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Development and validation of the food cue responsivity scale

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ABSTRACT

Food cues are ubiquitous in today's environment; however, there is heterogeneity as to the extent to which these cues impact eating behavior among individuals. This study examines the validity and reliability of the Food Cue Responsivity Scale (FCRS) to assess responsivity to distinct types of food cues. Items gathered from existing measures were combined in the FCRS to reflect two subdomains, uncontrolled eating behavior and cognitive rumination. The criterion validity of the FCRS was established using a paradigm that assesses psychophysiological responsivity to a craved food among adults with overweight or obesity. Higher overall FCRS scores were associated with greater physiological responsivity to food exposures. These findings may help identify specific phenotypes of individuals with overweight or obesity with high responsivity to food cues, which could be used to understand overeating and response to weight-loss programs.

1. Introduction

Eating for reasons outside of physiological hunger is considered a major contributor to current obesity rates [8,21,42]. Today's food environment makes it easy to chronically overeat as highly palatable and energy dense foods are easily accessible and often less expensive than more nutrient dense foods [2,3]. Yet, despite the ubiquity of food cues in today's environment, not everyone overeats in response to these cues.

Food cue responsivity (FCR) is an appetitive trait that refers to physiological, cognitive, and emotional responses to food cues in the environment which plays a role in driving overeating or uncontrolled eating. Physiological FCR includes increased salivation, physiological arousal and neural activity in brain regions associated with reward [4,28,41]. Cognitive FCR is potentiated by memories of previous eating events, attentional bias toward appetitive stimuli and preoccupation with food [13,17,22,38]. Emotional FCR refers to heightened emotional states associated with food cues, such as food cues leading to increases in urges to use food to cope with challenging emotions or emotional agitation caused by not obtaining a craved food [37]. The assessment of FCR is necessary to further elucidate risk factors for overeating and weight gain and develop targeted treatments [7].

Numerous measures assess concepts related to FCR, including the Food Craving Questionnaire-Trait [11], the Power of Food Scale [23], Reward-based Eating Drive scale [13,24], the Adult Eating Behavior Questionnaire [20], and the Eating in the Absence of Hunger Questionnaire [43]. Many of the constructs assessed in these self-report questionnaires overlap since they are all related to responses to food or food stimuli and result in the behavioral outcome of overeating/uncontrolled eating [47]. However, none of these questionnaires are validated with objective measures, raising questions about construct validity. Heart rate variability (HRV) in response to food cues is a useful measure of self-regulatory strength and arousal that relates to appetitive regulation and weight [12,18,26,39]. Individuals with obesity demonstrate increased high frequency power in HRV (HRV; a proxy of elevated parasympathetic response) in response to high-calorie visual food cues when compared to individuals with healthy weight [46]. Increased vagal activity (as measured by the Root Mean Square of Successive Differences (RMSSD)) is associated with an individuals' effort in resisting high-calorie foods [39]. Measuring HRV requires expensive equipment and expertise and thus is challenging to implement in a clinical setting. However, associations with HRV would suggest objective

Abbreviations: FCR, Food cue responsivity; HRV, Heart rate variability.

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physiological validity for a self-report measure of FCR.

Thus, the aim of this study is to develop a psychometrically-sound, brief, FCR questionnaire (herein named the Food Cue Responsivity Scale [FCRS]) that is related to an objective measure of FCR. Specifically, our goals were to develop a measure that: (1) meets the assumptions of monotonicity; (2) demonstrates criterion validity such that self-report scores relate to physiological response to food cues; and (3) demonstrates good convergent and discriminant validity.

