (0.0%)	3 (4.5%)	0 (0.0%)
Multiracial *	14 (5.2%)	6 (8.7%)	4 (5.8%)	2 (3.0%)	2 (3.0%)
Unreported	13 (4.8%)	3 (4.3%)	3 (4.3%)	3 (4.5%)	4 (6.0%)
BMI (kg/m^2), Mean (SD)	34.6 (5.2)	35.0 (5.5)	35.1 (5.0)	33.9 (5.7)	34.2 (4.8)
Household Income					
<$50,000/year	50 (18.5%)	13 (18.8%)	11 (15.9%)	13 (19.4%)	13 (19.7%)
$50,000-$99,999/year	85 (31.3%)	24 (34.8%)	23 (33.3%)	19 (28.4%)	19 (28.8%)
>$100,000/year	111 (41.0%)	24 (34.8%)	28 (40.6%)	32 (47.8%)	27 (40.9%)
Prefer not to answer	20 (7.4%)	6 (8.7%)	5 (7.2%)	3 (4.5%)	6 (9.1%)

Abbreviations: ROC, Regulation of Cues; BWL, Behavioral Weight Loss; ROC+, Regulation of Cues + Behavioral Weight Loss combined arm; AC, active comparator; BMI, body mass index

* Note: race/ethnicity percentages add up to > 100% due to selection of multiple categories by some respondents.

Table 2.

Model-based predicted cravings and 95% confidence intervals by assessment time point, treatment arm, and 2 levels of pre-treatment food cue reactivity.

Treatment Arm	Low FCRS (33rd percentile)	High FCRS = (67th percentile)
Baseline		
ROC	2.04 (1.70, 2.39)	2.30 (1.94, 2.65)
ROC+	1.94 (1.60, 2.29)	2.10 (1.75, 2.45)
BWL	2.03 (1.69, 2.38)	2.33 (1.98, 2.68)
AC	1.90 (1.55, 2.24)	2.03 (1.67, 2.38)
Post-Treatment		
ROC	1.54 (1.20, 1.89)	1.84 (1.48, 2.20)
ROC+	1.67 (1.32, 2.01)	1.75 (1.40, 2.10)
BWL	1.71 (1.36, 2.06)	1.89 (1.54, 2.25)
AC	1.72 (1.38, 2.07)	2.00 (1.64, 2.35)
12-Month Follow-Up		
ROC	1.51 (1.16, 1.86)	1.72 (1.36, 2.08)
ROC+	1.55 (1.20, 1.89)	1.75 (1.40, 2.11)
BWL	1.61 (1.27, 1.96)	1.73 (1.37, 2.08)
AC	1.63 (1.29, 1.98)	1.74 (1.39, 2.10)

Abbreviations: FCRS, Food Cue Responsivity Scale; ROC, Regulation of Cues; ROC+, Regulation of Cues + Behavioral Weight Loss combined arm; BWL, Behavioral Weight Loss; AC, active comparator

Table 3.

Simple slopes for the relationship between pre-treatment food cue reactivity and craving by assessment time point and treatment arm.

Treatment Arm	Simple Slope	Standard Error
Baseline		
ROC	0.57	0.08
ROC+	0.43	0.08
BWL	0.48	0.09
AC	0.33	0.10
Post-Treatment		
ROC	0.57	0.08
ROC+	0.31	0.08
BWL	0.44	0.09
AC	0.45	0.10
12-Month Follow-Up		
ROC	0.46	0.08
ROC+	0.44	0.08
BWL	0.36	0.09
AC	0.30	0.10

Abbreviations: Regulation of Cues; ROC+, Regulation of Cues + Behavioral Weight Loss combined arm; BWL, Behavioral Weight Loss; AC, active comparator