Food Addiction Correlates with Emotional and Craving Reactivity to Industrially Prepared (Ultra-Processed) and Home-Cooked (Processed) Foods but not Unprocessed or Minimally Processed Foods

Rafael Delgado-Rodríguez[a], María Moreno-Padilla[a], Silvia Moreno-Domínguez[a], Antonio Cepeda-Benito[b1].

[a] Department of Psychology (University of Jaén), Campus Las Lagunillas, 23009, Jaén, España. E-mail addresses: rfdelgad@ujaen.es, mmpadill@ujaen.es, smoreno@ujaen.es.

[b]Department of Psychological Science, 358 Dewey Hall, The University of Vermont, USA. E-mail address: Antonio.Cepeda-Benito@uvm.edu

[1] Corresponding author. Department of Psychological Science, 358 Dewey Hall, The University of Vermont, USA. E-mail address: Antonio.Cepeda-Benito@uvm.edu

Abstract

The NOVA classification system categorizes foods according to their level of processing to differentiate between industrially prepared, or Ultra-Processed (UP), and home-prepared, or Processed (P) and Minimally Processed (MP), foods. Whereas P and MP are recommended as part of a healthy diet, UP foods are considered unhealthy and a contributing factor to global, rising obesity rates. However, food addiction investigators include examples of both UP and P foods within their nomenclature of Highly Processed, addictive foods. Our study is the first to compare the potential addictiveness of *a priori* classified foods into UP vs P vs MP categories. We presented 169 women with a collection of 45 UP, P, and MP food pictures and recorded their subjective motivational reactivity to each picture. Analyses of covariance (ANCOVA) revealed that Yale Food Addiction Scale 2.0 (YFAS 2.0; Gearhardt et al., 2016) scores potentiated reactivity to both UP and P pictures, but not MP pictures. In addition, although both UP and P foods produced greater motivational reactivity than MP foods, UP foods elicited significantly greater reactivity than P foods. Our findings concur with previous suggestions that foods can be classified along a continuum of addictiveness potential, but our findings are the first to demonstrate that such classification might be accomplished by following the NOVA classification system. The findings also imply that nutrition experts may need to refine their NOVA classification system and, perhaps, even their healthy diet recommendations.

Keywords: NOVA Classification System; Ultra-Processed Foods; Processed Foods; Minimally Processed Foods; Highly Processed Foods; Food Addiction

1. Introduction

Overweight and obesity respectively affect about 13% and 39% of the adult world population and are known risks for serious noncommunicable diseases such as cardiovascular diseases, diabetes, musculoskeletal disorders, and many cancers (World Health Organization, 2022). In parallel to rising Global trends in overweight and obesity, economically developed countries have experienced a marked increase in the availability and consumption of palatable, high-energy dense foods that are cheaply produced and affordable (Jones et al., 2014; Rao et al., 2013). Growing evidence suggests that the consumption of these highly processed foods is a contributing factor to overeating and weight gain in vulnerable individuals (Gearhardt, 2011; Monteiro, 2009).

Gaining a better understanding of the underlying causes of overweight and obesity is important to decrease their health burden. Researchers have proposed that susceptible individuals gradually become physically and psychologically dependent on highly processed, high-energy-dense foods (Smith & Robbins, 2013). There is also a large body of research showing that food reward and overeating share psychological and neurobiological mechanisms instrumental in the development and maintenance of drug dependence (e.g., Barry et al., 2009; Berridge et al., 2010; Gearhardt, 2011; Johnson & Kenny, 2010; Kenny, 2011; Schulte et al., 2015; Smith & Robbins, 2013; Volkow & Wise, 2005; Wang et al., 2004; Wise, 1988). Nonetheless, the appropriateness of the term “food addiction” has been questioned because, unlike with drugs, people must consume food to survive (see Fletcher & Kenny, 2018;

Gearhardt & Hebebrand, 2021; Meule, 2019). Thus, acknowledging that the term “food addiction” is too broad and that not all foods are addictive, Schulte et al. (2015) proposed redefining the phenomenon as “Highly Processed Food Addiction” (HPFA). HPFA circumscribes the phenomenon of diminished eating control to a specific set of foods (Aguirre et al., 2022; Gearhardt & Hebebrand, 2021; Polk et al., 2017; Schulte et al., 2015); and, as noted earlier, HPFA emphasizes the role that overconsumption of highly processed foods plays in increasing overweight and obesity prevalence rates worldwide (Filgueiras et al., 2019). Although a complex multiplicity of causal factors contributes to obesity, there is little debate over the existence of a phenotype that identifies a subpopulation that experiences strong food cravings and diminished control, and repeated failed attempts to gain control, over their food intake (Gearhardt & Hebebrand, 2021). It is also accepted that individuals expressing the phenotype are likely to binge eat highly processed foods and are also likely to be overweight or obese (Filgueiras et al., 2019).