2. Methods

2.1. Participants

Participants were 271 treatment-seeking adults (Mean BMI = 34.59; mean age = 46.97; 82% female; 20% Hispanic) with overweight or obesity who participated in the Providing Adult Collaborative Interventions for Ideal Changes (PACIFIC) trial (Clinical Trial NCT02516839). Recruitment occurred between December 2015 and November 2017. A detailed report of the design and methods are reported elsewhere [5,6]. Eligibility criteria included 18–65 years of age; BMI $\geq$ 25 and $\leq$ 45 kg/m^2, English language skills at least at the fifth-grade reading level; and willingness to participate in assessment and treatment visits. Exclusionary criteria included history of diagnosis of a serious current physical disease (e.g., diabetes), any medical condition that would make physical activity unsafe, current substance abuse, current pregnancy, or lactation, and any medical or psychological problems (e.g., acute severe depression) that could make adherence to the study protocol difficult or dangerous. Participants completed baseline assessments at the University of California San Diego (UC San Diego) Center for Healthy Eating and Activity Research (CHEAR) prior to beginning treatment. These assessments included surveys of appetitive behaviors, indices of internalizing psychological symptoms, and a food exposure task developed to elicit psychophysiological responses to food cues. Written consent was obtained from all participants and the Institutional Review Board of the UC San Diego approved the study.

2.2. Measures

2.2.1. Self-report questionnaires

Adult Eating Behavioral Questionnaire (AEBQ) is a 35-item survey on a 5-point Likert scale (from "strongly disagree" to "strongly agree") that assesses appetitive traits in adults and includes 8 subscales [20]. The food responsiveness and satiety responsiveness subscales were included in this study given items include domains overlapping our construct of FCR.

Eating in the Absence Hunger Questionnaire (EAHQ) is a 14-item survey on a 5-point Likert scale (from "never" to "always") that assess how participants eat when not physically hungry [43]. The 14 items are summed for a single total score. [40]

Food Craving Questionnaire-Trait (FCQT) is a 37-item survey on a 6-point Likert scale (from "never/not applicable" to "strongly agree") that measures stable characteristics of craving, including intentions to eat, expectations of positive or negative reinforcement, lack of control, preoccupation with food, feelings of hunger, negative affect, cue-dependent eating, and guilty feelings [11]. The food preoccupation subscale was included in this study given items include domains overlapping our construct of FCR.

Power of Food Scale (PFS) is a 15-item survey on a 5-point Likert scale (from "don't agree at all" to "strongly agree") that assesses the psychological impact of living in food-abundant environments. It measures appetite for palatable foods rather than food consumption. The PFS captures thoughts and behavioral difficulties regulating appetitive drive for food at varying levels of food proximity and thus overlaps domains covered by FCR [10,23].

Reward-based Eating Drive (RED) is a 9-item self-report questionnaire on a 5-point Likert scale (from "strongly disagree" to "strongly agree") that measures vulnerability to reward-based eating behavior. Assessed domains include eating tendencies, preoccupation with food, lack of control around food, and lack of satiation from eating [13]. These domains are expected to have partial overlap with targeted FCR.

Godin Leisure Time Exercise Questionnaire (GLTEQ) assesses the frequency and occurrence of leisure time physical activity. It asks participants to report the number of times during a typical week participants participated in mild, moderate, and strenuous exercise for more than 15 min [16]. The items are summed for a single total score.

Demographics - Participants self-reported their age, gender, and race/ethnicity.

2.2.2. Psychophysiological measures

Food exposure paradigm - The food exposure paradigm utilizing electrocardiogram (ECG) is a laboratory-based assessment protocol to generate measurable changes in psychophysiological responses to food cues [28]. A detailed report of the design and methods are reported elsewhere [6]. Prior to starting the task, participants selected their top-rated food from a standardized list of eight foods: Lay's® Potato Chips, Fritos®, Cheez-Its®, Chocolate Chip Cookie, Hershey Kisses, M&Ms®, Gummy Bears and Blueberry Muffins. There were three 6 min phases in the paradigm - baseline, exposure, and recovery. During the baseline phase, the participant was asked to sit quietly and remain still. During the exposure phase, the participant's chosen food was put in front of them, and they were prompted by a research assistant to hold and smell the food at alternating 30 s intervals. The final phase was a recovery phase, where the food was removed and the participant sat quietly again, identical to the baseline phase.

