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Appetitive Traits, Craving, and Eating Behaviors in a Community Sample of Guidance-Seeking Adults

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By

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M.A., Emory University, 2018

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An abstract of
A dissertation submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
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Abstract

Appetitive Traits, Craving, and Eating Behaviors in a Community Sample of Guidance-Seeking Adults

By Devika Basu, M.A.

Brewer and colleagues (2018) propose positive and negative reinforcement pathways within a learning-based “habit loop” in order to explain non-homeostatic eating behaviors (i.e., external and emotional eating). Cravings (i.e., “action urges”) are identified as the critical link that maintains problematic non-homeostatic eating and thus, are a potential target for intervention. However, the Brewer model does not identify individual difference variables that may predispose individuals toward developing this habit loop. Behavioral Susceptibility Theory (BST; Llewellyn and Wardle, 2015) posits that appetitive traits (i.e., food responsiveness and satiety responsiveness) are two vulnerabilities through which differential risk for non-homeostatic eating and subsequent weight-related difficulties may be conferred, particularly in children. Little exploration of appetitive traits as reported by adults has been conducted. The aims of the present study were to assess support for both of these models within a guidance-seeking community sample of adults by examining: 1) cross-sectional relationships between appetitive traits, craving, and non-homeostatic eating; 2) changes in craving due to use of the Mindful Eating Coach mobile-based app (MEC-2); and 3) whether appetitive traits moderated changes in craving. Participants were 123 adults (mean age = 31.9 years) who volunteered for a 3-week randomized control trial utilizing the MEC-2 app. Results from hierarchical linear regression illuminated interesting relationships cross-sectionally. Cravings were positively associated with both external and emotional eating. Food responsiveness was positively associated with cravings and external eating, while satiety responsiveness was associated only with external eating. These results did not fully support theoretical predictions and warrant further investigation. A mixed-design repeated measures ANCOVA demonstrated no changes in craving due to the intervention, and moderation analyses (conducted using the PROCESS macro) indicated no significant interactions between appetitive traits and changes in craving although these analyses were underpowered. The results of this study provide preliminary support for using both the Brewer model and BST in conceptualizing non-homeostatic eating behaviors. Continued investigation of these relationships may improve our understanding of the role of cravings in the maintenance of problematic non-homeostatic eating and help to identify more targeted and effective interventions.

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Introduction

Overweight and obesity are associated with a range of chronic mental and physical health conditions, including but not limited to, depression, binge eating disorder, type 2 diabetes, cardiovascular disease, and increased mortality (Mitchell, Catenacci, Wyatt, & Hill, 2011). Epidemiological research has shown a consistent trend in prevalence, such that rates of overweight (i.e., body mass index [BMI] greater than 25.0) and obesity (i.e., BMI greater than 30.0) have increased dramatically over the past three decades within the United States (Hales, Carroll, Fryar, & Ogden, 2020). Current estimates classify 32.5% of US adults as overweight and another 42.4% of adults as obese (Center for Health Statistics, 2018; Hales et al., 2020). While these statistics are alarming, they reflect an environment in which eating solely for physiological and nutritional necessity (i.e., homeostatic eating) is increasingly difficult.

Although eating for reasons other than physiological hunger (i.e., non-homeostatic eating) can be maladaptive in terms of weight management, it is ubiquitous and normalized. A substantial body of evidence has demonstrated that physiological appetite regulatory systems are highly susceptible to the presence of external rewards (i.e., highly palatable foods that are increasingly available in the current environment) and behaviors, such as eating in the absence of hunger or when already satiated (Brownell & Walsh, 2017). Evolutionarily, humans are genetically programmed to maximize efficient calorie consumption by seeking out and remembering sources of energy dense foods—survival of the fittest included eating voraciously when such foods were available and storing energy as fat for times in which food was scarce (Brownell & Walsh, 2017). The modern food environment however, often referred to as the "obesogenic environment," is rife not only with food cues designed to entice individuals to eat, such as advertising on television and in social media, but also with a generally greater availability of highly palatable foods (Boutelle & Bouton, 2015; Jansen, Schyns, Bongers, & van den Akker, 2016). As such, in the modern environment, the thought processes leading to decisions to eat may be biased away from attending to innate, physiological cues (i.e., hunger, satiety) and towards attending to external triggers and internal experiences of the desire to eat for reasons other than hunger.

One recently proposed theoretical model has aimed to create a unified behavioral framework so as to comprehensively explain non-homeostatic eating and provide useful targets for intervention. In their 2018 paper, Brewer and colleagues propose two pathways within a "habit loop" that explicate the role of learning in the acquisition and maintenance of non-homeostatic eating. As the authors explain, these eating behaviors are learned over time via operant conditioning through both positive and negative reinforcement. Food is a powerful primary, or not-learned, reinforcer (Epstein & Leddy, 2006). When an individual eats a highly palatable food (i.e., high in fat and/or sugar), the person experiences physiological and psychological effects that are experienced as a reward, which serve to strengthen the link between the antecedents (i.e., context) and the behavior of eating (Epstein & Leddy, 2006). The positive reinforcement pathway initially forms when individuals experience the rewarding effect following actual eating in response to triggers in the external environment. As learning occurs within these specific contexts, over time a broad array of environmental cues associated with the reward of eating also become conditioned cues (i.e., triggers), eliciting urges to eat with or without the presence of internal hunger cues. These cues may include enticing pictures of desirable foods, seeing readily available foods at social gatherings, or being in an environment (e.g., a bakery) associated with positive eating experiences. Meanwhile, a negative reinforcement pathway also develops when an individual eats in the context of uncomfortable internal emotions—eating highly-palatable foods in these situations reduces the aversive stimulus (i.e., the negative emotion) for many individuals and thus reinforces the behavior of eating in response to negative emotions. Over time, both of these pathways become overlearned, thus forming a well-established habit loop in which eating episodes are often triggered by contextual cues (e.g., seeing food, negative affect) that may not be associated with physiological hunger cues.

Importantly, Brewer and colleagues propose that food cravings, defined as intense urges or desires to eat a specific food (or type of highly-palatable food such as candy or junk food), develop as a central downstream mechanism linking both the positive and negative reinforcement pathways to maladaptive, non-homeostatic eating (Brewer et al., 2018; Weingarten & Elston, 1991). That is, as individuals experience those external or internal cues that have been established as a context for eating, they experience a psychological state of wanting or "action urge" (viewed as distinct from whether or not they experience physiological hunger or liking of the food) which further prompts the behavior (Berridge, 2009). Within the Brewer model, cravings are conceptualized as "thoughts and images that motivate further elaboration and movement toward the desired food," (Brewer et al., 2018, p.4) that have been strongly reinforced by being associated with subsequent positive effects, such as increases in positive emotions or decreases in negative emotions. Thus, cravings themselves may be considered overlearned responses to certain internal or external cues, exerting strong pulls to action which may be operating at least partially below the level of conscious awareness. As such, cravings provide a useful link explaining the maintenance of the habit loop in spite of conscious efforts to resist urges to eat.

Food Cravings

Food cravings have long been implicated as central to the maintenance of maladaptive eating patterns (Weingarten & Elston, 1991). When discussing food cravings, an important distinction must be made between momentary, or state, craving and tonic, or trait, craving. State craving refers to food cravings experienced immediately following either an external (e.g., picture of a highly-palatable food, presence of food) or internal (e.g., a thought about food, negative emotional state) cue. Trait craving refers more broadly to the degree to which an individual has frequent and/or intense experiences of cravings (Meule, Richard, & Platte, 2017). Although referred to in the literature as a trait, measures of this construct actually reflect the person's report of craving experiences, that is how an individual typically experiences and responds to certain urges to eat, rather than directly assessing an individual's predisposition (in the sense of genetic "trait" vulnerability, for example) toward experiencing craving.

Research has consistently demonstrated associations between measures of both state and trait craving and difficulty maintaining adherence to and success with diets (A. E. Mason, Jhaveri, Cohn, & Brewer, 2018; Potenza & Grilo, 2014). For example, Massey and Hill (2012) demonstrated that dieters reported significantly more state food cravings than "watchers" (i.e., individuals who were maintaining current weight rather than trying to lose weight) and non-dieters in their quasi-prospective study in which individuals were asked to maintain a daily diary of state food cravings. In a study of 617 participants, Meule and colleagues found that trait craving (measured using the Food Craving Questionnaire – Trait [FCQ-T], a reliable and valid measure of trait craving; Meule, 2020) mediated the inverse association between rigid control (i.e., an all-or-nothing approach wherein "forbidden foods" are eliminated from the diet) and overall dieting success, with trait craving positively associated with rigid control and negatively associated with diet success (Meule, Westenhöfer, & Kübler, 2011). In this study, the authors demonstrated that the practice of eliminating specific foods from the diet actually increased experiences of cravings and led to decreased perceived dieting success. In addition, overweight and obese individuals report greater frequency and intensity of cravings for highly palatable foods compared to normal-weight individuals (Chao, Grilo, White, & Sinha, 2014; A. E. Mason et al., 2018).

When examining prospective associations between experiences of craving and subsequent actual eating behaviors however, the relationships are less clear. Recently, researchers conducted a quantitative meta-analysis in order to summarize the mixed evidence from prospective studies in the literature (Boswell & Kober, 2016a). The omnibus analyses (N = 2948 from 45 studies) revealed a medium effect of craving ($r = 0.33$; combined state and trait) on eating behavior and weight gain, indicating that experiences of food craving significantly predicted non-homeostatic eating behaviors (measured using self-report questionnaires and/or lab-based paradigms) as well as weight gain (Boswell & Kober, 2016a). The authors also examined whether trait craving on its own predicted these outcomes. From their sample of seven identified prospective studies, they found significant medium effects of trait craving on actual eating (operationalized in these studies via lab-based eating paradigms; $r = 0.26$) and weight outcomes (i.e., weight gain over time or weight loss within the context of interventions; $r = 0.27$; Boswell & Kober, 2016). Taken together, evidence suggests that experiences of craving (both momentary and more habitual) may be implicated in maladaptive eating patterns although more information must be gathered in order to further elucidate these relationships.

Non-homeostatic Eating Behaviors

As discussed above, Brewer and colleagues propose two mechanisms of reward-related eating patterns: 1) via positive reinforcement, in which individuals eat in response to the presence of food cues in the external environment; and 2) via negative reinforcement, in which individuals eat to reduce negative affect. The former pattern corresponds closely to the construct of external eating as used in the obesity literature, whereas the second corresponds to the construct of emotional eating.

External eating refers to eating or overeating (i.e., continuing to eat past fullness) in response to external environmental cues such as seeing desirable foods (van Strien, Frijters, Bergers, & Defares, 1986). Although estimates of prevalence are not available for this behavior, a large community sample of 590 adults demonstrated that higher levels of self-reported external eating (measured using the Dutch Eating Behavior Questionnaire [DEBQ]) were cross-sectionally associated with higher BMI and more self-reported instances of overeating (Koenders & Van Strien, 2011). However, data is mixed regarding prospective associations between external eating and weight status over time. In the same study, the authors found that the moderating effect of external eating on BMI change was wiped out after accounting for clinically-significant weight change (i.e., operationalized as a greater than 3% change in BMI; Koenders & Van Strien, 2011). Nonetheless, consistent evidence suggests that individuals who frequently engage in external eating may be more sensitive and responsive to food cues in the environment in comparison with individuals who engage in less frequent external eating (Hou et al., 2011).

Emotional eating, on the other hand, is typically defined as eating or overeating in response to internal negative emotional states (e.g., sadness, anxiety, boredom, etc.) and does not usually refer to eating motivated by desires to enhance positive emotional states (e.g., to celebrate or socialize; van Strien et al., 1986). Within Brewer's model, eating to enhance positive emotions would fall within the positive reinforcement pathway. Evidence suggests that a pattern of eating in response to negative states is common in both non-clinical (i.e., normal weight) and clinical (i.e., overweight-obese) populations, with estimates indicating that between 20 – 43% of non-clinical individuals and up to 63% of individuals in clinical samples frequently engage in this behavior (Gibson, 2012). Although such data are prone to retrospective recall bias, studies utilizing ecological momentary assessment (EMA) to prospectively examine associations between experiences of negative affect and actual eating behaviors in both non-clinical and clinical (e.g., individuals reporting frequent binge eating) samples have also demonstrated support for this phenomenon (Thomas, 2009). For example, in a recent study that aimed to examine relationships between common eating motives and real-life eating episodes using EMA, the authors found that individuals who endorsed using eating for “affect regulation” purposes (i.e., emotional eating) using a trait measure at baseline (i.e., The Eating Motivation Survey [TEMS], Renner, Sproesser, Strohbach, & Schupp, 2012) did report actual eating episodes that they initiated to regulate negative emotions (Ronja et al., 2020). Across studies, females tend to report greater emotional eating than males, and more frequent emotional eating seems to be positively associated with BMI cross-sectionally (Brewer et al., 2018; Gibson, 2012). In addition, emotional eaters may engage in more frequent overeating in general (i.e., regardless of type of initial cues; Bongers & Jansen, 2016; Brewer et al., 2018). A number of prospective studies have similarly demonstrated that greater emotional eating, as measured by the DEBQ (van Strien et al., 1986), predicts weight gain over time (Dohle, Hartmann, & Keller, 2014; Koenders & Van Strien, 2011). Limited evidence exists to suggest that initially lower levels of emotional eating may predict better long-term outcomes in weight-loss targeting interventions, although further studies are needed to make conclusions in this regard (Braden et al., 2016; Frayn & Knäuper, 2018).

Brewer and colleagues provide an evidence-based and parsimonious model to explain how and why maladaptive eating patterns develop as well as how they may be maintained over time. When applying this theoretical model within the current obesogenic environment, one would predict that most individuals would develop both external and emotional eating behaviors at least to some extent, leading to maladaptive eating patterns which would promote weight gain and/or weight-related concern. However, this is not reflected in reality—despite the ubiquity of highly-palatable food cues and pop-culture references to emotional eating, not everyone engages in non-homeostatic eating to an extent that would be considered either pathological or clinically relevant. It is notable, however, that overweight, which may be viewed as a consequence of maladaptive eating patterns over time, now characterizes at least a third of the adult population, suggesting that development of these pathways is quite normative. Nonetheless, approximately one-third of individuals living in the "obesogenic" environment do not become overweight (Hales et al., 2020). As such, it is essential that theoretical models geared toward informing effective intervention investigate individual differences that could help to explain potential vulnerabilities to developing eating-related difficulties within the predominantly obesogenic environment.

