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Reward sensitivity and food addiction in women

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23 Abstract

24 Sensitivity to the rewarding properties of appetitive substances has long been implicated in
25 excessive consumption of palatable foods and drugs of abuse. Previous research focusing on
26 individual differences in reward responsiveness has found heightened trait reward sensitivity
27 to be associated with binge-eating, hazardous drinking, and illicit substance use. Food
28 addiction has been proposed as an extreme form of compulsive-overeating and has been
29 associated with genetic markers of heightened reward responsiveness. However, little research
30 has explicitly examined the association between reward sensitivity and food addiction.
31 Further, the processes by which individual differences in this trait and excessive over-
32 consumption has not been determined. A total of 374 women from the community completed
33 an online questionnaire assessing reward sensitivity, food addiction, emotional, externally-
34 driven, and hedonic eating. High reward sensitivity was significantly associated with greater
35 food addiction symptoms ($r = .31$). Bootstrapped tests of indirect effects found the
36 relationship between reward sensitivity and food addiction symptom count to be uniquely
37 mediated by binge-eating, emotional eating, and hedonic eating (notably, food availability).
38 These indirect effects held even when controlling for BMI, anxiety, depression, and trait
39 impulsivity. This study further supports the argument that high levels of reward sensitivity
40 may offer a trait marker of vulnerability to excessive over-eating, beyond negative affect and
41 impulse-control deficits. That the hedonic properties of food (especially food availability),
42 emotional, and binge-eating behavior act as unique mediators suggest that interventions for
43 reward-sensitive women presenting with food addiction may benefit from targeting food
44 availability in addition to management of negative affect.

45

46 *Keywords:* Food Addiction; reward sensitivity; personality; hedonic eating; Reinforcement

47 Sensitivity Theory

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49 Reward sensitivity and food addiction in women

50 In recent years, there has been growing interest in the ‘addictive’ qualities of high
51 caloric foods. In a series of empirical and review papers, Davis and colleagues have
52 convincingly argued that overeating in today's "obesogenic environment" falls along a
53 spectrum of eating behavior that ranges from "passive overeating" to binge-eating disorder,
54 and at the most extreme level, to food addiction (Carlier, Marshe, Cmorejova, Davis, &
55 Muller, 2015; Davis, 2013a, 2013b). Food addiction is characterized by the excessive
56 overeating of high calorie food accompanied by loss of control and intense food cravings
57 (Gearhardt, Corbin, & Brownell, 2009). The impact of the concept in the area of addiction and
58 eating is further supported by a 9-fold increase in the number of journal articles referring to
59 food addiction from 2006 to 2010 (Gearhardt, Davis, Kushner, & Brownell, 2011). Following
60 from these comprehensive reviews, there is a current call “to think more mechanistically in the
61 evaluation of food addiction by examining the contribution of biological, psychological, and
62 behavioral circuits implicated in addiction to problematic eating behaviors.” (Meule &
63 Gearhardt, 2014, p. 3665). To that end we investigate a biologically-based trait of reward
64 sensitivity that has been used to better understand individual differences in the vulnerability to
65 addiction.

66 *Reward sensitivity - general approach motivation*

67 Beyond the role of basic metabolic processes, there is growing evidence that
68 psychological factors and brain chemistry regulate eating behavior. A burgeoning avenue of
69 enquiry in this area has focused on a personality trait referred to as Reward Sensitivity (Gray
70 & McNaughton, 2000). Reward sensitivity is a biologically-based, normally-distributed,
71 predisposition to seek out rewarding substances and to experience enjoyment in situations
72 with high reward potential. Reward sensitivity is proposed as the expression of an underlying

73 Behavioural Approach System (BAS); the mesolimbic dopamine “reward” pathways have
74 been proposed as the key biological basis of this trait (Gray & McNaughton). Both highly
75 palatable foods and potent drugs of abuse have long been known to activate the dopaminergic
76 “reward pathways” of the mid-brain, and are clearly implicated in the pursuit of natural (and
77 now, quite unnatural) rewards in the environment (Davis, 2013a). A core theme of recent
78 research has been the proposal that highly reward-sensitive individuals are more attuned to the
79 rewarding properties to the reinforcing properties of drugs of abuse and high fat/high sugary
80 “tasty” food (Dawe & Loxton, 2004; Hennehan, Loxton, & Mattar, 2013). Indeed, there has
81 been a rapidly increasing body of evidence supporting the association between reward
82 sensitivity and a range of addictive behaviors including alcohol abuse and illicit drug use
83 (Bijttebier, Beck, Claes, & Vandereycken, 2009; Dawe et al., 2007; Smillie, Loxton, & Avery,
84 2011). Heightened reward sensitivity has also been consistently associated with binge-eating,
85 a motivated approach response towards dessert images, having a preference for foods high in
86 fat and sugar, and a preference for colorful and varied food (Davis et al., 2007; Guerrieri,
87 Nederkoorn, & Jansen, 2007; Loxton & Dawe, 2006; May, Juergensen, & Demaree, 2016;
88 Schag, Schonleber, Teufel, Zipfel, & Giel, 2013). Activation of the reward pathways to
89 images of food correlates strongly with self-report measures of reward sensitivity (Beaver et
90 al., 2006). As such, heightened responsiveness to the rewarding properties of highly palatable
91 foods and drugs of abuse has been proposed as a common factor to over-eating and the abuse
92 of other substances (e.g., Loxton & Dawe, 2001; Loxton & Dawe, 2006).