Heart rate variability (HRV) was measured throughout the paradigm with a BIOPAC MP150 [31] using ECG. HRV indices were calculated using Kubios [44]. We included the ratio between components of low and high frequency (LF/HF ratio) for the frequency domain, and the standard deviation of the average normal R-R intervals (SDNN) for the time domain. For analysis of the fractal properties of the heart rate, detrended fluctuation analysis(DFA) alpha-1 was applied to a time series of the R-R intervals obtained from participants [29,30]. We used the short-term fractal exponent (alpha 1), which corresponds to a period of 4 – 11 beats. The change in the three HRV indices from baseline to exposure was used as a measure of individual responsivity level in response to food.

2.3. Analytic plan

We conducted all analysis in R [45] using the KernSmoothIRT [25], Mokken [48], psych [34] and brms [9] packages.

2.3.1. Scale development

The initial phase of scale development focused on item selection from a candidate item pool. The selection process was empirically driven testing assumptions of Item Response Theory and dimensionality as summarized in Fig. 1. Briefly, the study team compiled a pool of 55 items that reflected the different domains thought to characterize FCR from the AEBQ, EAH, FCQT, PFS, and RED measures. Next, we evaluated monotonicity of each item using Mokken scale analysis and visual inspection of item step response functions. The Mokken scale analysis provided the H scalability coefficient (H)- to quantify the strength of item pairs when assessing a common construct [27,48]. We removed 35 items failing to achieve a high scalability index (H > 0.5) using stepwise item selection. We then evaluated the ability to assess a single primary dimension and local independence assumptions using parallel analysis [19], very simple structure (VSS) [32], minimum average partial (MAP) criterion [14], and exploratory bifactor analysis [33]. A total of 14 items were selected as a candidate pool of items providing a balance coverage of target domains and unique variance focusing on FCR. These 14 items were further evaluated using non-parametric kernel smoothing item response models and items were removed when displaying inconsistent

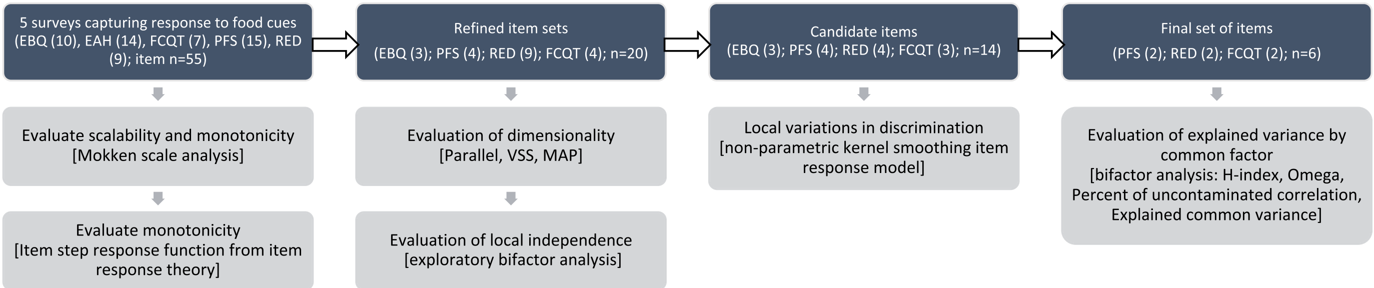

Fig. 1. Selection of process for items to create the food cue responsivity scale. Eating behavior questionnaire (EBQ); Eating in the absence of hunger (EAH) questionnaire; Food craving questionnaire trait (FCQT); Power of food scale (PFS); Reward-based eating drive (RED); Item response theory (IRT); Very simple structure (VSS); Minimum average partial (MAP) criterion.

discrimination and/or redundant information across levels of FCR. Eight of the 14 items failed to meet inclusion criteria and the scale was reduced to the final 6-item Food Cue Responsivity Scale (FCRS). The final six items contained two items each that originated from the PFS, FCQT and RED (see Table 1). The construct replicability (measured by H-index), reliability (measured by omega), percentage of uncontaminated correlation (PUC), and explained common variance were estimated using bifactor analysis [35,36]. For the subsequent evaluation of these six items, we converted the RED items from a 0–4 to 1–5 response scale to make the minimum item level be consistent with other scales.