Appetitive Traits

Individual difference-level variables that have recently received growing attention in the literature are appetitive traits, conceived of as inherited differences in predispositions toward eating behaviors (Llewellyn & Wardle, 2015). Rooted in Schachter's Theory of Externality, which suggested that obese individuals are more responsive to food cues and less responsive to internal satiety signaling than normal-weight individuals (Schachter, 1968), contemporary researchers have begun focusing on appetitive traits as central mechanisms in the development of eating-related problems. Of primary focus are two appetitive traits: food responsiveness (i.e., an individual's general tendency to respond to food cues in the environment) and satiety responsiveness (i.e., an individual's tendency to respond appropriately to internal satiety cues which prompt the individual to stop eating once full and not eat beyond nutritional requirements). Behavioral Susceptibility Theory (BST), proposed and investigated by Wardle and colleagues, posits that natural variations in these appetitive traits confer differential risk for developing obesity within the context of the obesogenic environment (Llewellyn & Wardle, 2015). By examining variations in appetitive traits, Wardle and colleagues have sought to explain why certain individuals may be at greater risk for developing obesity even within a shared environment (e.g., why siblings within the same family demonstrate significantly different weight status or weight gain over time).

BST has primarily been investigated in children and adolescents as the traits are hypothesized to reflect genetic vulnerability to the obesogenic environment (French, Epstein, Jeffery, Blundell, & Wardle, 2012). Since these genetic predispositions likely interact with environmental variables, assessing phenotypic appetitive traits in adults would more clearly reflect learned responses and behavioral patterns as well as any genetic vulnerability. Numerous cross-sectional studies in children have demonstrated that food responsiveness is positively associated with measures of weight and adiposity, while satiety responsiveness is negatively associated with these measures (Llewellyn & Fildes, 2017). In these studies, authors operationalized satiety responsiveness using the Child Eating Behavior Questionnaire (CEBQ), a reliable and valid parental-report measure of eating behaviors including four items (such as "My child is always asking for food") assessing a child's perceived food responsiveness, and four items (such as "My child gets full before his/her meal is finished") assessing a child's perceived satiety responsiveness (Carnell & Wardle, 2007). Importantly, these studies have also shown that these appetitive traits explain variation in weight across the whole spectrum, rather than simply differentiating between normal-weight and obese (Llewellyn & Fildes, 2017). In addition, evidence suggests that these parent-reported appetitive traits are associated with actual eating behaviors observed in children, with satiety responsiveness negatively associated and food responsiveness positively associated with energy intake in a lab-based experiment (Carnell & Wardle, 2007). In this study, the authors used Birch and colleagues' "eating in the absence of hunger" (EAH) paradigm, in which children are given the opportunity to eat to the point of satiety and are then presented with additional highly palatable foods (J. O. Fisher & Birch, 2002). As such, this measure is theorized to tap into both satiety responsiveness (i.e., initiating eating even after reaching a point of satiety just prior to the task) and food responsiveness (i.e., susceptibility to easily available highly palatable foods). Carnell and Wardle (2007) demonstrated that children higher in parent-report satiety responsiveness had lower intake in the EAH task, while children with higher parent-reported food responsiveness ate more of the highly palatable food during the task.

Furthermore, some evidence exists to suggest that children may respond differentially to intervention based on their initial levels of these appetitive traits. Secondary analyses from a behavioral weight-loss intervention program for 8-12-year-old children (N = 150) found distinct "phenotypes" that predicted differential patterns of weight-loss maintenance following treatment through a 24-month follow-up (Boutelle et al., 2019). Three phenotypes emerged, which the authors classified as "high satiety responsiveness," "high food responsiveness," and "high emotional eating," measured via the CEBQ and the Emotional Eating Scale for Children (EES-C; a self-report questionnaire assessing eating in response to a range of emotional cues). The first group consisted of children (47.4% of the sample) with baseline high satiety responsiveness (that remained high throughout the intervention) who demonstrated decreasing food responsiveness over time but stable low levels of emotional eating. The second group (34.6% of the sample) demonstrated baseline high food responsiveness which remained high, low satiety responsiveness which also remained low, but decreasing levels of emotional eating over the 24-months. The third group (18.0% of the sample) were children with baseline high levels of emotional eating which remained high but showed increasing satiety responsiveness, and decreasing food responsiveness over the course of the intervention. Although all three groups showed weight loss at similar rates over the course of the intervention, only individuals with the baseline high satiety responsiveness phenotype demonstrated sustained weight-loss at the 24-month follow-up (Boutelle et al., 2019). Children with either the high food responsiveness group or the high emotional eating phenotype regained weight at follow-up. These data suggest that satiety responsiveness and emotional eating may be negatively associated, while associations between food responsiveness and emotional eating were less evident (the authors did not report correlations between the measures). Nonetheless, this study provides compelling support for the existence of distinct subgroups of children for whom certain interventions may be more or less effective.

To date, similar research in adults has been minimal, due in part to a lack of comparable measurement tools to capture these specific appetitive traits. Most work in adults within this area has been conducted using the construct of “disinhibition,” which is typically measured using the Eating Inventory (EI), also known as the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985). The Disinhibition subscale of the TFEQ assesses a combination of responsiveness to food cues, emotional eating, and weak satiety responsiveness and has been consistently shown to be positively associated with BMI and weight gain over time in adults (French et al., 2012). However, the measure has performed poorly in confirmatory factor analyses and demonstrates a relative weakness in its lack of discriminant validity, as each subscale is multidimensional and combines theoretically separate constructs (Cappelleri et al., 2009; Frayn & Knäuper, 2018; Mazzeo, Aggen, Anderson, Tozzi, & Bulik, 2003). To respond to this lack of availability of comparable measures of appetitive traits in adults, researchers within the BST team extended the existing childhood measure of appetitive traits (the CEBQ; Carnell & Wardle, 2007) in order to continue examining these traits across the life span (the Adult Eating Behavior Questionnaire [AEBQ]; Hunot et al., 2016).

There is limited evidence regarding the utility of using appetitive traits to understand and treat maladaptive eating patterns (including eating in the absence of hunger and eating past satiety) in adult samples. If such behavioral phenotypes could be reliably identified among adults, and if those phenotypes are associated with specific non-homeostatic eating behaviors, there may be significant implications for developing more personalized interventions to target those patterns. For example, individuals with high food responsiveness may respond better to strategies to reduce exposure to highly palatable foods and to tolerate food cues without eating. Individuals low in satiety responsiveness, on the other hand, may respond better to portion control strategies and mindful awareness of fullness during eating. Even if the majority of overweight adults endorse both high food responsiveness and low satiety responsiveness, a better understanding of these behavioral vulnerabilities may inform the development of additional strategies to target non-homeostatic behaviors including responses to cravings.

Current Interventions

Taken together, substantial evidence suggests that both individual differences in appetitive traits and operant learning processes may be implicated in eating- and weight-related difficulties. Standard behavioral and cognitive behavioral intervention approaches to eating- and weight-related issues are clearly established as the first-line treatments for binge and overeating problems as well as weight loss, but many individuals do not benefit significantly and typically less than half are able to sustain clinically significant behavior change or weight loss (Brewer et al., 2018). These approaches rely heavily on lifestyle changes predicated upon dietary restriction. A recent meta-analysis of 45 trials found extremely limited evidence for weight-loss maintenance following lifestyle (i.e., dieting) interventions, especially after considering risk for publication bias (Dombrowski, Knittle, Avenell, Araújo-Soares, & Sniehotta, 2014). The failure of programs centered on dietary restraint is not surprising, given consistent research suggesting that deprivation and restraint are associated with increases in non-homeostatic eating behaviors (Polivy, Coleman, & Herman, 2005; Polivy & Herman, 1985; Ricca et al., 2009). In addition, recent studies exploring biological mechanisms suggest that hormonal and metabolic changes that promote weight gain via increased appetite may occur with restraint-induced weight-loss (Fothergill et al., 2016; MacLean, Bergouignan, Cornier, & Jackman, 2011). Thus, recent efforts to investigate non-dieting approaches have been encouraged.

As Brewer and colleagues (2018) argue, approaches that more directly target interrupting the habit loop without encouraging dietary restraint may be more successful. Craving, hypothesized to be the downstream mechanism central to the maintenance of the habit loop, may be a particularly useful target for intervention, as studies have shown that food cravings predict non-homeostatic eating behaviors both within lab-based paradigms and using self-report assessments (Boswell & Kober, 2016a; Brewer et al., 2018). Evidence from a parallel literature of another habitual behavior, smoking, suggests that mindfulness training may directly target experiences of cravings themselves by bringing awareness and curiosity to the craving, rather than an immediate response to relieve or control the craving, avoidance, or judgment (Brewer et al., 2011; Kabat-Zinn, 2003). Presumably, mindfulness practice would promote a decoupling of cravings from the behavior of interest by encouraging the individual to accept and approach the bodily sensations, thoughts, and emotions that encompass craving, as opposed to compulsively acting on them or struggling to control them. Over time, this focus on greater awareness and understanding of food cravings (including their overlearned nature) may allow individuals to slow down, tune in to their experiences, and gain mastery over decision-making, in turn reducing the frequency of cravings via extinction. This would also presumably reduce maladaptive responses to those cravings (i.e., overeating, especially of highly palatable foods; Elwafi, Witkiewitz, Mallik, IV, & Brewer, 2013).

Mindfulness-based strategies have already been included in a multitude of eating-related interventions and have demonstrated some effectiveness in targeting emotional eating, external eating, and binge eating (Warren, Smith, & Ashwell, 2017). Although many of these interventions include components specifically focused on managing cravings, few studies have examined direct effects of mindfulness training on reducing cravings (Warren et al., 2017). A pair of small weight-loss studies (the first a non-clinical sample of 26 women, and the second a sample of 19 overweight or obese adults) demonstrated decreased craving (trait measure) in the treatment groups compared to controls following an 8-week mindfulness-based intervention (Alberts, Mulkens, Smeets, & Thewissen, 2010; Alberts, Thewissen, & Raes, 2012). Relevant to the present study, participants (N = 104; overweight or obese women who reported food cravings most days of the week) in a recent single-arm trial of a mobile app-based intervention utilizing principles of mindful eating (Eat Right Now; A. E. Mason et al., 2018) showed a mean 40.21% reduction in craving (trait) post-intervention. Although designed as a 28-day intervention, the mean time to intervention completion was around 58 days. These studies provide promising support for the efficacy of mindful eating strategies in reducing trait craving.

Relatedly, a group of researchers developed an intervention designed to target food cue reactivity and satiety responsiveness in adults called the Regulation of Cues program (ROC; Boutelle, Knatz, Carlson, Bergmann, & Peterson, 2017). This novel treatment consists of a 4-month group-based program incorporating principles of appetite awareness (described in more detail below) and cue-exposure therapy (similar to exposure therapy used in treatment of anxiety disorders) within four core components: in-vivo exposures, self-monitoring of hunger and satiety, psychoeducation, and coping skills (Boutelle et al., 2017). Participants learn to self-monitor internal hunger and fullness cues and experiences of cravings (defined in this program as urges to eat when not physically hungry). In each group session, participants engage in an in-vivo inhibitory learning paradigm during which participants are guided through experiences of induced craving (i.e., state craving) while looking at, holding, and eating two small bites of a (self-provided) highly-palatable food. After habituation to the craving (i.e., decreases in the intensity), participants practice throwing away the food and tolerating any subsequent discomfort. In addition, participants learn coping skills (e.g., mindful breathing, distraction delay, cost-benefit analysis, etc.) to use when cravings arise outside of the sessions. In the sample of overweight and obese individuals who endorsed weekly binge eating (single-arm trial; N=28), participants demonstrated significant improvements in binge eating, overeating episodes, and food responsiveness (as measured by an adapted version of the CEBQ, the adult version did not yet exist; Boutelle et al., 2017). Although this was not a randomized control trial and craving was not measured, these data provide compelling support for the use of interventions that target both awareness of appetite cues and responsiveness to external cues as mechanisms through which to decrease non-homeostatic eating behaviors.

The Present Study

The primary aim of the study was to evaluate baseline associations between appetitive traits defined within BST, cravings (as identified within the Brewer model), and non-homeostatic eating behaviors. The second aim was to evaluate changes in craving resulting from a mindfulness-based intervention within a sample of guidance-seeking adults, while a third aim of the present study was to evaluate potential moderators of changes in craving. The current study sampled adults reporting difficulties with overeating who volunteered to participate in a 3-week randomized control trial utilizing a recently updated version of a mobile-based app, the *Mindful Eating Coach* (MEC-2). Feasibility and acceptability of this updated app were concurrently assessed as part of a larger project from which the present study's data was collected. Rooted within principles of Appetite Awareness Training (AAT; Allen & Craighead, 1999), the mobile app was not designed as a weight-loss program, but rather to target non-homeostatic eating that may impede weight-maintenance or achievement of weight-loss goals. AAT combines facets of mindfulness-based strategies (i.e., mindful awareness, curiosity, non-judgment) with the cognitive behavioral technique of self-monitoring in order to train participants to become more aware of interoceptive appetite cues (i.e., hunger and satiety) and to use that awareness to decrease non-homeostatic eating behaviors (Allen & Craighead, 1999; Jones, 2012; Marx & Craighead, 2016).

Previous versions of the app demonstrated initial efficacy in improving mindful eating, appetite awareness, and general eating pathology during brief, 3-week interventions (Jones, 2012; Martinez, 2017; Marx, 2016). The current, updated version of the app includes psychoeducational information and guided prompts to promote using internal appetite cues (when making decisions to initiate or stop eating) and alternative actions when experiencing urges to eat in the absence of physiological hunger (including food cravings). Although the revised version of the app does not include the multiple, structured exposure sessions that form the core of the in-person ROC program (Boutelle et al., 2017), a modified version of self-exposure is included as an option for users. Individuals are instructed to practice "deliberate mindful eating" of problem foods—eating a single portion size slowly and with intention when faced with urges to eat when not physiologically hungry, including strong urges which the individual might label as cravings.

Specific Aims and Hypotheses

Aim 1. Brewer and colleagues' model of the habit loop and Wardle and colleagues' BST both serve to provide possible explanations for the maintenance of maladaptive eating patterns. However, to the best of our knowledge, no studies in adults have directly examined the variables identified in these models in conjunction with one another. As such, the primary purpose of the present study was to examine support for both the Brewer model and BST; we examined whether these self-reported traits and behaviors were associated in theoretically-predicted ways at baseline.

Specifically, it was hypothesized (Hypothesis 1a) that food responsiveness and satiety responsiveness would both be associated with reported levels of craving. According to BST, food responsiveness refers to an individual's susceptibility to food cues in the environment, so we predicted that food responsiveness would be positively associated with cravings—an individual who is more sensitive to food cues in the environment is likely to experience more frequent cravings. Although the link between satiety responsiveness and craving has not been explicitly studied in adults to date, BST posits that low satiety responsiveness is another vulnerability that would predispose individuals to be less able to make decisions to either start or stop eating based on internal satiety cues. With regard to cravings, as theorized by the Brewer model, one may predict that individuals lower on satiety responsiveness would be more likely to respond to experiences of cravings, thus reinforcing the cravings themselves over time. As such, we predicted that individuals lower on satiety responsiveness would report greater cravings.