Based on the incentive-salience theory of drug addiction (Berridge & Robinson, 2016; Robinson et al., 2013; Robinson & Berridge, 2003), Berridge et al. (2010) posited that consuming highly palatable foods sensitize dopaminergic systems and increases the salience of cues associated with those foods. Like drug cues in the addicted brain, food cues may elicit food cravings and trigger binge consumption episodes (Berridge et al., 2010; Johnson, 2013). Considerable research has documented that exposure to food cues elicits strong food cravings (e.g., Fedoroff et al., 1997, 2003; Rodríguez et al., 2005), that self-reported food cravings, including cue-induced cravings, are considerably stronger among individuals who binge eat (e.g., Moreno et al., 2009), and that craving reactivity to food images correlates with caloric intake (e.g., Moreno-Domínguez et al., 2012). In a meta-analysis, Boswell and Kober (2016) found that food cue reactivity, cue-induced craving, and trait food cravings reliably predicted food consumption and body mass index (BMI). These authors also concluded that exposure to food cues and drug cues produces similar cue-reactivity effects (Boswell & Kober, 2016).

The range of hypotheses tested in food cue reactivity studies is wide and diverse but often involves predicting differential food-cue reactivity between groups that differ across relevant variables including clinical diagnoses (e.g., Delgado-Rodríguez et al., 2019; Moreno et al., 2009), BMI (e.g., Miccoli et al., 2018; Tetley et al., 2009), trait-craving levels (e.g., Rodríguez et al., 2005), or food satiety levels (e.g., Overduin & Jansen, 1996). Many food cue reactivity studies also use within-subjects designs that modulate cue-reactivity levels by manipulating mood (e.g., Rejeski et al., 2010) and hunger states (Wever et al., 2021), or even through exposure and response prevention to extinguish the cue-craving-binge cycle (see Jansen et al., 2016). Frequently, experiments compare reactivity to images representing low- vs high-calorie dense foods (e.g., Miccoli et al., 2014, 2016; Wever et al., 2021); highly processed vs minimally processed foods (e.g., Schulte et al., 2017b); or highly desirable foods (e.g., chocolate) vs non-food images (e.g., Hernández-Rivero et al., 2021; Rejeski et al., 2010; Rodríguez et al., 2005).

Independently from food addiction theory and research, Monteiro (2009) and colleagues (e.g., Monteiro et al., 2012, 2016, 2018) classified foods into four groups according to their level of "processing." Their intention was to emphasize and reduce the health impacts of overconsuming industrially manipulated foods. Their long-term goals and objectives included improving public health policies and interventions that promote healthy eating. Proponents of the NOVA classification system divide foods into four groups and recommend the consumption of freshly prepared, home-cooked meals (Food Groups 1 and 3) over the consumption of industrially prepared, ready-to-eat foods (Food Group 4; Monteiro et al., 2019). Group 1 includes *Unprocessed or Minimally Processed* (MP) foods, such as vegetables, unsalted nuts, boiled eggs, or milk. Group 2 corresponds to *Processed Culinary Ingredients* such as oils, fats, salts, sugars, and starches that, when added to Group 1 foods, contribute to creating Group 3 foods. Thus, Group 3 includes most home, or artisan *Processed* (P) foods, such as baked beans, fried eggs, or cooked meats (e.g., bacon or steak), but also includes foods such as cheese and salted nuts. Group 4 or *Ultra Processed* (UP) foods includes industrially processed foods, such as frozen pizza, restaurant fast foods, cakes, or ice creams. UP foods are prepared with substances not commonly used in home culinary preparations, including artificial additives meant to enhance the sensory qualities of the food or to extend its shelf-life. When consumed, industrialized highly processed (IHP) foods (a.k.a. UP foods) likely have addictive, drug-like properties, such as relatively rapid rates of absorption or intense hedonic effects that mediate addition-like eating (Gearhardt & Difeliceantonio, 2023).

Although HPFA researchers differentiate between highly processed and non-processed foods, they often include P and UP foods within their classification of “highly processed” foods, and/or may also mix P and MP foods within their definition of non-processed or minimally processed foods. For instance, the *Yale Food Addiction Scale 2*.0 (YFAS 2.0; Gearhardt et al., 2016), “A self-report questionnaire for the assessment of addiction-like consumption of high-calorie, processed foods” (Meule & Gearhardt, 2019), lists both P foods (e.g., rice, steak) and UP foods (e.g., chocolate, cake) as examples of problematic, difficult to resist eating foods.

Similarly, food-cue reactivity researchers have exposed participants to high (e.g., Blechert et al., 2010; Delgado-Rodríguez et al., 2022; Versace et al., 2016, 2019) or high vs low calorie/palatable food stimuli (e.g., Blechert et al., 2011; Meule et al., 2013; Svaldi et al., 2010), but have never differentiated between P (Group 3) vs UP (Group 4) foods in their manipulation of exposure to high calorie/palatable food stimuli. On the other hand, Schulte et al., (2017b) classified bacon, steak, cheese, and salted nuts within their minimally processed food category, all of which would be classified as P foods by the NOVA classification system (Monteiro et al., 2016). In conclusion, while proponents of the NOVA system recommend consuming MP and P foods instead of UP foods (or IHP foods), HPFA researchers have usually combined P and UP foods within the highly processed category, and may have also mixed P and MP foods within the non-processed or minimally processed categories.

Thus, we designed a study to test differential, subjective motivational reactivity (i.e., mood valence, arousal, dominance, and craving responses) to MP, P, and UP food images and assess the relationship between this measured reactivity and self-reported HPFA levels (using the YFAS 2.0). We predicted that if UP foods were differentially more addictive (e.g., more likely to be craved and abused) than P foods, food addiction scores would potentiate motivational reactivity to UP food images more than to P and MP food images. We also hypothesized that motivational cue reactivity would be greater for UP than P and MP foods.