2.3.2. Criterion validity

To evaluate the criterion validity of the FCRS, we used positive or negative HRV change ratios (SDNN, LF/HF ratio, and DFA alpha1) observed between the baseline and food exposure phases. Bayesian computational methods for binomial generalized linear mixed models were used with weak prior information to adapt Markov chain Monte Carlo methods. The target outcome was the derived dichotomous (positive or negative) HRV change variables, and the variable of interest was total FCRS score, which was adjusted for demographic characteristics (e.g., age, gender, ethnicity). To address non-linearity of the FCRS scores, we used quantiles of total FCRS scores (‘6:12’; ‘12:16’; ‘16:20’; ‘20:32’) as knot points for piecewise linear functions to estimate relationships with the target outcomes.

2.3.3. Convergent and discriminant validity

To assess convergent validity, we compared the FCRS with the total score from the EAH measure since it assesses a construct expected to be elevated among those with high FCR and pragmatically, no items from the EAH measure were used in the final FCRS. For discriminant validity, we expected total scores reflecting levels of physical activity (GLTEQ) to be independent of levels of FCR and thus expect low correlations between GLTEQ and FCRS. All assessments compared selected validation scales with the FCRS scores using bi-variate correlations.

Table 1
List of final FCRS items with strong scalability.

Items description	Source	H
When I am around fattening food I love, it’s hard to stop myself from at least tasting it	PFS	0.51
I feel out of control in the presence of delicious food	RED	0.59
When it comes to foods I love, I have no willpower	RED	0.56
I can’t stop thinking about eating no matter how hard I try	FCQT	0.61
If I am craving something, thoughts of eating it consume me	FCQT	0.61
It seems like I have food on my mind a lot	PFS	0.56

PFS: The Power of Food Scale Permission of Dr. Lowe for use required, RED: The Reward-Based Eating Drive, FCQT: Food Craving Questionnaire-Trait.

3. Results

3.1. Evaluation of dimensionality

The parallel analysis, VSS, MAP, and exploratory bifactor analytic solution of the FCRS suggested the retention of either one or two potential sources of variability underlying item responses. Bifactor analysis suggested that the assigned single general factor accounted for 82% of reliable variance, with 18% of the residual variance spread across two subscales. The summed items had excellent replicability and reliability (H coefficient = 0.83; omega reliability coefficient = 0.71; PUC = 0.60; explained common variance = 0.70).

3.2. Criterion validity

Results supported hypothesized criterion validity of the FCRS (see Table 2). The FCRS scores differentiated individuals with positive versus negative changes in DFA (effect size: 1.64) and SDNN (effect size: 2.05). The association between FCRS and HF/LF ratio was in the expected direction but was not statistically significant (effect size: 0.57). To facilitate increased interpretability of estimates of the strength of relationship between FCRS and binary outcomes, we transformed the logit estimates to a probability scale by dividing regression parameters by 4 [15]. Individuals who scored 20 or more on the FCRS were 74% (2.97/4 = 0.74) more likely to present positive HRV change from baseline to food presentation in DFA and 92% more likely in SDNN; however, were only 26% more likely to have high HF/LF ratio.

As a post-hoc examination of the critical content of the items selected for the FCRS, we repeated validity analyses to compare performance of the full RED-9 and the RED-9 excluding the two items selected for the FCRS. Results indicated a significant positive change from baseline to food presentation in SDNN for the RED-9 (effect size: 1.52). The other HRV outcomes were not statistically significantly related to the RED-9. We then explored whether removing the two items included in the FCRS from the RED-9 impacted HRV outcomes to see whether the critical FCRS items were driving the relationship between the RED-9 and HRV. The RED-9 without the two critical FCRS items was no longer significantly related to any of the HRV measures. Furthermore, Spearman’s correlations were conducted to examine the relationships between HRV outcomes and measures of food cue responsivity (AEBQ, EAHQ, FCQT, RED, PFS). There were no significant correlations between HRV and measures of food cue responsivity (range of r: 0.01 – 0.13; p-value > 0.05).