Using a semi-naturalistic behavior measure, van Strien and colleagues demonstrated that individuals high on external eating ate more when exposed to food versus non-food environmental cues (van Strien, Peter Herman, & Anschutz, 2012). These data suggest that individuals high on external eating may be more susceptible or sensitive to food cues (i.e., high on food responsiveness) and less likely to be aware of or use satiety cues (i.e., low in satiety responsiveness). These findings are supported by evidence suggesting that individuals who report higher food responsiveness or lower satiety responsiveness are more likely to eat in the presence of highly-palatable foods, even after previously reaching a state of satiation (Carnell and Wardle, 2007). Less clear, however, are potential relationships between food responsiveness, satiety responsiveness, and emotional eating. Limited evidence suggests that emotional eaters may overeat in general, which would reflect a general tendency toward low satiety responsiveness, although further exploration is needed (Bongers & Jansen, 2016; Brewer et al., 2018). As the Brewer model posits, cravings are understood to be learned (i.e., conditioned) cues themselves which serve to prompt initiation of eating episodes (Brewer et al., 2018), and individuals who report greater experiences of craving are also likely to report more episodes of eating regardless of whether they were cued by external food cues, spontaneously generated food thoughts, or negative affect. As such, we predicted that food responsiveness, satiety responsiveness, and cravings would each contribute uniquely to self-reported external eating (Hypothesis 1b) and emotional eating (Hypothesis 1c).

Aim 2. Brewer and colleagues (2018) posit that experiences of cravings serve as important sources of motivation when an individual is making a decision to eat. However, to date, cravings have not received much focus as a treatment outcome within the mindful eating intervention literature. Based on limited data showing decreased experiences of cravings following mindfulness-based eating interventions (Alberts et al., 2010, 2012; A. E. Mason et al., 2018), we hypothesized that individuals in the intervention group would report greater reductions in cravings when compared to those in the waitlist control group (Hypothesis 2). The MEC-2 app provides guidance prior to initiating an eating episode (the "before you eat" tool in the app), suggesting the app could help individuals recognize urges to respond to cravings and choose more effective strategies (e.g., mindful acceptance of emotions, opposite action, alternative valued action).

Aim 3. Intervention studies in adults have yet to examine the potential moderating effects of appetitive traits on treatment outcomes. As discussed above, Boutelle and colleagues (2019) examined distinct "phenotypes" that predicted differential patterns of weight-loss maintenance following intervention in a sample of children. The authors found that children with the high satiety responsiveness phenotype at baseline remained most successful in terms of weight-loss maintenance through the 24-month follow-up, whereas children with the baseline high food responsiveness phenotype regained weight by follow-up (Boutelle et al., 2019). Although craving was not assessed and this was not a mindfulness-based intervention, these data provide support for the potential role of appetitive traits in elucidating for whom certain interventions may be most effective. As such, we hypothesized that baseline appetitive traits would moderate changes in craving due to the intervention. More specifically, we predicted that individuals lower on baseline food responsiveness would show greater changes in cravings (Hypothesis 3a), while individuals higher on baseline satiety responsiveness would also have greater changes in cravings (Hypothesis 3b).

Significance

The present study aimed to evaluate support for two contemporary models that attempt to explain the maintenance of eating-related difficulties. By examining variables central to each of these models in conjunction with one another, this study intended to bring together these two separate areas of the eating behavior literature. The Brewer model primarily addresses the cognitive processes at play in the initiation of non-homeostatic eating episodes and does not explicitly incorporate factors, such as satiety responsiveness as identified within BST, that may influence decisions to stop eating. Thus, examining relationships between appetitive traits as theorized by BST along with constructs central to the Brewer model (i.e., emotional and external eating), may provide a greater understanding of non-homeostatic eating behaviors. The study also aimed to provide further support for the use of mindful eating practices in interventions to reduce craving, a key link within the chain of non-homeostatic eating patterns. We also hoped to identify individuals for whom brief, mobile-based mindful eating interventions may be more or less effective in reducing cravings.

Method

Data analyzed in this study come from a larger, ongoing project utilizing the updated Mindful Eating Coach app. The current study analyzed data from the baseline and post-test assessments only. Relevant procedures for the present study follow.

Participants

Participants were 123 adults recruited through flyers circulated via community centers and collaborating Emory Healthcare offices, utilization of the ResearchMatch.org database (a national web-based recruitment tool maintained by Vanderbilt University), e-mail announcements sent out to Emory University faculty and staff, media announcements and internet postings (i.e., Facebook and Instagram), and word-of-mouth. An a-priori power analysis using the G*Power 3.1.9.7 software (Faul, Erdfelder, Lang, & Buchner, 2007) was used to determine a sufficient sample size to achieve 80% power and a medium effect size (Cohen's F = 0.25) for a mixed within-between subject design (specific to hypothesis 2). This analysis indicated a sample of 34 participants per group as sufficient, assuming a weak-to-moderate repeated measures correlation of $r = 0.50$. As attrition rates in similar mobile-based interventions have been shown to be around 25% (Brindal et al., 2013; A. E. Mason et al., 2018), the current study aimed to recruit approximately 60 participants per group.

Interested individuals were directed to complete a brief internet-based screening questionnaire (administered via a secure online platform such as Qualtrics or RedCap) in order to determine whether individuals met inclusion criteria. For inclusion in the study, participants were required to be English-speaking adults between the ages of 18 and 45 years (inclusive), have a qualifying iOS or Android mobile phone, indicate concerns about overeating, have a self-reported BMI of at least 22.00 and no more than 35.99 (i.e., upper-half of the normal range to moderately obese), and agree to random assignment. This inclusion criteria allowed for exclusion of lower-weight individuals who may engage in more severe forms of restricted eating, for which appetite awareness training may be contraindicated (National Collaborating Centre for Mental Health, 2004), and which are not adequately targeted by the app. In addition, individuals in the moderate-severe range of obesity who may engage in more severe forms of overeating and would likely require more intensive intervention than the app (B. L. Fisher & Schauer, 2002; Kushner, 2014) were excluded. Individuals in the upper-half of the normal BMI range were included as those individuals are at greater risk of becoming overweight or obese. Interested individuals were excluded from participating in the study if they indicated being currently pregnant or having given birth within the last 12 months, receiving a diagnosis of either Anorexia Nervosa or Bulimia Nervosa within the past 5 years, or current involvement in treatment for an eating disorder or another weight management program (e.g., Noom, Weight Watchers, etc.,). Following this screening, individuals eligible for the study were contacted via e-mail and phone and informed. Individuals ineligible for the study were notified via email and provided with referrals for alternative treatments and resources.

Procedure

The larger project was a repeated-measures, randomized control design with two groups (i.e., intervention and wait-list control) and was approved by the Emory University Institutional Review Board. The project was designed with a 3-week intervention period, similarly to studies conducted using the previous iterations of the MEC-2 app (Jones, 2012; Martinez, 2017; Marx, 2016). Prior to enrolling participants, a stratified, block randomization schedule was generated in order to ensure adequate balance in sample size across both study groups (Suresh, 2011). Given associations between gender and reported eating behavior (Brewer et al., 2018), and in order to ensure that men (who typically account for smaller proportions of samples volunteering for eating interventions; Dombrowski et al., 2014) were evenly randomized to each study group, randomization was stratified by gender (i.e., man or woman) and blocks of two with predetermined group assignments (each block contained one intervention and one waitlist predetermined random subject ID). When enrolling a participant, the research assistant would use either the man or woman randomization schedule based on the participant's reported gender to assign the next available study group and random subject ID. Individuals who identified as anything other than man or woman were randomly assigned to either schedule by a coin toss.

Baseline

Following completion of the screening questionnaire and established eligibility, a research assistant contacted interested participants over the phone to provide further information and complete the informed consent process. Participants were randomized to either study group per the previously described procedure at this time. During the phone call, participants were scheduled for a virtual one-on-one study visit conducted on a HIPAA compliant version of Zoom. Participants were also sent baseline questionnaires at this time and instructed to complete them prior to the virtual session. Questionnaires included self-report measures of appetitive traits, non-homeostatic eating behaviors, and craving. Participants also provided self-reported demographic information and previous experience with weight-management related treatment and apps. Individuals who did not complete these baseline measures prior to the scheduled virtual session were asked to reschedule for a later time. Participants who did not present at the scheduled time for their virtual study visit were contacted to reschedule no more than three additional times. If participants did not complete the study visit, they were not contacted for any further study participation.

Following completion of the baseline assessment, participants were notified of their group assignment (oftentimes at the beginning of the scheduled virtual study visit). For individuals in the control group, the virtual session lasted approximately 5-10 minutes and was administered by either a clinical psychology graduate student or trained research assistant.

Research assistants shadowed at least one wait-list session administered by a graduate student prior to facilitating on their own. This session included further information about participation in the larger project. For individuals in the intervention group, the virtual session lasted approximately 30 minutes and was facilitated by either a graduate student or a trained research assistant. Research assistants shadowed at least two intervention study visits conducted by a graduate student and were then shadowed by a graduate student at least once prior to facilitating intervention study visits on their own in order to ensure reliable administration of intervention materials.

During the virtual session for the intervention group, participants received information about study procedures and the rationale for appetite awareness training. A PowerPoint presentation was used in order to give participants uniform introductory information regarding mindful eating (i.e., principles and goals for mindful eating practice) and the MEC-2 app. Participants were instructed to have a small meal or snack available to use during the session. Participants were led through a guided practice which included didactics explaining use of the various functions of the app and an in-vivo mindful eating task utilizing the app. During this in-vivo task, participants were asked to rate their hunger prior to eating, and then were instructed to tune into their hunger and use the "before you eat" tool in the app. After being guided through this tool, participants were guided through an intentional mindful eating practice with their selected snack or meal. Participants were instructed to notice thoughts, feelings, and sensations when mindfully observing their food prior to taking a bite, and then were asked to notice sensations while eating. Participants were encouraged to remain mindfully aware of their internal hunger and fullness cues via strategies such as placing their hand on their stomach periodically to feel for stomach distension. Participants determined on their own when to finish eating, and were then guided through rating their hunger and fullness using the “after you eat” tool in the app. Finally, participants were instructed to use the app to self-monitor hunger and fullness cues before, during, and after each eating episode as often as possible for the immediate 3-week period following the virtual session. Participants were also encouraged to use any other functions of the app that they found personally useful.

Post-Intervention Assessment (Post-test)

Approximately three weeks after completion of baseline, participants in both groups were sent online self-report measures to complete. Individuals in the intervention group were also instructed to send data of their app usage to the research team at this time via email. Following the completion of the online measures, participants in the wait-list control group were emailed a PowerPoint with information about the intervention and instruction in the use of the app and were given the option to contact research staff for more information. After completing questionnaires, participants were compensated with an electronic gift card totaling up to $40. All participants were also reminded of the opportunity to complete a final follow-up assessment approximately three weeks after the completion of this timepoint.

Materials

Mindful Eating Coach (MEC-2) Application

The MEC-2 app (previous version known as EAT-C) was developed in conjunction with our research group in the Healthy Eating and Weight Support Lab, Emory University, by Big Data SME. The app is designed to be a tool to aid individuals in becoming aware of internal appetite cues and learning to eat mindfully. Recently, MEC-2 was redesigned and updated to reflect feedback from participants who had used the original app in previous studies (Martinez, 2017; Marx, 2016). Qualitative feedback indicated that users wanted additional coaching tools.

As such, the updated app is a more comprehensive self-guided intervention with additional and more extensive coaching tools as well as improved usability.

As in the first version of the app, MEC-2 coaches individuals to learn to eat mindfully by focusing on four main goals of mindful eating: 1) increase awareness of hunger and satiety cues while eating; 2) improve predictions of how they will feel after eating 3) reduce eating past the point of moderate fullness; 4) reduce frequency of unhelpful snacking (e.g., emotional eating, mindless snacking). These goals were reviewed during the intervention group's virtual session and are described on an introductory screen of the MEC-2 app.

Appetite Monitoring. Central to the principles of appetite awareness, the MEC-2 app places a primary emphasis on self-monitoring of hunger and fullness cues before, during, and after each eating episode.

Before Eating. The current version of the app added a new coaching tool to guide participants in making eating decisions before eating episodes. Using this tool, individuals are instructed to mindfully tune in to hunger (i.e., place hand on stomach and take 5 deep breaths) and consider reasons other than physiological hunger that may be prompting an eating urge (e.g., negative emotions, food availability, food craving, distraction, etc.). Guidance in the app encourages individuals to practice self-awareness and self-compassion, so as to avoid using restrictive techniques to avoid eating (which subsequently increase feelings of deprivation, leading to overeating or binging episodes).

Deciding to Eat. After completing the "before you eat" screen, participants are prompted to make a conscious decision about whether or not to eat. If individuals are feeling physiological hunger or decide to eat in order to prevent hunger or meet other non-hunger needs (e.g., to satisfy a strong craving), they are reminded to practice mindfulness during eating. If individuals choose not to eat, they are presented with options to practice evidence-based strategies to delay eating in response to food cravings, which include distraction and emotion regulation techniques (e.g., opposite action, self-soothe, mindful acceptance).

After Eating. Similar to the first version of the app, individuals are prompted to make an entry after any eating episode. This "After Eating" screen allows the individual to use three coaching tools in order to reflect on the eating episode, tune into their feelings after eating specific foods and amounts, and identify strategies that may lead to more mindful eating decisions in the future.

Hunger/Fullness Meter. As with the first version of the app, the updated version prompts individuals to use the 7-point Likert hunger rating scale used in AAT (ranging from 1 indicating "too hungry" to 7 indicating "too full") to rate their level of hunger and fullness after each eating episode (i.e., meal or snack). Participants are encouraged to begin eating in response to moderate hunger (i.e., a 2 to 3 on the scale) and stop eating in response to moderate fullness (i.e., a 5 to 6 on the scale). This screen shows the individual how well they followed the guidelines (i.e., stayed in the targeted "green" area of the scale on the app).

Mindful Reflection. After completing the hunger and fullness ratings, individuals are prompted to indicate how mindful they felt during the eating episode (i.e., ate slowly and tuned in, somewhat tuned in, or tuned out/could not stop). If the person ate past moderate fullness, they are encouraged to select from a number of options that may help them identify problematic patterns, such as waiting until they are too hungry before eating or ignoring cues to stop eating.

Worth-It Scale. Finally, individuals are prompted to reflect on the eating episode in a holistic manner (reflecting both type of food as well as amount eaten) by rating the degree to which the episode feels "worth-it" (defined in AAT as an eating episode that was both enjoyable in the moment, and the individual feels good about afterward). Individuals have the option of noting specific foods or amounts that they want to remember as being "mostly not worth-it," but consistent with the principles of mindful eating, the purpose of this scale is to encourage individuals to learn from their own personal experience with eating rather than engaging in self-criticism or guilt.