2. Method

2.1 Participants

A total of 208 young adults taking psychology courses at the University of (*anonymized*) volunteered to participate in exchange for partial credit towards their courses. The University of (*anonymized*) is a medium size, urban university of about 17000 students located in Southern Spain. Because very few men participated in the study (n = 21), and because men and women substantively differ in eating-related phenomena, including self-reported trait (food) cravings (Cepeda-Benito et al., 2003) and food addiction symptoms (Yu et al., 2018), we restricted the analyses to women participants. We also excluded from data analyses participants (n = 7) who provided incorrect answers to "catch" questions ("What is 2 + 2?" and "Have you ever had a fatal heart attack?"), were older than 30 (n = 1), or reported being vegetarian or vegan (n = 10). The average age of the final sample (n = 169) was near 21 (*M* = 20.6 years, *SD* = 2.1), and had an average BMI within the normal range (*M* = 22.81, *SD* = 4.26). This research was conducted according to the Declaration of Helsinki and the Ethics Committee of the University of (anonymized) approved this study (OCT.22/23.PRY).

2.2 Measures

In addition to the measures described below, participants reported their hunger and food craving states pre- and post-imagery exposure, as well as completed three questionnaires that variously assessed trait cravings and eating disorder symptoms post-imagery exposure. Here we describe the measures that contributed to the current analysis of the relationship between food addiction scores and subjective reactivity to UP, P, and MP food images.

Self-Assessment Manikin (SAM; Bradley & Lang, 1994; Muñoz et al., 2010).

The original SAM (Bradley & Lang, 1994) is a non-verbal pictorial rating scale with nine levels of intensity (from 1 [lower end] to 9 [upper end]), represented by five human-like drawings and the four spaces that separate the manikins. Participants are asked to pick the manikin or the space between manikins that best represents how they feel “right now” as they are responding. Bradley and Lang (1994) varied specific features of the prototype image to represent three distinct emotional states; valence (unhappy vs. happy), arousal (relaxed vs. activated), and dominance (dominated vs. dominant). Muñoz et al. (2010) further modified the SAM prototype to create a salivating manikin to represent “cravings” (from weakest to strongest craving; see also Miccoli et al., 2014, 2016, 2018).

To ensure that participants anchored the 9-point Likert-type scale to their own range of lived experiences, we incorporated the *gLMS* method (Bartoshuk et al., 2004). That is, we guided participants to recall the time or situation when they felt the most extreme states (lowest/weakest vs highest/strongest) of the dimensions represented by the various manikins. After giving them a few seconds to think about how they felt in those occasions, we asked them to think of them respectively as their “1” and “9” manikins. For example, for food craving, participants were told to think first about “that" which caused them to experience their strongest craving and to anchor that felt craving state to the right-most manikin. The procedure was then followed for the weakest craving and anchored it to their left-most manikin. Participants were then told, “Remember those extremes that give you the weakest and strongest craving when rating the images.” The complete set of instructions is provided within the supplementary files (see also Polk et al., 2017).

Researchers have used SAM scores to successfully index the extent to which various substance cues may elicit different valence, arousal, dominance, or craving responses across different populations and situational contexts, as well as in comparison to positive, negative, and neutral cues (e.g., Lovett et al., 2015; Muñoz et al., 2010; Rodríguez et al., 2005). Valence, arousal, and dominance are conceptualized as first-order emotional states that govern appetitive (approach) and defensive (avoidance) motivational states (e.g., Bradley & Lang, 1994). Muñoz et al. (2010) provide a comprehensive summary of the applicability of the SAM scales to drug cue-reactivity research, which we believe also applies to food-cue reactivity research within the context of food addiction research. To summarize, valence is assumed to indicate whether a stimulus elicits an approach response (toward the appetitive) or a defensive response (withdrawal from) the noxious. Arousal level is simply an index of the level of activation required to cope with or respond to what the stimulus represents. In general, the more neutral a stimulus is, the least activation it will generate. Feeling dominant vs feeling dominated indexes the degree of power or sense of control a person has over a particular situation or challenge. Dominance is especially relevant to abused drugs and foods because drug abuse and binge eating are often defined as impulsive and difficult to control. Finally, craving is often defined as an intense desire, a difficult-to-resist urge to seek and consume a particular drug or food (e.g., Cepeda-Benito et al., 2000). Generally, “addictive” food cues should generate positive valence, high arousal, low dominance, and high cravings (e.g., Muñoz et al., 2010; Rodríguez et al., 2005). However, contextual, and/or personal circumstances may modulate the direction and intensity of drug/substance-cue reactivity (Tiffany, 1990).

The Yale Food Addiction Scale 2.0 (YFAS 2.0; Gearhardt et al., 2016).