3.3. Convergent and discriminant validity

We found a strong, statistically significant correlation between the FCRS score and the EAH-total score ($r = 0.63$; $p < 0.01$) which supports convergent validity. The correlation between FCRS and GLTEQ was small, negative, and not statistically significant ($r = -0.07$; $p > 0.05$).

Table 2
Regression model estimates of non-linear relationships between levels of FCRS scores and changes in physiological responses during the food exposure paradigm.

FCRS	Change in DFA alpha-1		Change in SDNN		Change in HF/LF ratio	
Quantiles	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
(Min:11)	−0.05	(−1.60, 1.41)	0.40	(−1.02, 1.74)	−0.09	(−1.62, 1.36)
(12:15)	−0.88	(−2.49, 0.70)	−0.52	(−2.11, 1.00)	−0.53	(−2.15, 0.99)
(16:19)	−0.94	(−4.58, 2.52)	0.35	(−2.89, 3.58)	0.03	(−3.62, 3.43)
(20:Max)	2.97	(0.31, 5.93)	3.71	(1.19, 7.10)	1.04	(−1.11, 3.38)

FCRS: Food Cue Responsivity Scale, Model adjusts for age, sex, ethnicity, 95% CI = 95% credible interval, DFA α1 represents the non-linear domain, SDNN represents the time domain and HF/LF ratio represents the frequency domain.

4. Discussion

The present study developed a brief six-item Food Cue Responsivity Scale (FCRS) from several questionnaires assessing responses to food among a clinical sample of treatment-seeking adults with overweight or obesity. The strong factor loadings on the general primary dimension, the large common variance explained by the general factor, and the small common variance accounted for by the subdomains in the bifactor model suggested that the resulting six items represent a unidimensional construct of FCR. Despite the item pool containing items related to physiological, cognitive, and emotional FCR as well as uncontrolled eating, only items from the cognitive and uncontrolled eating domains were selected. Results demonstrated the FCRS had strong criterion validity with an objective psychophysiological measure. Further, in line with hypotheses, the FCRS demonstrated strong convergent validity with a measure of eating in the absence of hunger, and discriminant validity with a measure of physical activity.

To our knowledge, this is the first study to develop a short list of FCR self-report items that were validated using objective psychophysiological measures. In line with our a priori hypotheses, participants' physiological FCR was associated with their FCRS total score, and those with high FCRS scores (top quantile) displayed even greater psychophysiological reactivity to a craved food than participants with the moderate FCRS scores (below top quantile). By contrast, the RED score was only significantly related to one measure of HRV and the effect was smaller than the two significant effects of the FCRS. When the overlapping items of the RED that were included the FCRS were removed, the remaining items from the RED were not significantly associated with any measure of HRV. This provides further support for the potential utility of the FCRS as a brief and unique self-report measure of FCR. Importantly, in a randomized controlled trial [5], the beneficial effect of a traditional behavioral weight loss program were shown to depend in part on low levels of pre-treatment FCRS. Thus, the FCRS may be used to identify individuals who are high on FCR, for whom traditional behavioral weight loss programs may not suffice.