93 *Food Addiction and Reward Responsiveness*

94 Food addiction or addictive-like eating has been operationalised in recent years by the
95 Yale Food Addiction Scale (YFAS) – a 25 item measure based on the diagnostic criteria for
96 substance dependence (Gearhardt et al., 2009). This scale, which assesses tolerance,

97 withdrawal, loss of control over eating, inability to stop eating, and negative impact on social
98 and occupational function, derives both a symptom count score (0 to 7) and a diagnosis (meet
99 3 or more criteria and clinical impairment). Both symptom count score and diagnostic status
100 classification have been used in research examining the validity, prevalence, and correlates of
101 food addiction (e.g., Davis et al., 2011; Davis & Loxton, 2014; Davis et al., 2013). Although
102 controversial, there is growing support for addictive-like eating behavior as assessed by the
103 YFAS (e.g., Carlier et al., 2015; Schulte, Joyner, Potenza, Grilo, & Gearhardt, 2015).

104 Differences in the responsiveness of the "reward" circuits of the mid-brain in the
105 vulnerability to food addiction have been supported by studies using fMRI and genetics.
106 Gearhardt, Yokum, et al. (2011) found the activation of brain regions involved in the
107 expectation of reward and attention and planning of food reward (when anticipating the
108 receipt of a chocolate milkshake) to be associated with food addiction symptom scores.
109 Taking a different approach, Davis et al. (2013) found a quantitative multilocus genetic profile
110 score, based on six polymorphisms related to elevated dopamine function (Nikolova, Ferrell,
111 Manuck, & Hariri, 2011), was positively associated with food addiction. This same profile
112 score was associated with a number of addictive behaviors (Davis & Loxton, 2013). Using a
113 computer task (Go/No-Go task), Meule, Lutz, Vogele, & Kubler (2012) found college women
114 with high food addiction symptom scores responded more quickly (pressed a computer key) to
115 high calorie food pictures than those with low scores. Together, such studies suggest greater
116 reward responsiveness are involved in food addiction.

117 *Mediators of reward responsiveness and food addiction*

118 In a previous study we found the association between genetic vulnerability and food
119 addiction to be mediated by binge-eating and food cravings (Davis et al., 2013). A composite
120 "hedonic responsiveness" (hedonic eating, food cravings, and a preference for high fat/sugary

121 foods) was found to mediate the association between a genetic variant linked with opioid
122 (pleasure) signaling and food addiction symptom scores (Davis & Loxton, 2014). We have
123 also found self-reported reward sensitivity to be associated with greater attention to food
124 stimuli, and a greater desire to eat when presented with food images (Hennegan et al., 2013).
125 Thus, potential mediators include an attraction to the hedonic properties of food, and a
126 tendency to notice and respond to food cues in the environment.

127 *Hedonic eating*

128 A key component of reward sensitivity is noticing and seeking out of appetitive
129 substances (Corr, 2008). While reward sensitivity is underpinned by a system involved in
130 seeking out appetitive substances more generally, hedonic eating refers to noticing and
131 seeking of food specifically. As such, hedonic eating is potentially a food-specific form of
132 reward-driven outcomes. Lowe et al. (2009) developed a scale to assess the motivation of
133 individuals to consume food beyond homeostatic need; i.e., hedonic eating. The Power of
134 Food Scale (PFS) assesses three aspect of hedonic eating based on proximity of food, 1) food
135 available but not present, 2) food present but not tasted, and 3) food tasted but not consumed.
136 The scale assesses the desire for food rather than the response to the consumption of food (as
137 would be captured by binge-eating measures). Thus, we would anticipate that reward
138 sensitivity and hedonic eating aspects would be positively associated, with reward sensitivity
139 being an enduring trait and hedonic eating a specific arena in which this desire for appetitive
140 substances is played out. In two previous studies, we found hedonic eating to be associated
141 with food addiction (Davis & Loxton, 2014; Davis et al., 2013). However, in these studies we
142 used the total PFS score. In the current study we were interested in the subscale scores (each
143 with increasing proximity to food) as Gray and McNaughton (2000) argue that those high in
144 reward sensitivity will notice and approach appetitive substances. However, reward sensitivity

145 is not associated with pleasure when consuming the substance (Corr, 2008). Using the PFS
146 subscale scores may provide greater insight into the specific aspects of hedonic eating
147 associated with reward sensitivity and food addiction.