The YFAS 2.0 is a modified version of the original YFAS (Gearhardt et al., 2009) to represent the 11 criteria used by the Diagnostic and Statistical Manual of Mental Disorders (Fifth Edition; DSM-5) to diagnose “Substance-Related and Addictive Disorders” (Gearhardt et al., 2016). The instructions of YFAS 2.0 inform participants that the questionnaire is intended to gather information about their eating habits in the past year. The instructions state, “People sometimes have difficulty controlling how much they eat of certain foods” and then provide a short list with examples of foods and non-alcoholic beverages. Each of the 35 items of the YFAS 2.0 is scored on an 8-point Likert-type scale from “Never” (0) to “Every Day” (7). Detailed scoring instructions are found in Gearhardt et al. (2009, 2016). We used the continuous, 0 to 11 scoring method to calculate a total food addiction score per participant. Validated versions of the YFAS 2.0 exist in many languages, including the Spanish version used in this study (Granero et al., 2018). In the present sample, the internal consistency of the scores was high (α = .89).

2.3 Stimuli

A licensed nutritionist well versed in the NOVA system classified 90 food images into MP, P, and UP food groups (for a full description of the classifying criteria see Angelovičová et al., 2020; Monteiro et al., 2016). The sources of the images included the Open Library of Affective Foods (OLAF) (Miccoli et al., 2014, 2016) and images used in previous cue-reactivity research (authors anonymized). A sample of 40 undergraduate volunteers rated the 90 images according to the “physical” attractiveness of the image. Each image was rated using a 9-point, Likert-type scale from “not at all physically attractive” (1) to “very physically attractive” (9).

Using these ratings, we selected the 15 pictures that averaged the most attractive ratings within each food group.

The list and description of the 45 classified images are provided in a table within the supplementary files. In the UP-food category, all images correspond to foods most Spaniards very rarely, if ever, prepare at home, and if so, certainly not from scratch. UP food images included dessert-type foods (e.g., banana split ice cream, molten chocolate cake, cheesecake), and high-fat, fast-food restaurant meals (e.g., French fries with melted cheese, cheeseburger with mustard and fries, chicken nuggets with ketchup, pizza). The P-food category included hearty foods Spaniards may prepare at home or may order when eating out at a traditional, sit-down restaurant (e.g., grilled salmon with veggies, Spanish potato omelet, roasted chicken with rice). Finally, the MP-food category was exclusively populated by fruits, with most from the OLAF library (Miccoli et al., 2014, 2016).

2.4 Procedures

Participants volunteered to participate in a study about the emotional processing of affective images in exchange for partial credit towards their psychology courses. Interested participants self-signed for pre-scheduled, “Google Meet” group sessions. Participants were greeted and given a brief description of the procedures. We emphasized the importance of carefully reading the informed consent form and asked them to complete the study in a quiet place free of distractions, to not multitask while completing the experiment, and to remain connected to the Google Meet conference until they were informed that their participation had concluded.

After the brief introduction, we provided a link with access to the informed consent form. Participants were instructed to read the form and sign it electronically. Participants who consented to participate received a second link to a Google Forms questionnaire. We instructed participants to create a code they would need to use before completing each of the three phases or parts of the study (pre-assessment, imagery exposure, and post-assessment). We advised participants to write down the code and check it before re-entering it at the beginning of each study phase.

The first short survey was used to record their age, gender, weight, and height. Once all participants notified us that they had finished answering the short questionnaire, we proceeded to explain the image-exposure phase of the study. The experimenters read out loud a power-point presentation that included standard SAM manikin instructions (Lang et al., 2008), as well as "*gLMS*" instructions (Bartoshuk et al., 2004). Following the instructions, we sent a link that gave them access to the imagery exposure phase of the study.

Imagery exposure was programmed in "Psychopy 3.2.3" and administered using "Pavlovia" (https://pavlovia.org/) (see also Peirce et al., 2019). The imagery exposure phase was preceded by a short practice trial. The practice trial consisted of presenting 3 sample pictures (one per MP, P, and UP food group). Each picture was presented for 6 s and followed by the valence, craving, dominance, and arousal SAM assessments, in that order and one at a time. The image exposure phase followed the practice trial procedure but presented 45 pseudorandomized food images (15 per food group). Participants were randomly assigned to one of three pre-arranged image-type orders. That is, we reshuffled the 45 pictures three times until the food category of the first picture differed across the three orderings, a single food category did not appear consecutively more than two times in a row, and no more than four pictures separated two pictures from the same food category. Once the image-exposure phase concluded, participants received a link to the final set of Google Forms measures, which included the YFAS2.0. Participants were informed their participation had concluded after completing the post-assessment phase.

2.5 Statistical analyses.

All analyses were conducted using SPSS for Mac (Version 21, SPSS Inc.), statistical significance was set at $p < .05$, and we used partial eta squared (η^2) to report effect sizes. Analyses of covariance (ANCOVA) compare mean score differences between the various levels of the within-factor models while controlling for the linear relationship or slope between a covariate and each level of the within-subjects variable (Schneider et al., 2015). To control for deviations from sphericity we used Greenhouse-Geisser adjusted degrees of freedom to assess statistical significance. To diminish the impact of outliers, we winsorized scores > 3 SDs. A small number of scores were winsorized (valence UP = 1; arousal MP = 1). Missing data were very sporadic (< .05 %) and the analyses were carried out using pairwise deletion.