The FCRS items reflect two conceptual domains – preoccupation about food (i.e. cognitive FCR) and the behavioral response of FCR (i.e. uncontrolled eating). Interestingly, when separated into subscales, neither of these two domains were independently able to predict physiological responses to food cues as well as when both domains were combined into a single construct. It is possible that this is due to the increased reliability and domain coverage of a larger number of items; however, more likely the two concepts work in tandem to reflect a broadened construct where urges to overeat and attempts to suppress thoughts about highly craved foods arise from a common cause. One hypothesis is that individuals who experience preoccupying thoughts around food may exhaust their cognitive resources in an attempt to inhibit these thoughts, which ultimately places them at a higher risk of overeating [1,49]. Underlying heightened physiological reactivity to food cues also may drive uncontrolled eating and increased thoughts about reducing overeating. Alternatively, underlying heightened physiological reactivity to food cues could be necessary when triggering increased thoughts which in turn depletes cognitive resources and increases risk for overeating [50]. While speculative, this study suggests the potential utility of access to a very brief FCRS, more research is needed to test whether the FCRS can predict treatment response and explore the role of FCR when understanding how physiological reactions and thoughts about eating impact eating behavior.

We developed the FCRS from existing questionnaires that included items across multiple domains associated with FCR. Our intent was to find a measure that reflected aspects of FCR associated with an objectively observed behavioral/physiological response. The RED includes a subset of items conceptually similar to FCR domains motivating development of the FCRS: loss of control overeating and preoccupation with food [13]. Compared to the FCRS, evidence for criterion validity for the full RED with HRV measures of food-cue responsiveness was not as strong. Further, once the two items from the RED included on the FCRS were excluded, the remaining RED items did not show any associations with the HRV changes in response to food cues. The FCRS also had a strong positive association with EAH, a construct predicted by higher levels of FCR. Furthermore, discriminant validity was demonstrated with the measure of physical activity. Thus altogether, the FCRS demonstrated strong psychometric properties and appears to represent a unique measure of FCR that closely reflects physiological responsivity to food cues.

There are a number of strengths and weaknesses that need to be noted. With the implementation of rigorous scale development protocols, utilization of psychophysiological measures as criterion validity, and strong empirical evidence of consistency, reliability, and validity, we have created a psychometrically sound six-item measure of FCR. This study also used a large and relatively diverse sample of treatment-seeking adults with overweight or obesity. However, despite the strengths of the current study, it is not without limitations. First, as the study participants were treatment-seeking individuals with overweight or obesity, these results may not be generalized to a broader population. Furthermore, while the final six items converged well through statistical analyses, the resulting six-item scale was not tested in its new, brief format to evaluate its psychometric properties as a standalone measure. Thus, the FCRS warrants validation against additional objective measures when administered as a stand-alone scale. Future studies should focus on evaluating psychometric properties of the six-item scale and to contribute to evidence about whether this scale can differentiate individuals who are likely to succeed or struggle in behavioral weight loss programs.

5. Conclusion

FCR is an important factor which includes physiological reactivity to food cues and may be critical in identifying a specific phenotype of individuals who may struggle in behavioral weight loss programs. The six-item FCRS is brief and psychometrically sound and can be deployed much more easily to a large sample as compared to time-consuming psychophysiological assessments. The present findings may facilitate the rapid identification of a specific phenotype of individuals with overweight or obesity, who may better respond to individualized treatment protocols that directly target this appetitive trait.

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Author contributions

DK and MM conducted the statistical analyses with the supervision of DS. KB, DS, and DE designed the study. KB obtained the funding. DE and KB recruited the study participants. All authors were involved in writing the paper and had final approval of the submitted and published versions.

Data sharing statement

The authors support data sharing. All data summarized in this publication may be available in a deidentified format to other investigators for research purposes with the approval of the principal investigators and the institutional review board.

Data availability

Data will be made available on request.

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We recognize the contribution of all the research participants and the staff and students at the Center for Healthy Eating and Activity Research at University of California San Diego. Data sharing for this study may be available for requests that meet the approved process contained within the informed consent and other policies at University of California San Diego. Investigators interested in deidentified data from this study should contact Dr. Boutelle at kboutelle@health.ucsd.edu, who is the principal investigator, for data sharing policies and procedures after publication. Permission was obtained from Dr. Michael Lowe for use of the Power of Food Scale © 2006 Drexel University. All rights Reserved.

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