Reflect on the day. An additional, optional tool in the MEC-2 app encourages individuals to reflect on their entries at the end of the day. Using a model of gentle guidance, individuals are prompted to consider mindful eating intentions to focus on for the future and given space to type in personal reflections about patterns they notice.

Lessons. The updated version includes brief lessons consisting of didactic content to further guide individuals to understand principles behind mindful eating. These lessons are available in a separate screen and are optional for users. Study participants were encouraged to read through these modules as they practiced with the app, but were not required to do so in order to maintain the self-guided premise of the intervention and better reflect the way that individuals may choose to use supplemental information provided in an app. Lessons in the updated app of particular relevance to the present study include:

Stomach or tricky hunger. This screen provides psychoeducation about distinguishing between stomach hunger (i.e., physiological hunger) and tricky hunger (i.e., urges to eat unrelated to physiological hunger such as cravings).

Tricky hunger and tension. This screen discusses physical sensations in the stomach that may be unrelated to physiological hunger, but rather symptoms of anxiety. This lesson also provides guidance regarding strategies to reduce this stomach tension.

Two-hour guide. This guide helps individuals learn to use "time since eating" in order to better understand differences between physiological and psychological hunger cues. Specifically, individuals are prompted to notice that if they have eaten a sufficient amount of food during a recent (i.e., within two hours) meal or snack, they are likely experiencing tricky hunger, rather than stomach hunger. If more than two hours have passed, it is more likely that eating urges may be in response to stomach hunger.

Review Data. As in the first version, the updated app allows individuals to track their progress on a separate screen with the aid of several graphs. These graphs utilize data from individuals' entries and allow for simple visualization of five goals: 1) improving mindfulness during eating; 2) improving worth-it ratings after eating; 3) decreasing frequency of eating past moderate fullness; 4) increasing awareness of reasons behind mindless eating; 5) learning types of hunger that prompt eating.

Measures

Screening Questionnaire. Participants provided ratings on a 5-point Likert scale ranging from *not at all concerned* (1) to *very concerned* (5) on a 2-item questionnaire assessing level of concern managing overeating and perceived ability to manage eating in response to reasons other than physiological hunger (e.g., negative emotions, availability, etc.). This screening questionnaire was modeled on similar measures used within our research group (Martinez, 2017; Marx, 2016). To be eligible for the study, participants needed to report at least *moderate concern* (3) on at least one of the two items.

Demographics. Participants provided self-reported age, gender, race, ethnicity, weight, and height at baseline. A measure of BMI (weight adjusted for height, kg/m^2) was calculated using these self-reported values. Given the short-term nature of the present study, clinically meaningful changes in weight were not expected. As such, BMI was only assessed at baseline. Participants also provided information regarding level of education and current household income as a measure of socioeconomic status.

Food Security. A measure of food security was included in order to account for potential changes in food accessibility due to the COVID-19 pandemic. Participants completed the 8-item food security measure from the 2020 Household Pulse Survey developed by the US Census Bureau (Fields et al., 2020). This measure assessed for changes and barriers in access to food due to the COVID-19 pandemic.

Appetitive Traits. Food responsiveness (FR) and satiety responsiveness (SR) were measured using the Adult Eating Behavior Questionnaire (AEBQ; Hunot et al., 2016), a 35-item self-report measure. For the purpose of this study, only the Food Responsiveness (4 items; e.g., "I often feel hungry when I am with someone who is eating,") and Satiety Responsiveness (4 items; e.g., "I often leave food on my plate at the end of a meal,") subscales were used. Individuals responded to items using a 5-point Likert scale from *strongly disagree* (1) to *strongly agree* (5). Scores were calculated by taking the mean within each subscale. Higher values on FR indicated greater reactivity to food cues, while higher values on SR indicated better control and responsiveness to internal satiety cues. Regarding the measure's external validity, studies have demonstrated that these two scales tend to be negatively associated with each other and show differential associations with BMI, such that FR is positively associated and SR is negatively associated (Ellis, Zickgraf, Galloway, Essayli, & Whited, 2018; Hunot et al., 2016; Mallan et al., 2017). Both subscales have also demonstrated adequate internal consistency (Cronbach's α's > 0.70) and test-retest reliability in multiple large samples (ICC's > 0.70; He, Sun, Zickgraf, Ellis, & Fan, 2019; Hunot-Alexander et al., 2019; Hunot et al., 2016; Mallan et al., 2017).

Participants completed the subscales twice at baseline, using two different sets of instructions. The instructions for the previously validated version read: “Please read each statement and select the answer most appropriate to you in general.” However, given the theoretical framework conceptualizing these appetitive traits as longstanding, partly inherited individual differences, a second administration of the measure was included to assess whether individuals would respond significantly differently when more specifically prompted to consider their lifetime rather than the usual “in general” instructions. To prompt individuals to rate more in terms of long-term “traits” rather than more relatively recent responses, these instructions stated: “Please select the answer most appropriate to you over your lifetime, or for as long as you can remember.” However, values on the FR and SR subscales between administrations were significantly highly correlated (*r's* > 0.88, $p < .001$), suggesting there were not meaningful differences between instructions. As such, only the version utilizing the previously validated instructions was used for data analyses.

Adequate internal consistency was achieved for both the FR (Cronbach’s $\alpha = 0.67$) and SR ($\alpha = 0.68$) subscales, although these values were slightly lower than what has been achieved in validation studies. Cronbach’s α for the scale if item deleted, interitem correlations, and item to scale correlations were assessed in order to further examine the internal consistency (see supplemental materials, tables 7 and 8). For FR, all of the scale items seemed to meaningfully contribute to the internal consistency of the scale (i.e., the Cronbach’s α if item deleted were all below the total scale Cronbach’s α), so dropping any items would have decreased the scale reliability. Of note, all but one interitem correlation was statistically significant; items “I am always thinking about food” and “I often feel hungry when I am with someone who is eating” were non-significantly correlated at $r = 0.17$. All items were significantly correlated with the scale at $p < 0.001$, however. For SR, similarly all of the scale items seemed to meaningfully contribute to the internal consistency of the scale, as dropping any items would have decreased the reliability (i.e., i.e., the Cronbach's α if item deleted were all below the total scale Cronbach's α). All interitem correlations were statistically significant at $p < 0.05$, and all items were significantly correlated with the scale at $p < 0.001$.

Non-homeostatic Eating Behaviors. External eating and emotional eating behaviors were assessed using two subscales from the widely-used Dutch Eating Behavior Questionnaire (DEBQ; Strien, Frijters, Bergers, & Defares, 1986), a 33-item measure assessing external, emotional, and restrained eating. The external eating subscale (10 items) includes questions such as "If you see others eating, do you also have the desire to eat," and "If food smells and looks good, do you eat more than usual?" The emotional eating (13 items) includes items such as "Do you have a desire to eat when you are feeling lonely," and "Do you have a desire to eat when you have nothing to do?" Individuals answered questions on a 5-point Likert scale ranging from *never* (1) to *very often* (5), and items within each subscale were totaled (range for external eating = 10 – 50 and range for emotional eating = 13 – 65). Higher scores on each subscale indicated greater presence of that eating behavior in the individual. The DEBQ has demonstrated adequate internal consistency and test-retest reliability in both clinical and non-clinical samples (Cronbach's α's > 0.80, *r's* = .73 - .82; Malesza & Kaczmarek, 2019; T. B. Mason et al., 2017; van Strien et al., 1986). The measure has also demonstrated sensitivity to changes in eating behaviors in obese individuals after bariatric surgery or behavioral weight-loss treatment (Pepino, Stein, Eagon, & Klein, 2014). However, laboratory-based experiments have thus far demonstrated mixed evidence regarding the external validity of the subscales (Domoff, Meers, Koball, & Musher-Eizenman, 2014). Nonetheless, a recent study examining the DEBQ's ecological validity using EMA demonstrated associations between the emotional eating subscale and greater negative affect before eating, as well as between the external eating subscale and greater pre-eating expectations about enjoyment of food (T. B. Mason et al., 2017). In the present sample, good internal consistency was achieved for the external eating subscale ($\alpha = 0.80$) and excellent internal consistency was achieved for the emotional eating subscale ($\alpha = 0.94$).

Craving. Experiences of cravings were measured using the Trait Craving-Reduced questionnaire (FCQ-T-R; Meule, Hermann, & Kubler, 2014), a 15-item self-report measure. The FCQ-T-R assesses cognitive components of craving including preoccupation with food, difficulty regulating behavior when exposed to food cues, intentions to eat, and the tendency to have cravings while experiencing strong negative emotions (Meule, Hermann, et al., 2014). Scores on this measure have been shown to be positively associated with BMI and weight gain over a period of six months, as well as negatively associated with self-perceived dieting success (Meule, Hermann, et al., 2014; Meule et al., 2017). Respondents were asked to indicate answers on a 6-point Likert scale from *never* (1) to *always* (6) on items such as, "If I am craving something, thoughts of eating it consume me," or "Whenever I have cravings, I find myself making plans to eat." At both baseline and post-test, participants were asked to indicate answers typical of their experiences "in the past week." This provided a specific timeframe for which to indicate responses. All items were summed to create a total score (range 15-90) with higher scores indicating higher levels of experiences of cravings. A recent review summarized the measure's psychometric properties based on its use over the past 20 years. The FCQ-T-R has demonstrated high internal reliability and internal consistency (Cronbach's α's > 0.90; Meule, 2020; Meule et al., 2014), and has demonstrated sensitivity to change during mindful eating interventions (A. E. Mason et al., 2018; Schnepper, Richard, Wilhelm, & Blechert, 2019).

Construct validity has been demonstrated by studies examining reactivity to food cues in the laboratory setting (i.e., higher FCQ-T-R scores predicted stronger increases in state food craving when exposed to pictures of palatable foods; Meule et al., 2014), and discriminant validity has been established such that scores on the FCQ-T-R have been shown to be unrelated to measures of hunger, food deprivation, and satiety within lab-based eating manipulations (Meule, 2020; Meule, Teran, et al., 2014). In the present sample, excellent internal consistency was achieved for the FCQ-T-R at baseline ($\alpha = 0.93$) and at post-test ($\alpha = 0.94$).

Intervention Engagement. Participants were asked to send app data to the research team after completing three weeks of app use (intervention group only at post-test). Data included all entries made by participants when utilizing the before you eat, after you eat, and reflect on your day tools. The before you eat tool is of primary interest for the present study aims, as participants are guided through tuning into hunger and deciding whether or not to eat in the moment. Participants experiencing cravings are instructed to use strategies to delay eating. As such, intervention engagement was quantified as the number of times the "before you eat" tool was used per day of participant app use (i.e., average "before you eat" entries per day).

Data Analyses

Data analyses were conducted using IBM SPSS Statistics for Macintosh Version 27 (IBM Corporation, 2017). Descriptive analyses were performed to determine sample characteristics (see Table 1). Patterns of missingness were analyzed and multiple imputation procedures were used. Using tolerance statistics and univariate procedures, data were then evaluated for normality and multicollinearity, and transformations were applied as needed. For aim one, bivariate correlations and hierarchical linear regressions were conducted in order to examine baseline associations between appetitive traits, cravings, and non-homeostatic eating behaviors. To examine the second aim, a mixed-design repeated measures ANCOVA was conducted with time (baseline, post-test) entered as the within-subject factor, group (intervention or waitlist) and total craving score entered as the repeated measure. For aim three, the PROCESS macro for SPSS was used to evaluate the two proposed moderation models (Hayes, 2013). Hypothesis 3a would be supported by finding that the interaction between group and food responsiveness was statistically significant. If significant interaction effects between the study moderator (i.e., food responsiveness) and the predictor (i.e., group) were detected, the sample was stratified by selecting participants one standard deviation above and one standard deviation below the mean level of food responsiveness. To interpret the pattern of the interaction effects, the main effects of group on change in craving were then estimated within the subsamples. Hypothesis 3b would be supported by finding that the interaction between group and satiety responsiveness was statistically significant. If significant interaction effects between the study moderator (i.e., satiety responsiveness) and the predictor (i.e., group) were detected, the sample was stratified by selecting participants one standard deviation above and one standard deviation below the mean level of satiety responsiveness. To interpret the pattern of the interaction effects, the main effects of group on change in craving would then be estimated within the subsamples.

Results

Preliminary Analyses

As shown in the flow chart of study enrollment (Figure 1), of the 123 individuals enrolled and randomized into the study, two individuals did not begin baseline questionnaires or complete the virtual study visit (i.e., no data was collected on these individuals following completion of the informed consent process). One individual (who had been assigned to waitlist) was withdrawn from the study during the initial visit by the principal investigators due to the participant's significant reported distress and concerns about potential night-eating syndrome. Another individual (who had been assigned to the waitlist group) endorsed purging behaviors within the past 5 years at baseline (this person had not endorsed these behaviors during screening, which would have resulted in study exclusion). All four of these individuals were excluded from analyses, yielding a total sample size for the present study of 119.

Demographics. Of the 119 participants, 60 individuals were randomly assigned to the intervention group, while 59 were assigned to the waitlist control group. Sample demographics are presented in Table 1. At baseline, the mean age of the 119 participants was 31.89 years (SD = 6.49, range 18 – 45). The mean self-reported BMI of the sample was 27.60 kg/m^2 (SD = 3.86, range 21.58 – 38.44), which is in the overweight range. Although three participants reported BMIs under the study inclusion criteria of 22.00, and one reported a BMI over 35.99, these individuals were not statistical outliers or influential cases and were thus included in analyses. Of the study sample, 76.4% identified as women, 19.3% as men, and 4.2% as either non-binary or transgender. A majority of participants identified as White/Caucasian (63.9%), while 14.3% identified as Black or African American, 13.4% identified as Asian, and 8.4% identified as multiracial or other. Approximately 10.1% of the sample identified as Hispanic/Latinx. When compared to national demographics (i.e., 76.3% White/Caucasian, 13.4% Black or African American, 5.9% Asian, 4.4% other, 18.5% Hispanic/Latinx based on data from the US Census Bureau; 2019), the current sample included a higher proportion of Asian individuals and lower proportion of Hispanic/Latinx individuals. Nonetheless, the present study obtained a relatively representative community sample. With regard to SES, the present sample was generally highly educated, with over 80% of the sample reporting having completed a Bachelor's degree or more. Within the present sample, very few individuals indicated any food insecurity. Approximately

3.4% indicated sometimes or often not having enough to eat within the previous 7 days (n = 4). However, 19.3% (n = 23) indicating feeling moderately confident or less that they would be able to afford the kinds of food needed for the next four weeks. Independent samples *t*-tests and chi-squared tests indicated no significant differences between groups for most of the demographic characteristics or baseline measures, with one exception. Individuals who identified as Black or African American were more likely to be assigned to the waitlist control group during the randomization process (χ^2=4.68; $p = 0.03$).