Differential reactivity as a function of the food-image NOVA group, was examined using four within-subject measures ANCOVAs, one per SAM measure (valence, arousal, craving, and dominance). The food group (MP, P, and UP) constituted a three-level within-subjects factor and YFAS scores represented the covariate. Significant within-factor effects were followed by pairwise contrasts to test our *a priori* anticipated NOVA effect. Namely, we predicted greater reactivity to UP than P and MP food images. The ANCOVA output in SPSS also includes a significance test of the interaction between the covariate and the within factor, as well as *a priori* specified, comparisons between the different covariate parameters. For each ANCOVA, we examined the 95% confidence intervals (*CI*) of the YFAS slopes predicting reactivity scores for each of the four food image types. Slopes with 95% CI ranges that did not straddle over zero were considered statistically significant. Significant interactions between the covariate and the within factor were interpreted by examining discrepancies in the direction and/or statistical significance of the various parameters, as well as by identifying nonoverlapping 95% *CI*s among isodirectional and statistically significant parameters.

3. Results

3.1 Relationship between YFAS scores and reactivity to NOVA food processing categories

YFAS scores ranged from 0 to 11 (M = 1.53, SD = 2.55) and 13% of the participants met the criteria for at least Mild Food Addiction (for scoring instructions see Gearhardt et al., 2016). Estimation of the covariate *b* parameters for YFAS scores yielded the following results (see also Table 1). For valence, the interaction between YFAS scores and the within factor was not statistically significant, $F_{(2, 334)} = 0.231$, $p = .71$, partial $\eta^2 = .001$. All of YFAS *b* parameters or slopes were negative but none significantly predicted valence reactivity: UP (*b* = -.071; 95% *CI* [-.145, .002]), P (*b* = -.047; 95% *CI* [-.123, .029]), and MP (*b* = -.043; 95% *CI* [-.135, .050]).

Table 1 Summary of Associations between YFAS Scores and Reactivity to NOVA Food Processing Categories

SAM	NOVA Group	*b*	*p*	*95% CI*	Effect

	Minimally Processed	-.043	= .363	-.135, .050	ns
Valence	Processed	-.047	= .227	-.123, .029	ns
	Processed	-.071	= .058	-.145, .002	ns
	Minimally Processed	-.019	= .708	-.120, .082	ns
Arousal	Processed	.124	< .05	.021, .226	Potentiation
	Ultra-processed	.140	< .05	.034, .245	Potentiation
	Minimally Processed	-.016	= .787	-.135, .102	ns
Craving	Processed	.147	< .01	.042, .252	Potentiation
	Ultra-Processed	.158	< .01	.056, .260	Potentiation
	Minimally Processed	.001	= .978	-.097, .100	ns
Dominance	Processed	-.110	< .05	-.202, -.019	Inhibition
	Ultra-Processed	-.134	< .01	-.232, -.035	Inhibition

For arousal, the interaction between YFAS scores and the within factor was statistically significant, $F_{(2,\ 334)} = 8.289$, $p < .01$, partial $\eta^2 = .047$. The predictive parameter associated with UP ($b = .14$; 95% *CI* [.034, .245]), and P ($b = .124$; 95% *CI* [.021, .226]) were positive and statistically significant. Conversely, YFAS scores did not significantly impact arousal reactivity to MP images ($b = -.019$; 95% *CI* [-.120, .082]). However, the 95% *CI*s of the *b* parameters associated with UP and P food images overlapped and were not significantly different from each other.

For craving, the interaction between FYAS and the within factor was also statistically significant, $F_{(2, 334)} = 5.144$, $p < .05$, partial $\eta^2 = .03$. The predictive parameter associated with UP ($b = .158$; 95% *CI* [.056, .260]), and P ($b = .147$; 95% *CI* [.042, .252]) were positive and statistically significant. Conversely, food addiction scores did not significantly impact craving reactivity to MP images ($b = -.016$; 95% CI [-.135, .102]). As with arousal, the 95% *CI*s of the *b* parameters associated with UP and P food images overlapped and were not significantly different from each other.

For dominance, the interaction between YFAS scores and the within factor was statistically significant, $F_{(2, 334)} = 5.454$, $p < .05$, partial $\eta^2 = .032$. The parameter associated with UP ($b = -.134$; 95% CI [-.232, -.035]), and P ($b = -.110$; 95% CI [-.202, -.019]) food images were negative and statistically significant, however, the parameter associated with MP ($b = .001$; 95% CI [-.097, .100]) was not statistically significant. As with arousal and craving, the 95% *CI*s of the *b* parameters associated with UP and P food images overlapped and were not significantly different from each other.

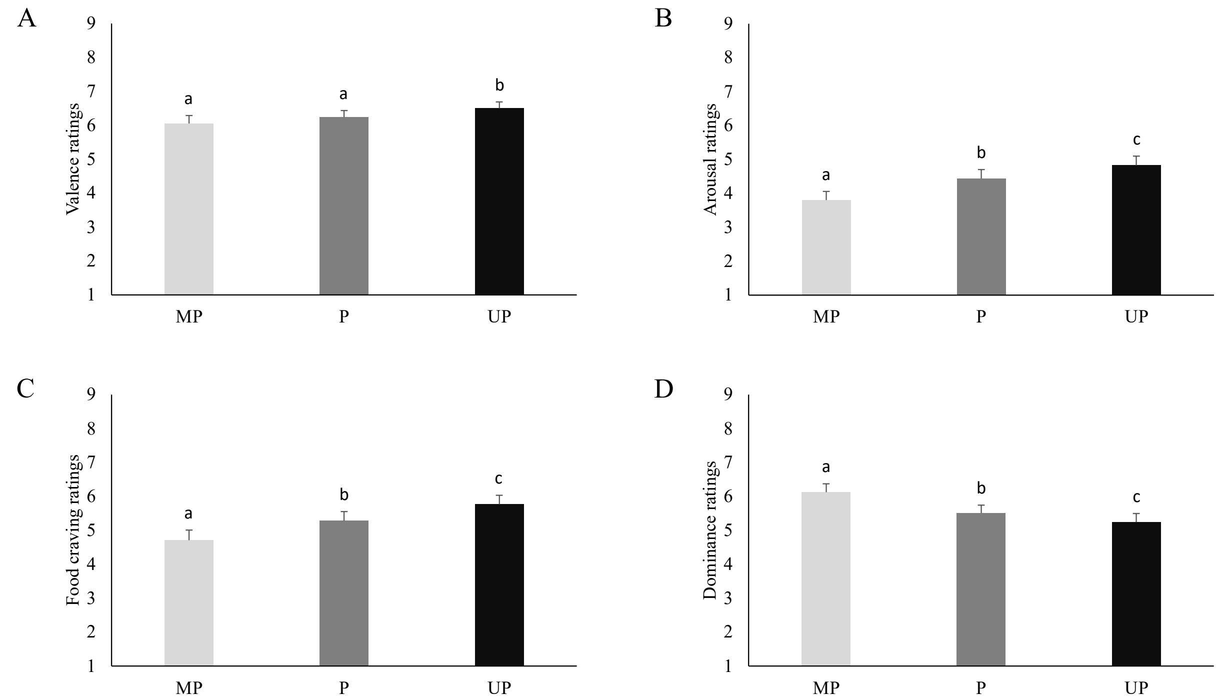
To summarize, food addiction scores did not influence reactivity to MP food images, food addiction scores significantly potentiated arousal and craving and significantly inhibited dominance reactivity to UP and P food images. However, the associations between food addiction scores and cue reactivity to UP and P food images were isodirectional and very similar in strength. Finally, food addiction scores neither potentiated nor inhibited valence reactivity to any type of food images.

3.2 Reactivity to NOVA food processing categories while controlling for YFAS scores

Figure 1A-D depicts adjusted mean reactivity scores to UP, P, and MP food images for valence (1A), arousal (1B), food craving (1C), and dominance (1D). The within-subjects ANCOVAs yielded significant food category effects for all motivational reactivity measures: valence ($F_{(2, 334)} = 6.833$, $p < .01$, partial $\eta^2 = .039$); arousal ($F_{(2, 334)} = 18.824$, $p < .001$, partial $\eta^2 = .101$); dominance ($F_{(2, 334)} = 14.079$, $p < .001$, partial $\eta^2 = .078$); and craving ($F_{(2, 334)} = 9.751$, $p < .01$, $\eta^2 = .055$). Our *a priori* planned predictions were confirmed in that, for each of the four SAM measures, reactivity scores to UP food images were significantly different and in the expected direction than reactivity to P and MP images. For valence, participants reported greater positive mood in response to UP images than in response to P ($p < .001$) and MP food images ($p < .01$), and responses to P and MP images were not significantly different from each other ($p = .144$). UP images produced greater arousal and craving reactivity than P food images ($p < .001$), but P food images produced greater arousal ($p < .001$) and craving ($p < .01$) reactivity than MP food images. For dominance, as expected, UP food images were associated with significantly lower dominance scores that P food images ($p < .001$), but P food images also produced significantly lower dominance scores than MP food images ($p < .001$).

To summarize, without exception, UP food images produced greater motivational reactivity than P and MP food images. Except for valence, P food images also produced greater motivational reactivity than MP food images.

Figure 1. Emotional and motivational responses to food processing categories.



Note: MP, minimally processed foods; P, processed foods; UP, ultra-processed foods. Bars with different letter identifiers depict statistically significant differences between means.

4. Discussion

Whereas addiction researchers do not explicitly differentiate between UP and P foods and usually classify both as highly processed, addictive foods (Gearhardt et al., 2016; Meule & Gearhardt, 2019; Schulte et al., 2015), public health experts do not consider the consumption of P foods problematic (e.g., Monteiro et al., 2018). Therefore, we questioned whether P foods should be considered highly processed (addictive) foods (Meule & Gearhardt, 2019; Schulte et al., 2015). To examine our question, we designed a food-cue/motivational reactivity study and reasoned that if UP foods were more addictive (e.g., more likely to be craved and abused) than

P and MP foods, food addiction symptoms would potentiate motivational reactivity to UP food images uniquely, or at least significantly more than to P and MP food images.

We found that food addiction symptoms, as measured continuously by the YFAS 2.0 (Gearhardt et al., 2016), interacted with type of food image exposure across reactivity measures of arousal, dominance, and food cravings. The interaction revealed that food addiction scores potentiated arousal and food craving reactivity to UP and P food images but not to MP food images, with reactivity potentiation being similar for UP and P food images. Similarly, food addiction scores inhibited dominance reactivity to UP and P food images, with reactivity inhibition being similar between UP and P food images. Food addiction symptoms neither potentiated nor inhibited valence reactivity to any of the food image groups. That is, our hypotheses for valence, arousal, dominance, and food cravings were falsified in that, contrary to our prediction, the relationship between food addiction symptoms and cue reactivity never differed between UP and P food images.