Following randomization and completion of baseline measures, an additional nine individuals did not attend the virtual study visit despite multiple attempts to reschedule (n = 6 assigned to the intervention, n = 3 assigned to waitlist). Independent samples *t*-tests and chi-squared tests indicated no significant differences between individuals who did or did not complete the study visit for most of the demographic characteristics and baseline measures, with the notable exception of reported SES. Analyses indicated that individuals who did not complete the study visit were more likely to have completed less education (i.e., Associate's degree or less; $\chi^2 = 16.68$, $p < .001$) and have a lower total household income ($t = -2.19$, $p = 0.03$) than those who did complete the study visit. These differences likely reflected real-life challenges that individuals of lower SES face with regard to daily hassles and stressors which may have prevented engagement in the study. However, there were no significant differences between study visit completers and non-completers on baseline variables of interest (i.e., appetitive traits, eating behaviors, cravings), and self-reported SES was not significantly associated with any of these variables (all *p's* > 0.14). As such, in order to maintain statistical power for analyses, both study visit completers and non-completers were included in further analyses (N = 119).

Missing Data. Criterion for imputation was set such that if a participant had missed more than 50% of the current study's measures, values for that individual were not imputed. At baseline, a small percentage (0.67%) of self-report data was missing. Little's MCAR test was used to determine that data were missing completely at random at baseline ($p = 0.67$). The Expectation-Maximization (EM) algorithm was used to impute the missing self-report items. At post-test, the nine individuals who did not complete the study visit were excluded, as these individuals had greater than 50% of missing data for the study. Out of the remaining 110 individuals, 6.78% of the self-report data for the outcome measure (i.e., items on the FCQ-T-R) was missing. Little's MCAR test indicated that these data were missing completely at random at post-test as well ($p = 0.23$). As such, the EM algorithm was used to impute the missing self-report items. Sensitivity analyses were conducted in order to determine whether there were any significant differences found between the imputed data set and that of the original data set. No differences for any of the results described were found, indicating that imputation did not skew the results of the current study.

Variable Transformation. Using tolerance statistics and univariate procedures, data were evaluated for normality and multicollinearity, and transformations were applied as needed. Satiety responsiveness at baseline demonstrated significant positive skew (skewness = 0.61, standard error = 0.22, kurtosis = .38; Shapiro-Wilks test significant at $p = .002$). A square root transformation was employed to ensure a normal distribution (skewness = 0.14, kurtosis = 0.07; Shapiro-Wilks test no longer significant at $p = 0.06$). The Shapiro-Wilks test for normality indicated that all other covariates and variables of interest at baseline and post-test were normally distributed.

Descriptive statistics of dependent variables. No group differences between intervention and waitlist were observed on any of the dependent variables of interest (i.e., food responsiveness, satiety responsiveness, craving, external and emotional eating) at baseline. Descriptive statistics of these variables are presented in Table 2. When compared to reported means from larger validation studies (N's > 708 in each; sample of adults in the UK across the weight spectrum; Hunot et al., 2016) the present sample reported slightly higher food responsiveness (M = 3.25 in the present sample, compared to M = 2.98 in the validation study) and comparable satiety responsiveness (M = 2.36 in the present sample, compared to M = 2.61 in the validation study). With regard to external eating, the present sample mean fell in the moderate range (M = 35.67). The lowest reported external eating score (i.e., 21) was well above the potential low score based on the measure scoring (potential range = 10 – 50), indicating that in general, participants reported engaging in at least some external eating, as would be expected of individuals enrolling in a mindful eating intervention. In addition, the sample mean on emotional eating fell in the moderate range as well (M = 38.38), although the range of scores indicated that a wider range of engagement in emotional eating was reported by participants (potential range based on measure scoring = 13 – 65; sample reported range = 14 – 64). The sample mean for craving at baseline feel in the moderate range (M = 48.48, range = 21 – 80), and was significantly lower than that of the sample in the 2018 Mason and colleagues mindful-eating intervention (M = 61.78 pre-intervention; A. E. Mason et al., 2018).

Correlations between dependent variables. Pearson correlations coefficients for relationships between appetitive traits, craving, and non-homeostatic eating behaviors are summarized in Table 3. Consistent with what would be expected within the Brewer model, bivariate correlations indicated that baseline craving was significantly positively associated with both external ($r = 0.59$) and emotional eating ($r = 0.61$). External and emotional eating were also significantly associated with each other at baseline ($r = 0.43$). Significant positive correlations were observed between food responsiveness, craving, emotional and external eating (all *r's* > 0.41) indicating moderate to strong associations. Notably, satiety responsiveness was not associated with food responsiveness ($r = -0.03$), was only moderately negatively correlated with external eating ($r = -0.29$, $p < 0.01$), and was not associated with any other measure (all *p's* > 0.05). Baseline craving was strongly correlated with post-test craving ($r = 0.72$, $p < 0.01$ total sample; intervention group $r = 0.70$, $p < 0.01$; waitlist group $r = 0.75$, $p < 0.01$).

Aim 1: Baseline Associations

In order to assess relative baseline associations between appetitive traits, craving, and non-homeostatic eating behaviors, three separate hierarchical linear regression models were performed. For each model, assumptions of regression analyses were tested. Tolerance and Variance Inflation Factor (VIF) were examined and determined to be within acceptable limits for all three models (i.e., tolerance > 0.2, VIF <10 and average VIF around 1.0; Field, 2009), so no evidence of significant multicollinearity was found. Residuals were examined and determined to be homoscedastic across all three models as well, and no outliers or influential cases were identified. Participant gender and BMI were entered as covariates in the first block of each model based on prior literature demonstrating significant associations between these characteristics and non-homeostatic eating behaviors (Brewer et al., 2018; Gibson, 2012; Koenders & Van Strien, 2011). These covariates were retained in the model even if found not to be significantly associated with the dependent variable per recent guidelines for regression models, as using data-driven rather than theory-driven decisions can reduce replicability and generalizability (Rohlfs, 2018). Variables of interest were then entered into the models in order of importance in predicting the dependent variable based on theoretical hypotheses (i.e., "known" predictors first, with newly hypothesized predictors following; Field, 2009). Adjusted R^2 is reported in order to describe the total model fit adjusted for the number of predictors entered into the model. To examine contributions of predictors in explaining variance in the dependent variables at each step, the change in R^2 (ΔR^2) for each block was also obtained. Cohens f^2, a measure of effect size widely used in multiple regression analyses, was calculated for the total model as well as for each significant block; conventional benchmarks for f^2 are 0.02, 0.15, and 0.35 for small, medium, and large effects respectively (Field, 2009). An adjusted p-value (using a Bonferroni correction due to the three models being tested) was used to determine statistical significance. Results for the regression analyses were considered statistically significant at the $p < 0.017$ level. Results of the regression analyses can be found in Tables 4-6.

Hypothesis 1a. A hierarchical linear regression was conducted to examine whether the BST variables (food responsiveness and satiety responsiveness) each explained variance in craving at baseline. Covariates were entered into the model in the first step, while food responsiveness and satiety responsiveness were entered together into the model in the second step. In the first block, neither gender nor BMI predicted craving (p's > 0.58). As predicted, results of the analyses indicated that food responsiveness was significantly positively associated with craving (β = 0.71, SE = 1.28, $p < 0.001$). However, contrary to the hypothesis, satiety responsiveness was not associated with craving ($p = 0.83$). The total regression model accounted for 47% of the variance in craving indicating a large effect ($f^2 = 0.89$, $p < 0.001$).

Hypothesis 1b. A second hierarchical linear regression was conducted in order to examine whether food responsiveness, satiety responsiveness, and craving were each associated with external eating at baseline. As with the previous model, covariates were entered into the model in the first step. Given the theoretical link between cravings and external eating as posited by Brewer and colleagues (2018), craving was then entered into the second step of the model. Finally, food responsiveness and satiety responsiveness were entered together into the model in the third step in order to examine whether the BST-proposed appetitive traits would further contribute to our understanding of cravings. The covariates did not contribute significantly to external eating (all *p*'s > 0.35). As predicted, all three variables of interest were associated with external eating. Craving was positively associated with external eating (β = 0.34, SE = 0.04, $p < 0.001$) and explained an additional 34.2% of the variance (above and beyond the covariates) indicating a large effect ($f^2 = 0.51$). Food responsiveness was positively associated (β = 0.36, SE = 0.75, $p < 0.001$), and satiety responsiveness was negatively associated (β = -0.28, SE = 1.58, $p < 0.001$) with external eating. Together, the two BST variables explained an additional 14.4% of the variance in external eating at baseline indicating a medium effect ($f^2 = 0.17$). The total regression model accounted for 47% of the variance in external eating ($f^2 = 0.89$, $p < 0.001$).

Hypothesis 1c. The final hierarchical linear regression tested associations between food responsiveness, satiety responsiveness, craving, and emotional eating. As with the previous model, covariates were entered into the model in the first step, while craving was entered in the second step (given the proposed link between craving and emotional eating). Finally, food responsiveness and satiety responsiveness were entered together into the model in the third step. No covariates contributed significantly (all *p*'s > 0.91). As predicted, craving was positively associated with emotional eating (β = 0.61, SE = 0.07, $p < 0.001$; $\Delta R^2 = 0.37$; $f^2 = 0.59$) demonstrating a large effect. We had predicted that both food responsiveness and satiety responsiveness would be associated with emotional eating. However, when entered into the model in the third step, neither food responsiveness ($p = 0.78$) nor satiety responsiveness ($p =$

0.09) demonstrated significant associations with emotional eating. The total regression model accounted for 35% of the variance in emotional eating ($f^2 = 0.54$, $p < 0.001$).

Aim 2: Intervention Effects on Craving

To assess the effectiveness of the intervention in reducing craving (Hypothesis 2), a mixed-design repeated-measures analysis of covariance (ANCOVA) was conducted with time (baseline, post-test) as the within-subjects factor and group (intervention, waitlist) as the between-subjects factor. Given established associations between weight and cravings (Boswell & Kober, 2016b), participant BMI was entered as a covariate. The assumption of sphericity was met, and Levene's test of equality of variances was non-significant for craving at baseline and post-test (*p's* > 0.17). A significant time by group interaction would indicate that changes in craving differed by study group. Partial η^2 is the effect size reported for the mixed-design ANCOVAs; conventional benchmarks for partial η^2 are 0.01 for a small effect, 0.06 for a medium effect, and 0.14 for a large effect (Field, 2009).

Results of the mixed-design repeated measures ANCOVA (n = 110) revealed no significant main effect of time after controlling for participant BMI on changes in craving ($p = 0.07$). There was no main effect of group on changes in craving ($p = 0.38$) after accounting for participant BMI, and no significant time-by-group interaction ($p = 0.91$) indicating no differences by group in changes in craving. As such, hypothesis two was not supported. Post-hoc power calculations using G*Power 3.1.9.7 software (Faul et al., 2007) indicated that achieved power for this analysis was approximately 54%.

Intervention Engagement. Descriptive analyses were conducted in order to assess intervention engagement at post-test within individuals assigned to the intervention group. Of the 54 individuals in the intervention group included in post-test analyses, 38 individuals sent in their app data (70.4%). Bivariate analyses indicated no differences between individuals who did or did not send in app data on sample characteristics (i.e., age, gender, race, BMI, SES, food security) or variables of interest (i.e., food responsiveness, satiety responsiveness, baseline or post-test craving, external eating, emotional eating). Within this group, individuals used the app (i.e., any function) on average approximately 51.3% of the total possible days (M = 11.29 days of use out of a total 22 possible days, SD = 8.15, range = 0 – 22 days). On average, individuals used the “before you eat” coaching tool approximately 14.4 times (SD = 18.22, range = 0 – 69), with 32 individuals indicating use of the tool once a day or less on average, and only 6 individuals reporting use of the tool more than once per day on average.

Aim 3: Moderation Analyses

To examine whether food responsiveness and satiety responsiveness moderated changes in craving due to the intervention, the PROCESS macro for SPSS was used (Hayes, 2013). Specifically, two separate moderation models were run for each proposed moderator (n = 110; Model 1 in PROCESS; Hayes, 2013) with participant BMI entered as a covariate. In order to account for baseline levels of craving, baseline craving was also entered as a covariate. For each model, assumptions of regression analyses (as described within Aim 1 analyses) were tested and met.

Results of the first regression analysis indicated no significant interaction between food responsiveness and intervention group in predicting change in craving ($\Delta R^2 = 0.01$; $F[1,104] = 1.36$, $p = 0.25$). This non-significant interaction (i.e., using one standard deviation above and below the mean) is depicted in Figure 2. The total regression model accounted for 54.05% of the variance in post-test craving ($f^2 = 1.17$, $p < 0.001$), and achieved power for the moderation analysis was approximately 22%.

Results of the second regression analysis similarly indicated no significant interaction between satiety responsiveness and intervention group in predicting change in craving ($\Delta R^2 = 0.001$; F[1,104] = 0.30, $p = 0.58$). This non-significant interaction is shown in Figure 3. The total regression model accounted for 54.45% of the variance in changes in craving ($f^2 = 1.17$, $p < 0.001$), and achieved power for the moderation analysis was approximately 7%. Altogether, neither moderation hypothesis was supported, indicating that in the present sample baseline food responsiveness and satiety responsiveness did not moderate changes in craving due to the intervention.

Discussion

The primary purpose of the present study was to examine cross-sectional associations between appetitive traits, cravings, and non-homeostatic eating in a guidance-seeking community sample of adults in order to further elucidate theoretical links proposed by Brewer and colleagues (Brewer et al., 2018) and Wardle and colleagues (Llewellyn & Wardle, 2015). The present study also assessed changes in craving in response to a mindfulness-based intervention, and potential moderators of change. Participants were adults reporting difficulty managing overeating who volunteered to participate in a 3-week randomized control trial utilizing the updated version of the Mindful Eating Coach app.

Results from the present study illuminated interesting relationships between appetitive traits, cravings, and non-homeostatic eating behaviors at baseline—although not all predictions were supported. In addition, the 3-week mindful eating intervention did not result in statistically significant reductions in experiences of craving. Results indicated that neither baseline food responsiveness nor satiety responsiveness moderated changes in craving.