The finding that food addiction symptoms correlated with arousal, dominance, and craving reactivity equally across both UP and P foods suggests both NOVA food categories are potentially addictive. Theories of addiction predict that exposure to cues associated with the consumption of addictive substances produces motivational states that promote the consumption of such substances (Drummond et al., 1995). Consequently, investigators interpret the degree of reactivity to substance-related cues as the motivational value and strength of such cues (Glautier & Tifanny, 1995). Craving reactivity indexes the desire or intensity with which the substances represented by the cues are wanted (Carter & Tiffany, 1999). Arousal reactivity is believed to be an index of the motivational response intensity or the energy needed or recruited to pursue or avoid an outcome (Muñoz et al., 2010). Finally, dominance reactivity refers to the extent an individual feels “in control of” vs “dominated by” the motivational state elicited by the cues (e.g., Mehrabian & Russell, 1974). Thus, individuals with greater degrees of addiction to a substance are expected to self-report greater desire (craving), activation (arousal), and less control than less (or not) addicted individuals when exposed to cues that represent the addictive substance. For example, substance-use, cue exposure studies often report greater craving and arousal with lesser dominance reactivity among addicted than non-addicted groups exposed to either addictive drugs (e.g., Gu et al., 2021; Muñoz et al., 2010; Stritzke et al., 2004) or addictive foods (Rodríguez et al., 2005).

We also found that food addiction responses were not associated with valence reactivity to any of the food image groups. To the extent that valence may index the approachability, pleasantness, or hedonic value of stimuli (Muñoz et al., 2010), our findings are compatible with the incentive-salience theory of addiction (e.g., Berridge, 2009). According to the incentive-salience theory, “liking” (i.e., hedonic pleasure associated with cues) plays a relatively minor role in the manifestation of addictive behaviors (Berridge, 2009; Berridge & Robinson, 2016; Polk et al., 2017). For example, Polk et al. (2017) found that food addiction symptoms did not influence the liking of highly palatable food (Polk et al., 2017).

Valence may also be a “flaky” indicator of motivational reactivity that is highly sensitive to unmeasured individual and contextual circumstances. For example, to a smoker who has quit or a person who is consciously limiting their caloric intake, a cigarette or a chocolate bar may respectively elicit low valence scores because cigarettes and chocolate respectively represent a threat to their goals. Conversely, to a deprived smoker or a hungry chocolate connoisseur, a cigarette and a chocolate bar may respectively elicit positive valence reactivity because the substances represent the opportunity to satiate their cravings (see Tiffany, 1990). In a sample where both types of individual circumstances occur negative and positive valence reactivity would cancel each other and mask unidirectional bivariate relationships. Moreover, our finding is in line with drug-exposure research reporting similar valence reactivity to drug-related vs neutral images among drug users (e.g., Gu et al., 2021), that valence reactivity to drug cues is strongly modulated by contextual cues (e.g., Muñoz et al., 2010), and that drug-related cues tend to produce neutral valence scores under most contextual circumstances (e.g., Muñoz et al., 2010).

Independently of the association between addiction food scores and differential food-cue motivational reactivity, we also predicted that UP food images would elicit greater motivational reactivity than P and MP food images. In support of our hypothesis, we found a significant within-subjects effect for each of the four motivational reactivity measures, and in all instances, motivational reactivity to UP food images was greater than motivational reactivity to P and MP food images. However, arousal, food craving, and diminished control reactivity to P food images were also significantly greater than reactivity to MP food images. Overall, these findings align with previous food reactivity studies that have variously reported greater arousal, craving, and lesser dominance in response to highly processed food stimuli than to neutral and low-calorie food stimuli (Delgado-Rodriguez et al., 2019; Miccoli et al., 2014, 2016; Moreno-Padilla et al., 2018; Rodríguez et al., 2005).

Interestingly, our results are also congruent with the findings of Schulte et al. (2017b). These authors reported that four foods (cheese, bacon, steak, and salted nuts) scored relatively high on various dimensions of addictiveness potential, falling somewhere between their highly processed and minimally processed food classification. Given that these four foods would have been classified as P foods within the NOVA categorization system, our results appear to replicate the pattern of results reported by Schulte et al. (2017b). Thus, like with Schulte et al. (2017b), our results are congruent with a dimensional rather than a dichotomous understanding of foods' addictive potential. Whereas Schulte et al. (2017b) arrived at this conclusion by noting different degrees of addictiveness among what they classified as "minimally processed" foods, we arrived at the same results and conclusion by *a priori* separating food images into UP vs P vs MP food categories.

Whereas valence reactivity did not differ between P and MP food images, we have already noted that motivational reactivity drug or food cues measured as valence can be confounded by contextual circumstances. That is, although addictive substances may awaken appetitive states and be associated with positive and pleasurable experiences, their consumption can also be connected to aversive, negative outcomes and create ambivalence (see Rodríguez et al., 2005). Thus, P and MP images may have produced similar valence reactivity because valence likely interacts with individual and contextual circumstances to index addiction reactivity.

Taking together, the finding that food addiction symptoms potentiate motivational reactivity to UP and P food images but not MP food images, and the finding that differential reactivity to UP, P, and MP food images follow a dose-dependent pattern where UP and MP represent the poles and P the middle of an addictiveness continuum, our results suggest that P foods are potentially addictive and potentially problematic. Assuming our interpretation is accurate, our results have important implications for both food addiction researchers and public-health nutrition experts. On the one hand, food addiction investigators may need to reconsider or further refine the definition of addictive foods to differentiate between UP and P foods rather than include both within the lone highly processed food classification. This suggestion aligns with the position that all foods, like all drugs, may fall somewhere along a continuum of addictiveness (Aguirre et al., 2019; Gearhardt & Hebebrand, 2021; Polk et al., 2017; Pursey et al., 2017, 2021; Schulte et al., 2015).

For public-health nutrition experts, particularly those who adhere to the NOVA classification system, our findings carry two implications. First, and perhaps most importantly, the dietary recommendation to avoid UP foods and encourage natural and home-cooked meals likely needs to deemphasize or qualify the extent to which consumption of P foods is recommended. That is, if P foods were addictive, they could represent a risk for binge eating. For example, although researchers invariably find that UP foods are the preferred, most commonly binged foods, other non-UP foods are also consumed during binge-eating episodes (e.g., Allison & Timmerman, 2007; Kales, 1990; c.f., Ayton et al., 2021). Second, NOVA proponents should also consider the advisability of further refining their food processing classification by either further dividing or regrouping foods across the UP and P categories or adding greater nuance to their descriptions of UP and P foods.

Nonetheless, although both P and UP foods elicited addiction-like motivational states within our experimental manipulations, it is important to emphasize that contextual factors likely influence and differentiate the abuse liability of UP over P foods. That is, in comparison to P foods, UP Foods tend to be more accessible, convenient (often shelf-stable due to additives), inexpensive, and more heavily marketed (see Askari et al., 2020). Thus, motivational salience aside, availability and accessibility factors likely increase abuse-liability more for UP than P foods.

Our findings also speak to the existing debate about whether food addiction is better understood as a behavioral or “eating” addiction or as a substance or “food” addiction (for a comprehensive and nuanced discussion see Schulte et al., 2017a). Hebebrand et al. (2014) noted that the determination of whether someone engages in addictive-like eating ultimately relies on observing specific behavioral features (e.g., poor control over food consumption) rather than substance-use effects and indicators (e.g., intoxication or physical withdrawal). However, Schulte et al. (2017a) astutely point out that eating addiction is actually contingent or confined to some, but not all food types (i.e., substance-dependent). Thus, to the extent that our results show that different food types elicit different motivational reactivity (valence, arousal, dominance, and cravings), we would have to conclude our results support the “food-addiction” side of the debate.

Our inferences and speculations need to be couched within the design and methodological limitations of our study. We acknowledge the stimuli we selected may not fully or equally represent each of the NOVA food categories. For example, we notably left unprocessed vegetables out of the MP category. In addition, visually made distinctions between UP and P foods from photographs could be unreliable, particularly because some foods may exist in both UP and P versions. Nonetheless, given that images of fruit plates elicit comparatively greater cravings and activation than vegetable plates (e.g., Miccoli et al., 2016), any differences we found between MP foods and the other two categories (P and UP foods) would most likely have been maintained or enhanced had we included a more heterogeneous or representative sample of MP foods. Regarding difficulties differentiating between MP and P foods, we acknowledge that our design probably inherited some of the intrinsic shortcomings of the NOVA classification system, which can be imperfect but nonetheless largely reliable and valid (Sneed et al., 2023).

As with any other research that relies on subjective data, our study was vulnerable to the demand characteristics of the experimental setting, as well as to the participants' overall insight into their own motivational states and accuracy in reporting them. Thus, it would be important to replicate the study but adding objective motivational reactivity measures, such as galvanic skin response to gauge motivational arousal (e.g., Cepeda-Benito & Tiffany, 1996), the cardiac defense response and the startle reflex (e.g., Rodríguez et al., 2005), and neuroimaging (e.g., Giuliani et al., 2020; Moreno-Padilla et al., 2018) or brain potentials (e.g., Wolz et al., 2017) to corroborate self-reported food craving. It would also be important to attempt to replicate the present findings in samples representative of more directly relevant populations, such as individuals seeking weight loss treatment or people diagnosed with binge eating disorder. Finally, replication of the finding using different stimuli to improve the range and variety of foods represented within each category would be advisable; such an effort would perhaps benefit from a more nuanced, nutrient (e.g., carbohydrate, fat, protein), and/or taste (e.g., salty, sweet, bland) classification.

5. Conclusions

To conclude, the present study represents the first investigation to test differential reactivity to UP, P, and MP foods across the motivational dimensions of valence, arousal, craving and dominance. Our findings suggest that both UP (NOVA 4) and P (NOVA 3) foods have a greater addictive potential than MP (NOVA 1) foods. We also found clear evidence showing that UP (NOVA 4) foods have greater addictive potential than P (NOVA 3) foods. Together, the findings support the notion that foods can be classified along a continuum of addictiveness potential. Finally, our findings have three main implications. First, food addiction researchers would do well to desegregate UP and P foods rather than mix them into a "highly processed" classification category. Second, public-health nutritionists should consider desegregating more their diet recommendations regarding P and MP food meals. Finally, NOVA proponents may improve their four-group classification system by recognizing the likely overlap between UP and P foods and further refine their classification criteria.

6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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8. Data availability

Data will be made available on request.

9. References

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