Intercorrelations Between Measures

Several observations about baseline correlations between appetitive traits, cravings, and non-homeostatic eating behaviors are worth discussing. The Brewer model posits that cravings (i.e., intense desires to eat a specific food) link external and internal cues to non-homeostatic eating (i.e., external eating and emotional eating) through positive and negative reinforcement pathways. Repeated non-homeostatic eating then contributes to the maintenance of cravings themselves, thereby creating a highly reinforced habit loop that is resistant to intervention via traditional behavioral weight-loss methods. As it is posited to be a cycle, the Brewer model assumes a bi-directional relationship between craving and non-homeostatic eating behaviors (i.e., craving prompts non-homeostatic eating, while non-homeostatic eating reinforces cravings). In the current study, strong correlations between reported craving, external eating and emotional eating were observed. However, the current results do not address the bidirectionality assumed by the theoretical model, and this remains to be examined. Nonetheless, the current findings do provide initial support for the Brewer model as associations between craving and both types of non-homeostatic eating were demonstrated. Additionally, a strong positive association was found between external eating and emotional eating, indicating that individuals in the present sample likely reported similar frequencies of both types of non-homeostatic eating in general, as would be expected for individuals seeking intervention for overeating.

Interestingly, in this sample, food responsiveness and satiety responsiveness were not significantly negatively correlated, contradicting findings reported in other studies. According to BST, food responsiveness and satiety responsiveness are posited to be vulnerability factors that may predispose individuals to developing obesity (Llewellyn & Fildes, 2017). Numerous large non-clinical and clinical samples in both children and adults have demonstrated consistent but modest negative associations between food responsiveness and satiety responsiveness (Hunot-

Alexander et al., 2019; Hunot et al., 2016; Mallan et al., 2017; Zickgraf & Rigby, 2019). For example, in a large study of adults in the UK, Hunot and colleagues found a significant negative association (r = -0.23), which was replicated in another large study of adults in Australia (r = -0.26; Hunot et al., 2016; Mallan et al., 2017). In addition, a sample of bariatric surgery-seeking adults (N = 337) in the US demonstrated a moderate negative association (r = -0.31) between food responsiveness and satiety responsiveness at baseline (Zickgraf & Rigby, 2019). These findings have led some researchers to propose that these traits may exist on the same continuum (Boutelle, Manzano, & Eichen, 2020). However, no significant correlation (r = -0.03) between the two traits was observed within the present sample, suggesting that they may be representing distinct vulnerability factors. Further work needs to be done to examine associations between appetitive traits in adults. In addition, the internal consistency for both scales was slightly lower (Cronbach's α's = 0.67 and 0.68 for food responsiveness and satiety responsiveness, respectively) than previous validation studies (Cronbach's α's > 0.70). The addition of more items for each subscale could improve reliability estimates, as each subscale consists of only four items, and factor analysis would be useful to confirm the unidimensional nature of the scales (Tavakol & Dennick, 2011).

In addition, of particular interest was the observed strong positive relationship (r = 0.60) between food responsiveness and external eating. Given the very high correlation, these measures may be tapping into the same construct, even though the former is conceptualized as assessing a general vulnerability to eat in response to food cues, and the latter is described as assessing the frequency of eating in response to food cues. Of note, the food responsiveness subscale of the AEBQ contains only four items. Two items reflect a general tendency to think frequently about food (i.e., "I am always thinking about food," and "Given the choice, I would eat most of the time"), which might be conceptualized as preoccupation with thoughts of food. The other two items reflect frequency of urges to eat in response to external food cues ("I often feel hungry when I am with someone who is eating," and "When I see or smell food that I like, it makes me want to eat"). In comparison, all 10 items on the external eating subscale of the DEBQ assess responding to the actual presence of food (e.g., "If food smells and looks good, do you eat more than usual?" and "If you walk past a snack bar or café, do you have the desire to buy something delicious?") and ask the individual whether they eat more (or desire to eat more) in that specific situation. Thus, the food responsiveness subscale taps into a broader notion (i.e., tendency to respond both to the presence of food cues but also to un-cued, spontaneously generated food thoughts). According to BST, one would expect these two measures to be strongly correlated, as high food responsiveness is hypothesized to predispose an individual to engage in more frequent actual eating in response to food cues. However, given that the measure of external eating used in this study was a self-report of typical behavioral tendencies to respond to food cues and not a specific assessment of actual external eating episodes, it may be that true distinctions between the constructs of food responsiveness (i.e., a trait vulnerability factor) and external eating (i.e., a potentially observable behavior) were not clearly identified. Further examination of the overlap between these two self-report measures, possibly with factor analysis, is warranted. In addition, efforts to assess actual episodes of external eating (such as in a lab-based eating task) or through reporting specific episodes of eating cued by the presence of food (using EMA methods), could help clarify distinctions between these constructs.

Cross-sectional Relationships

BST posits that high food responsiveness and low satiety responsiveness both represent vulnerabilities which influence decisions to initiate and stop eating, and thus are associated with non-homeostatic eating behaviors and weight gain over time (Llewellyn & Fildes, 2017). The habit loop model (Brewer et al., 2018) on the other hand, describes non-homeostatic eating behaviors as developing purely within a learning framework, emphasizing the role of cravings (i.e., “action urges”) as the common pathway prompting non-homeostatic eating (i.e., external and emotional eating). The present study evaluated whether including food responsiveness and satiety responsiveness into the learning-based Brewer model would further explain non-homeostatic eating. Overall, the results of our analyses provided insights into the ways in which the two theoretical models may be linked.

Three hierarchical linear regressions were conducted to examine support for the Brewer model and BST at baseline. Our results indicated that food responsiveness, but not satiety responsiveness, was significantly associated with craving at baseline, lending partial support for our first hypothesis. Also as predicted, food responsiveness, satiety responsiveness, and craving all contributed variance to reported external eating at baseline, as predicted, and altogether accounted for 47% of the variance in external eating. Craving was likewise positively associated with emotional eating, but contrary to our prediction neither food responsiveness nor satiety responsiveness was associated with emotional eating. The full model (including all three variables) accounted for 35% of the variance in emotional eating at baseline.

We first hypothesized that the appetitive traits identified by BST (food responsiveness and satiety responsiveness) would both be associated with cravings (the common pathway in Brewer’s model), although in opposite directions (positively and negatively, respectively). In partial support of this hypothesis, food responsiveness was significantly positively associated with cravings at baseline. This finding lends credence to the notion that individuals who report being more sensitive to food cues in the environment may also experience more frequent food cravings and urges to respond to them. However, contrary to our hypothesis, satiety responsiveness was not associated with cravings at baseline. Within a learning-based model such as the one proposed by Brewer and colleagues (2018), individuals low on satiety responsiveness might initially be more likely to eat in the absence of hunger or past fullness when following either the positive or negative pathways within the habit loop, as they are less able to use internal satiety cues as guides when engaged in the decision-making process. Over time, the model suggests that eating reinforces the experiences of cravings themselves, by pairing the craving with the reward of food. On the other hand, BST would suggest that individuals high on satiety responsiveness may be somewhat protected from developing the problematic cycle leading to more frequent cravings, as such individuals would not be as vulnerable to non-homeostatic eating (i.e., eating past fullness in particular). Our findings do not support this hypothesized link between satiety responsiveness and craving, however, suggesting that poor satiety responsiveness may not be directly linked to experiences of cravings. Further exploration of the potentially protective role of satiety responsiveness would be informative.

We also predicted that food responsiveness, satiety responsiveness, and cravings would each contribute to reported external eating. Although cravings are understood to be directly linked to external eating within the Brewer model, food responsiveness and satiety responsiveness are not considered in the model. Our results indicated that all three variables were significantly associated with external eating as hypothesized, and each contributed unique variance in the model. Craving accounted for the largest effect on external eating, lending support for the Brewer model. In addition, food responsiveness and satiety responsiveness together accounted for a medium effect on external eating. These findings support the literature suggesting that individuals who report greater frequency of engaging in external eating may be inherently more sensitive to food cues and also less able to use satiety cues to guide decision-making (Carnell & Wardle, 2007; van Strien et al., 2012). Of course, given the strong correlation between the food responsiveness and external eating measures (and the measurement concerns as discussed previously), this result was not surprising. However, multicollinearity was not observed to be a problem within this analysis, and food responsiveness (in combination with satiety responsiveness) accounted for only 14.4% of the total variance of external eating. Although this is a medium effect, the results suggest that the two constructs as measured may not completely overlap. This would suggest that food responsiveness may be a distinct vulnerability factor rather than just a reflection of engagement in external eating, although further exploration of the overlap between these constructs is needed.

Finally, we examined whether food responsiveness, satiety responsiveness, and craving would each be associated with emotional eating (i.e., the negative pathway within the Brewer model). Limited evidence regarding associations between these three variables exists in the literature. Previous research has suggested that food responsiveness may not be associated with emotional eating, as individuals who report frequently engaging in emotional eating do not necessarily eat more when exposed to food versus non-food cues, but rather may experience a general tendency toward low satiety responsiveness (Bongers & Jansen, 2016; van Strien et al., 2012). However, given the limited nature of the prior data, we had predicted that food responsiveness, satiety responsiveness, and craving would all be associated with emotional eating. Contrary to our hypothesis, neither food responsiveness nor satiety responsiveness were associated with emotional eating at baseline. Rather, only craving was positively associated with emotional eating, with a large effect. BST conceptualizes food responsiveness as a general vulnerability that may predispose an individual toward eating in the absence of hunger regardless of whether that eating is within the Brewer conceptualized “positive” (i.e., external eating) or “negative” (i.e., emotional eating) pathway. As Brewer and colleagues posit, craving may act as a key mechanism between experiences of internal cues (i.e., emotions) and eating, and our results suggest that reported craving and emotional eating are strongly linked. However, this relationship was cross-sectional in nature. Further exploration using longitudinal data to probe craving as a mechanism maintaining emotional eating is warranted.

In understanding these divergent patterns for external and emotional eating, it is useful to note differences in the measurement of the two constructs. The items in the DEBQ subscale of external eating are asked both in terms of how often an individual eats in response to food cues, as well as in terms of how much an individual desires to eat in response to food cues. Thus, the current findings suggest that the BST theorized vulnerabilities (food responsiveness and satiety responsiveness), as well as the cognitive processes involved in craving, all contribute uniquely to external eating. In contrast, in the DEBQ subscale of emotional eating, all of the questions are asked in terms of how often the individual “desires” or wants to eat in response to emotions—they do not explicitly ask how often individuals actually eat in response to emotions. Thus, there is not as clear of a distinction between the measure of emotional eating (i.e., desires to eat in response to negative emotions) and the measure of craving (i.e., strong urges to eat for any reason). This might explain the strong link found between craving and emotional eating, as well as the lack of observed relationships with appetitive traits.

Altogether, results of the cross-sectional analyses of the data indicate interesting relationships between the Brewer model and BST. As discussed previously, the lack of association between food responsiveness and satiety responsiveness is notable, and the observed differences in relationships between those appetitive traits and reports of cravings and non-homeostatic eating behaviors may support the proposition that food responsiveness and satiety responsiveness represent distinct vulnerabilities, rather than one common factor. Our results suggest that both high food responsiveness and low satiety responsiveness may be associated with external eating, as would be predicted within both BST and the Brewer model. These findings highlight the importance of considering the role of established vulnerabilities (high food responsiveness and low satiety responsiveness) in understanding the experience of external eating, as this pattern of non-homeostatic eating is associated with weight-related concerns (Koenders & Van Strien, 2011). These findings also lend further support for the notion, as proposed by Brewer and colleagues, that individuals struggling with the positive pathway of the habit loop may benefit from mindfulness training to decrease the likelihood of acting on urges to eat cued by the environment (i.e., cravings). Per BST, and as suggested by our results, such individuals may also benefit both from a focus on managing one's environment (i.e., reducing availability of highly palatable foods to minimize the effect of high food responsiveness), and from appetite awareness training which is designed to encourage greater use of internal satiety cues (to mitigate effects of low satiety responsiveness). However, our finding that only cravings, and neither of the appetitive traits were associated with emotional eating was unexpected and warrants further investigation. Such investigation would benefit from more direct measurement of instances of emotional eating (via EMA, for example), in order to further elucidate relationships. Nonetheless, our current findings provide initial support for the notion posited by Brewer and colleagues, that cravings are implicated in the negative pathway of the habit loop (i.e., emotional eating), and may potentially be addressed directly via mindfulness strategies specifically targeting the reduction of cravings.

Intervention Effects on Craving

Given preliminary findings suggesting that mindfulness-based interventions may reduce experiences of cravings as well as craving-related eating (A. E. Mason et al., 2018), we predicted that individuals assigned to receive the MEC-2 intervention would report a significant reduction in cravings when compared to waitlist controls. Results of the present study did not support this hypothesis; no differences by group were observed in this sample, with neither group showing statistically significant changes in craving.

The observed lack of significant reductions in craving may be explained by a number of reasons. According to the Brewer model (2018), cravings are theorized to be automated, overlearned action urges that prompt eating. In the intervention tested by Mason and colleagues which demonstrated significant reductions in craving (A. E. Mason et al., 2018), participants were all women in the overweight to obese range who were only included in the study if they reported high levels of cravings (i.e., experiences of food cravings most days of the week and craving-induced eating at least three times within the week prior to enrollment). Their observed sample mean on the craving measure (the FCQ-T-R; the same as was used in the present study) was approximately 18% higher than what was observed in the present sample. As such, individuals in the Mason and colleagues intervention were experiencing higher and more distressing levels of craving prior to the intervention, which potentially contributed to the significant reduction observed over the course of the intervention. It is possible that, within our sample, levels of cravings at baseline were not severe enough to detect meaningful change due to the intervention.

In addition, the intervention in the Mason and colleagues study was much more intensive than the 3-week intervention in the present study. Individuals in the Mason and colleagues study were given access to a 28-module self-paced intervention that included mindfulness-based lectures and guided practices designed to address craving-related eating, and completed the program within an average of 58 days. This wider time period of engagement, combined with the intensity of the intervention, likely contributed to the moderate changes in experiences of craving reported. Participants were given more direct guidance and more time to target automatic, overlearned urges (i.e., cravings; A. E. Mason et al., 2018). It is likely that the self-guided 3-week intervention in the present study was not intensive enough to produce significant changes in cravings as assessed. The intervention included only one guided practice of mindful eating which was conducted during the virtual study visit. The "before you eat" tool in the MEC-2, the tool that specifically addresses experiences of urges to eat (including cravings) and promotes strategies to delay eating in response to urges to eat for non-hunger reasons, was not used heavily by intervention participants; of the 38 individuals who shared their app use with the research team, most used that tool less than once per day on average. Thus, lower initial levels of craving and infrequent use of the craving-related guidance in the app likely contributed to the lack of change in cravings observed in this study. More intensive, regular practice, as well as potentially greater support from a professional, might be necessary to prompt sustained and meaningful changes in craving.

Moderating Effects of Appetitive Traits

Finally, we predicted that food responsiveness and satiety responsiveness would moderate changes in craving over time based on secondary data analyses of a behavioral weight-loss program for children conducted by Boutelle and colleagues (2019). In their program, the investigators found support for distinct behavioral "phenotypes" which distinguished children who maintained weight loss at 24-month follow-up from those who regained weight. Within their sample, children with high food responsiveness at baseline regained weight by follow-up, while children with high satiety responsiveness at baseline remained most successful in terms of weight-loss maintenance. Based on these data, we predicted that individuals with lower baseline food responsiveness (who would be less vulnerable to the habit loop) would show greater reductions in craving (i.e., greater benefit) due to the intervention, and that individuals higher on baseline satiety responsiveness (who would similarly be less vulnerable to the habit loop) would similarly show greater reductions in cravings.

Our results did not support either of these hypotheses. Neither food responsiveness, nor satiety responsiveness significantly moderated changes in craving over the course of the present study. As discussed above, significant changes in craving were not observed. However, in examining the moderation analyses visually, interesting relationships (although non-significant) are evident. Individuals in the intervention group who reported higher baseline food responsiveness reported slightly lower craving at post-test, whereas those with low baseline food responsiveness showed slightly higher craving at post-test, contrary to predictions. If replicated in a larger sample and found to be significant, this pattern would suggest that individuals with initially greater vulnerability to eating in response to food cues might benefit most from this mindfulness-based intervention. With regard to satiety responsiveness, a weaker non-significant pattern for both intervention and control groups was observed; individuals higher on satiety responsiveness reported marginally higher craving at post-test, while those lower on satiety responsiveness reported marginally lower craving. If replicated in a larger sample and found to be significant, this pattern would suggest individuals with less sensitivity to internal satiety cues might benefit most from this intervention.

Again, these findings were not statistically significant and thus must be interpreted with caution. Achieved power for these analyses was very low (i.e., less than 41%). With a larger sample and adequate power, statistically significant moderations may be observed. Such findings could help to illuminate for whom the MEC-2 app intervention may be most effective in terms of reducing experiences of craving. For example, if a significant moderating effect of food responsiveness could be demonstrated as hypothesized, the MEC-2's emphasis on tolerating exposures to food cues in the environment and either engaging in deliberate mindful eating of craved foods or using alternative techniques to delay eating may make the app particularly useful for individuals higher on food responsiveness.

Limitations, Strengths, and Future Directions

The present study has a number of limitations that must be noted. As discussed with regard to the lack of observed changes in cravings due to the intervention, the brief, self-guided nature of the current intervention may not have allowed for adequate targeting of this specific outcome. The MEC-2 app was designed to increase mindful eating and decrease engagement in non-homeostatic eating; one goal of the app was to prompt alternative responses to urges to eat when not actually hungry, including, but not specifically limited to cravings. The current study was designed to mirror previously conducted 3-week trials examining the feasibility and acceptability of earlier versions of the MEC-2 app (Jones, 2012; Martinez, 2017; Marx, 2016). These prior investigations showed meaningful changes in mindfulness and targeted eating behaviors, but did not include measures of craving. The three-week period of time in the current study may not have been sufficient to promote changes in cravings due to the intervention, or participants may not have had a sufficiently high level of those concerns at baseline. The intervention group also received only one direct practice of mindful eating during the virtual study visit—more guided practices (such as those included in the ROC program; Boutelle et al., 2017) might be needed to provide additional coaching support for individuals throughout their time using the app. In addition, the present study did not include data from the follow-up assessment (completed in the larger project, three weeks after completion of post-test measures). Such data may provide further insight into changes in craving over time; the additional three weeks in which participants could have elected to continue using the app may have more closely paralleled the length of the intervention conducted by Mason and colleagues (A. E. Mason et al., 2018).

With regard to demographics of the present sample, participants were generally highly educated, so results may not be generalizable to the larger population. In addition, we found significant differences between individuals who completed the baseline study visit and those who did not; individuals who did not complete the baseline study visit reported lower levels of completed education and a lower household income on average. Although this likely reflected real-world challenges in scheduling, especially given the disproportionate impact of the COVID-19 pandemic on individuals of lower SES (Parker, Minkin, & Bennett, 2020), this oversampling of individuals of higher SES makes results of the analyses less generalizable. Nonetheless, these differences likely reflect accessibility of participation in a study generally (i.e., scheduling challenges, participant burden) and not accessibility of the app-based intervention itself (which was available at no cost to participants).

Numerous strengths of the present study are also evident. With regard to reported race and ethnicity, the present sample was largely representative of the population, with a greater proportion of individuals of minority status (36.1%) than expected based on general population estimates. In addition, the present sample was approximately 20% men, which is comparable to the proportion of men across samples in behavioral weight-loss trials (Dombrowski et al., 2014).

By contrast, Mason and colleagues (A. E. Mason et al., 2018) only included women in their sample when testing their mindfulness-based eating intervention.

Ease of study recruitment and intervention delivery was also a notable strength. A large number of individuals expressed interest in the study, which was advertised as testing a brief mindful eating mobile app for individuals struggling with overeating. Study recruitment was achieved (i.e., all 123 individuals enrolled) within just four months. The substantial interest in this study was likely due to the general appeal of non-dieting approaches to managing overeating, as well as the completely virtual nature of participation (i.e., online questionnaires and only one virtual study visit completed over Zoom) which allowed individuals to participate in the intervention without having to cope with typical logistical challenges for in-person research (i.e., more time, transportation, etc.). It is very likely that, with additional resources, a larger sample size could be feasibly obtained within a relatively short time frame.

Findings from the present study provided promising insights, and several future directions are noted. With regard to measurement of the study variables, and in particular the food responsiveness and external eating constructs, the substantial and meaningful overlap between the measures is problematic. One possible method to help clarify and establish discriminant validity for these measures could be to conduct a larger survey-based study in order to complete an adequately powered exploratory factor analysis. Doing so might allow for either further confidence in the measures as they are currently, or for development of more distinct and valid instruments for measuring food responsiveness and external eating. In addition, use of EMA methods at baseline (or self-monitoring data using an app) might provide a more specific and valid measurement of experiences of cravings and actual external and emotional eating episodes from which a greater understanding of both the constructs and their relationships with appetitive traits could be gleaned.

In addition, the Brewer model proposes a habit loop, in which bi-directional relationships between craving and non-homeostatic eating are conceptualized. The purpose of the present study was not to examine the directionality of these relationships, although such investigation would be important in order to further understand these phenomena. With a larger sample of longitudinal data and sophisticated analyses (e.g., structural equation modeling), one could potentially evaluate both the directionality and relative strength of these relationships—that is, whether craving more strongly predicts subsequent external and emotional eating, or whether such eating behaviors more strongly predict experiences of cravings (thus examining both parts of the habit loop).

Finally, as discussed previously, changes in cravings as hypothesized may not have been observed in the present sample due to the brief and limited nature of this intervention. Although the MEC-2 app contains specific psychoeducation and tools to target urges to eat in response to cravings, participants were not required to use these following the virtual study visit. During the visit, participants were instructed to use the app "as much or as little" as they wanted, in order to collect general reactions to the app and encourage more naturalistic use of the app (i.e., versus requiring participants to use the app for a specified time daily). Prescribed use of the app may have decreased study retention as seen in similar studies (A. E. Mason et al., 2018). Participants generally did not report using the "before you eat" tool enough to expect changes in cravings during the intervention period. In the future, it may be worthwhile to include greater encouragement of use of this tool as well as more direct guided practice (e.g., potentially through additional interactions with the research team) in order to test whether changes in cravings can be achieved with the MEC-2 app.

Conclusion

To the best of our knowledge, the present study was the first to examine support for both the Brewer "habit loop" model (i.e., cravings, external eating, and emotional eating; Brewer et al., 2018) and appetitive traits proposed by BST (i.e., food responsiveness and satiety responsiveness; Llewellyn & Wardle, 2015) in conjunction with one another within a community sample of guidance-seeking adults. In summary, our results provided some cross-sectional support for both models: cravings were positively associated with both external and emotional eating; food responsiveness was positively associated with cravings and external eating; and satiety responsiveness was negatively associated with external eating. The results did not completely reflect theoretical predictions, and warrant further investigation. The present study also assessed whether meaningful changes in cravings (hypothesized to be the critical link within the Brewer habit loop) would be observed after use of the MEC-2 mindful-eating app, and whether appetitive traits would moderate changes. We did not find any significant reductions in cravings, and moderation analyses were underpowered to detect significant effects. As both the Brewer model and BST aim to explain the development and maintenance of problematic levels of non-homeostatic eating, further elucidation of relationships between the constructs identified in both models would be helpful. Greater understanding of the ways in which individual differences (i.e., vulnerability factors such as food responsiveness and satiety responsiveness) interact with and predict eating-related behavior may help identify more targeted and effective interventions for individuals who struggle with non-homeostatic eating.

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Table 1. Sample Descriptive Statistics (N=119)

	Total		Intervention		Waitlist	
Variable	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**
Age (years)	31.87 (6.49)	18 - 45	31.97 (6.44)	22 - 45	31.78 (6.59)	18 – 44
BMI (kg/m^2)	27.60 (3.86)	21.58 – 38.44	27.34 (3.63)	21.79 – 35.14	27.87 (4.09)	21.58 – 38.44

	Total		Intervention		Waitlist	
Variable	**N (119)**	**%**	**N (60)**	**%**	**N (59)**	**%**
Gender						
Man	23	19.3	10	16.7	13	22.0
Woman	91	76.4	47	78.3	44	74.6
Non-binary or Transgender	5	4.2	3	5.0	2	3.4
Race						
White	76	63.9	40	66.7	36	61.0
Black or African-American*	17	14.3	4	6.7	13	22.0
Asian	16	13.4	11	18.3	5	8.5
Other	10	8.4	5	8.3	5	8.5
Ethnicity						
Hispanic/Latinx	12	10.1	6	10.0	6	10.2
Not Hispanic/Latinx	107	89.9	54	90.0	53	89.8
Education (SES)**						
Associate's degree or less	22	18.5	14	23.7	8	13.6
Bachelor's degree	40	33.6	19	32.2	21	35.6
Master's degree	40	33.6	16	27.1	24	40.7
Professional or Doctoral degree	16	14.3	10	16.9	6	10.2

*Chi-squared test indicated significant differences between groups (χ^2=4.68; p = 0.03), with more individuals identifying as Black or African-American randomly assigned to the waitlist-control group.
**One participant did not report level of education.

Table 2. Descriptive Statistics of Study Variables

	Total (N=119)		Intervention (n = 60)		Waitlist (n = 59)	
Measure	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**	**Mean (SD)**	**Range**
Food Responsiveness	3.25 (0.73)	1.00 – 5.00	3.16 (0.76)	1.00 – 5.00	3.34 (0.70)	1.82 – 4.75
Satiety Responsiveness	2.36 (0.79)	1.00 – 4.75	2.47 (0.71)	1.50 – 4.75	2.35 (0.82)	1.00 – 4.25
Emotional Eating	38.38 (11.74)	14.00 – 64.00	37.46 (12.09)	14.00 – 64.00	39.33 (11.40)	14.00 – 62.00
External Eating	35.67 (5.78)	21.00 – 49.00	35.18 (6.00)	21.00 – 49.00	36.15 (5.55)	21.00 – 48.00
Craving (baseline)	48.48 (13.76)	21.00 – 79.85	48.05 (14.77)	21.00 – 79.85	48.92 (12.48)	24.00 – 76.00
Craving (post-test)*	48.87 (14.22)	23.00 – 89.00	47.76 (15.43)	24.00 – 89.00	49.93 (12.99)	23.00 – 82.00

*Scores are reported only for the 110 individuals with post-test data for the present study (intervention n = 54, waitlist n = 56).

Table 3. Correlations between Study Variables (N = 119)

Variable	1	2	3	4	5	6**	7
1. Food Responsiveness	-						
2. Satiety Responsiveness	-0.03	-					
3. Emotional Eating	0.41*	-0.13	-				
4. External Eating	0.60*	-0.29*	0.43*	-			
5. Craving (baseline)	0.70*	-0.01	0.61*	0.59*	-		
6. Craving (post-test)**	0.54*	0.10	0.40*	0.40*	0.72*	-	
7. BMI (kg/m^2)***	-0.10	-0.03	0.01	-0.05	-0.01	-0.13	-

*Differences are significant at $p < 0.01$
** n = 110 for correlations with craving at post-test
***Self-reported BMI at baseline

Table 4. Results from Hierarchical Linear Regression Model 1 (Hypothesis 1a; N = 119)

	b (SE)	β	95% CI	*p*-value	ΔR^2	R^2	f^2
Block 1							
Gender (man)	-0.77 (3.26)	-0.02	-7.22 – 5.69	0.82		-	-
Gender (other)	-3.53 (6.42)	-0.05	-16.25 – 9.19	0.58	0.00	-	-
BMI	-0.03 (0.33)	-0.01	-0.69 – 0.63	0.93		-	-
Block 2							
Gender (man)	1.12 (2.36)	0.03	-3.56 – 5.80	0.64	-	-	-
Gender (other)	4.05 (4.68)	0.06	-5.23 – 13.33	0.39	-	-	-
BMI	0.17 (0.24)	0.05	-0.31 – 0.65	0.49	-	-	-
Food Responsiveness	13.35 (1.28)	0.71	10.81 – 15.89	.000*	0.48	-	0.92
Satiety Responsiveness	0.81 (3.77)	0.01	-6.66 – 8.27	0.83		-	
Craving	**-**	**-**	**-**	**.000***	**-**	**0.47**	**0.89**

*$p < 0.001$

Note: Dummy variables for gender were created using women as the reference group (as women accounted for 76.4% of the sample). ΔR^2 refers to the additional variance contributed to the model by all new variables entered within each block together. Total adjusted R^2 is reported for the final model next to the dependent variable in block 2. Cohens f^2, a measure of effect size widely used in multiple regression analyses, was calculated for the total model as well as for each significant predictor; conventional benchmarks for f^2 are 0.02, 0.15, and 0.35 for small, medium, and large effects respectively (Field, 2009).

Table 5. Results from Hierarchical Linear Regression Model 2 (Hypothesis 1b; N = 119)

	b (SE)	β	95% CI	*p*-value	ΔR^2	R^2	f^2
Block 1							
Gender (man)	-0.22 (1.36)	-0.02	-2.92 – 2.48	0.87		-	
Gender (non-binary)	-2.52 (2.67)	-0.09	-7.85 – 2.80	0.35	0.01	-	0.01
BMI	-0.06 (0.14)	-0.04	-0.33 – 0.22	0.69		-	
Block 2							
Gender (man)	-0.03 (1.11)	-0.00	-2.23 – 2.17	0.98	-	-	-
Gender (non-binary)	-1.66 (2.19)	-0.06	-5.99 – 2.68	0.45	-	-	-
BMI	-0.05 (0.11)	-0.03	-0.27 – 0.18	0.67	-	-	-
Craving	0.25 (0.03)	0.59	0.18 – 0.31	.000*	0.34	-	0.51
Block 3							
Gender (man)	-0.02 (0.99)	-0.00	-1.98 – 1.95	0.99	-	-	-
Gender (non-binary)	-0.53 (1.97)	-0.02	-4.43 – 3.39	0.79	-	-	-
BMI	-0.02 (0.10)	-0.01	-0.22 – 0.18	0.84	-	-	-
Craving	0.14 (0.04)	0.34	0.06 – 0.22	.000*	-	-	-
Food Responsiveness	2.81 (0.75)	0.36	1.31 – 4.30	.000*	0.14	-	0.17
Satiety Responsiveness	-6.51 (1.58)	-0.28	-9.65 – -3.38	.000*		-	
External Eating	-	-	-	.000*	-	0.47	0.89

*$p < 0.001$

Note: Dummy variables for gender were created using women as the reference group (as women accounted for 76.4% of the sample). ΔR^2 refers to the additional variance contributed to the model by all new variables entered within each block together. Total adjusted R^2 is reported for the final model next to the dependent variable in block 3. Cohens f^2, a measure of effect size widely used in multiple regression analyses, was calculated for the total model as well as for each significant predictor; conventional benchmarks for f^2 are 0.02, 0.15, and 0.35 for small, medium, and large effects respectively (Field, 2009).

Table 6. Results from Hierarchical Linear Regression Model 3 (Hypothesis 1c; N = 119)

	b (SE)	β	95% CI	*p*-value	ΔR^2	R^2	f^2
Block 1							
Gender (man)	0.06 (2.79)	0.00	-5.46 – 5.58	0.98		-	-
Gender (non-binary)	-0.24 (5.49)	-0.00	-11.11 – 10.64	0.97	0.00	-	-
BMI	0.03 (0.29)	0.01	-0.53 – 0.60	0.91		-	-
Block 2							
Gender (man)	0.46 (2.22)	0.02	-3.94 – 4.86	0.84	-	-	-
Gender (non-binary)	1.60 (4.38)	0.03	-7.08 – 10.28	0.72	-	-	-
BMI	0.05 (0.23)	0.02	-0.40 – 0.50	0.84	-	-	-
Craving	0.52 (0.06)	0.61	0.39 – 0.65	.000*	0.37	-	0.59
Block 3							
Gender (man)	0.13 (2.23)	0.00	-4.28 – 4.54	0.95	-	-	-
Gender (non-binary)	1.31 (4.43)	0.02	-7.46 – 10.08	0.77	-	-	-
BMI	0.03 (0.23)	0.01	-0.42 – 0.48	0.89	-	-	-
Craving	0.54 (0.09)	0.63	0.36 – 0.71	.000*	-	-	-
Food Responsiveness	-0.47 (1.69)	-0.03	-3.82 – 2.88	0.78	0.02	-	0.02
Satiety Responsiveness	-6.02 (3.55)	-0.13	-13.05 – 1.01	0.09		-	
Emotional Eating	-	-	-	.000*	-	0.35	0.54

**p* < 0.001

Note: Dummy variables for gender were created using women as the reference group (as women accounted for 76.4% of the sample). ΔR^2 refers to the additional variance contributed to the model by all new variables entered within each block together. Total adjusted R^2 is reported for the final model next to the dependent variable in block 2. Cohens f^2, a measure of effect size widely used in multiple regression analyses, was calculated for the total model as well as for each significant predictor; conventional benchmarks for f^2 are 0.02, 0.15, and 0.35 for small, medium, and large effects respectively (Field, 2009).

Figure 1. Flow Diagram for the Present Study.

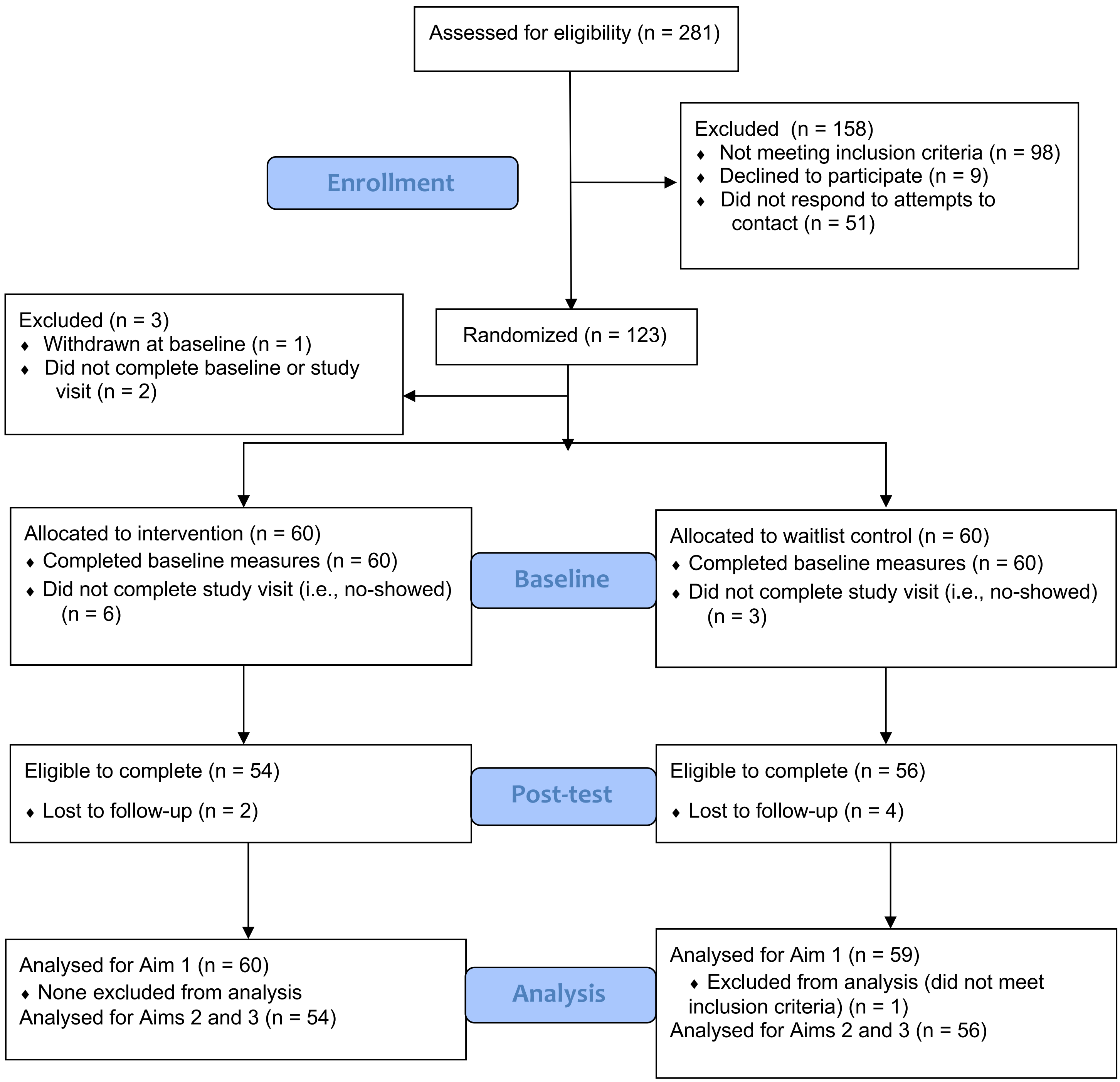
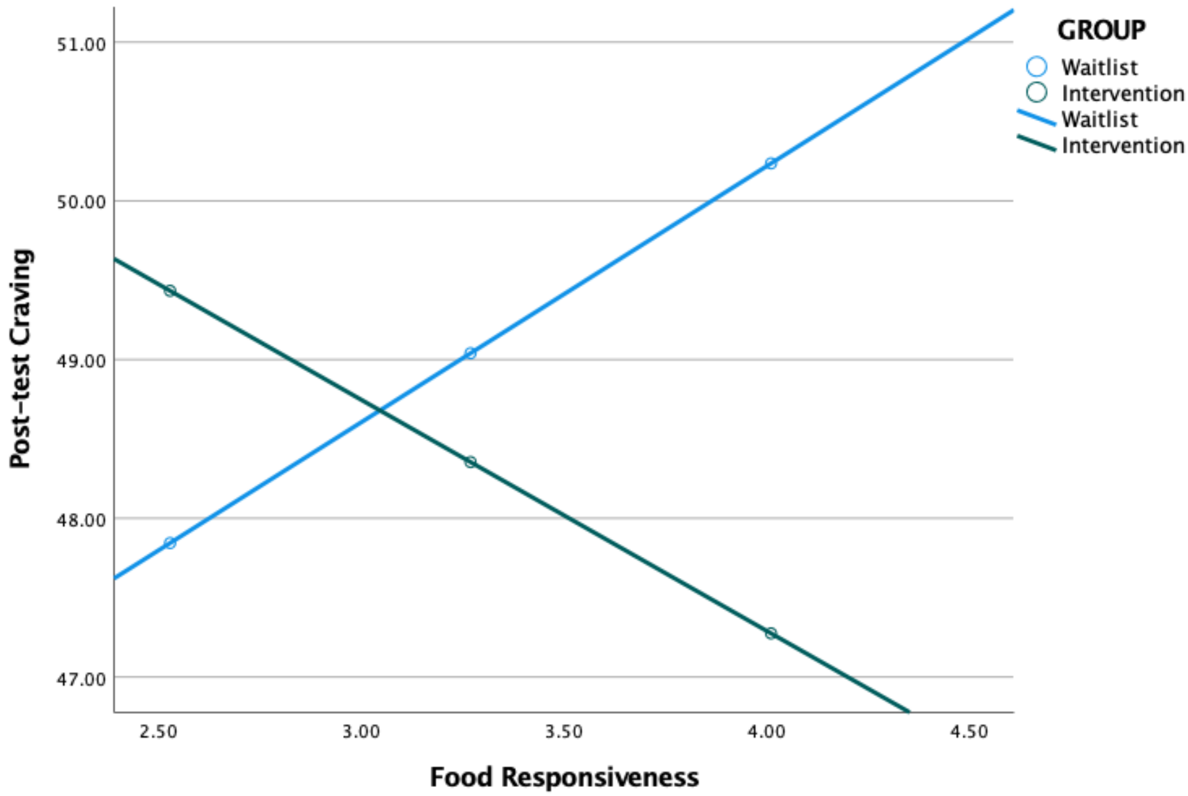
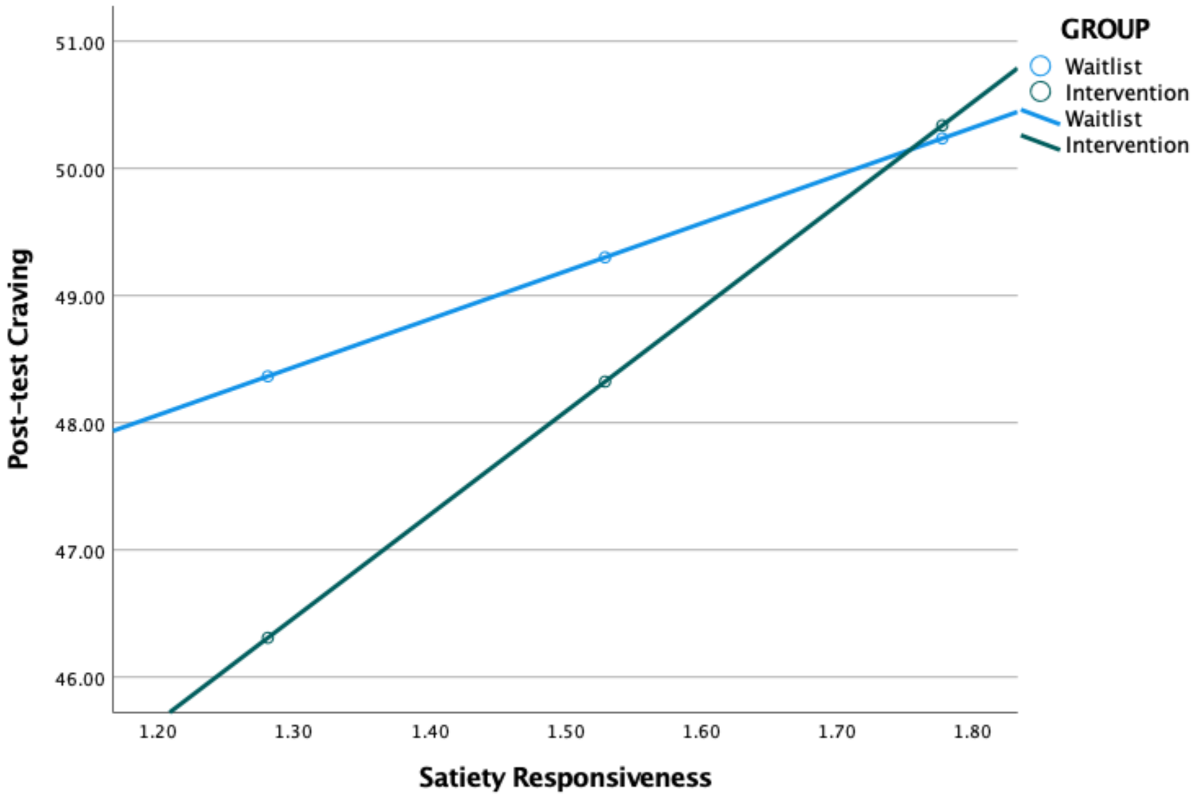


Figure 2. Interaction between Food Responsiveness and Group on Change in Craving (Aim 3, hypothesis 3a; n = 110).



Note. The interaction was non-significant ($p = 0.25$).

Figure 3. Interaction between Satiety Responsiveness and Group on Change in Craving (Aim 3, hypothesis 3b; n = 110).



Note. Satiety responsiveness is the square-root of self-reported satiety responsiveness at baseline (the variable was transformed in order to meet assumptions of normality). The interaction was non-significant ($p = 0.58$).

Supplemental Materials

Table 7. Interitem and Item to Scale Correlations for Food Responsiveness (N = 119)

Item	1	2	3	4	Scale
1. I often feel hungry when I am with someone who is eating	-				
2. Given the choice, I would eat most of the time	0.41*	-			
3. I am always thinking about food	0.17	0.52*	-		
4. When I see or smell food that I like, it makes me want to eat	0.32*	0.34*	0.31*	-	
Scale Score	0.67*	0.83*	0.73*	0.61*	-

*Correlations are significant at $p < 0.05$

Table 8. Interitem and Item to Scale Correlations for Satiety Responsiveness (N = 119)

Item	1	2	3	4	Scale
1. I often leave food on my plate at the end of a meal	-				
2. I often get full before my meal is finished	0.46*	-			
3. I cannot eat a meal if I have had a snack just before	0.22*	0.18*	-		
4. I get filled up/full easily	0.40*	0.40*	0.42*	-	
Scale Score	0.72*	0.72*	0.63*	0.77*	-

*Correlations are significant at $p < 0.05$