148 *External and Emotional eating*

149 Smells and images associated with tasty foods (e.g., the smell of hot chips, pictures of
150 chocolate cake) activate the reward pathways even more strongly than the consumption of
151 food itself and have been linked with eating when otherwise sated (Cappelleri, Bushmakin,
152 Gerber, Leidy, Sexton, Lowe, et al., 2009; Schultz, 1998). Individuals high in reward
153 sensitivity show stronger associations (e.g., believe that eating is a good way to celebrate) and
154 external eating (eating in response to external food cues) than less reward-sensitive
155 individuals (Hennegan et al., 2013). The association with food addiction is mixed - external
156 eating was associated with food addiction diagnostic status in one sample of obese individuals
157 (Pepino, Stein, Eagon, & Klein, 2014) but not in another (Davis et al., 2011). Relatedly,
158 emotional eating reflects the tendency to eat in order to assuage negative emotional states.
159 While the association tends to be weaker than with external eating, emotional eating was
160 associated to reward sensitivity (Davis et al., 2007; Hennegan et al., 2013) and more recently
161 with food addiction (Davis et al., 2011; Pepino et al., 2014). Thus, we test external eating and
162 emotional eating as additional mediators of reward sensitivity and food addiction.

163 *Binge eating*

164 Binge-eating has also been implicated in the progression from a preference for
165 palatable foods to food addiction. For instance, in a sample of 72 obese adults, Davis et al.
166 (2011) found 25% met criteria for food addiction. Seventy percent of those who met criteria
167 for food addiction, also met criteria for Binge Eating Disorder, leading some to suggest that
168 food addiction is simply another term for Binge Eating Disorder (see Davis et al. 2013, for a

169 review of this issue). However, while there was considerable overlap, half of the participants
170 who met criteria for BED did not meet criteria for food addiction. A recent systematic review
171 found reward sensitivity played a key role in binge-eating disorder in obese samples (Schag et
172 al., 2013). Davis et al. (2013) has argued that binge-eating is a eating-related sub-phenotype
173 that plays a role in mediating high reward responsiveness and food addiction. This was
174 supported by binge-eating mediating the association between a multilocus genetic profile of
175 reward responsiveness and food addiction diagnosis (Davis et al. 2013). However, to our
176 knowledge this indirect effect of binge-eating has not been tested when investigating reward
177 sensitivity.

178 *Aims of the study*

179 The present study aims to extend the research investigating the association between
180 individual differences in reward sensitivity and food addiction via binge-eating, hedonic,
181 emotional, and externally-driven eating. We used an online survey to collect data from a large
182 sample of women from the community to test the model shown in Figure 1. Only women were
183 recruited in keeping with previous research investigating reward sensitivity and eating
184 behavior (Hennegan et al., 2013; Loxton & Dawe, 2001; Loxton & Dawe, 2006). It was
185 hypothesized that 1) higher levels of reward sensitivity would be associated with more food
186 addiction symptoms, 2) the association between reward sensitivity and food addiction would
187 be mediated via a) hedonic eating, b) external eating, c) emotional eating, and d) binge-eating.
188 Given previous research that food addiction has been associated with body mass, negative
189 affect, and trait impulsivity (Davis et al., 2011), we also tested whether the proposed model
190 continued to be supported when also controlling for these variables.

191 **Method**

192 **Participants**

193 A total of 382 women completed the online survey as part of a study investigating food
194 addiction, over-eating and reward sensitivity in women. Following the deletion of women
195 with substantial missing data or identified as multivariate outliers, 374 participants were
196 included in the subsequent analyses. Ninety-five percent were Caucasian, with the remainder
197 Asian, Indigenous Australian, or other ethnicity. Mean age was 30.58 years ($SD = 12.70$,
198 range 17-70 with 70% aged under 32 years). Body mass was in the normal range ($M = 24.00$,
199 $SD = 5.95$).

200 **Procedure**

201 The questionnaires were administered online using Qualtrics (www.qualtrics.com:
202 Qualtrics Labs Inc., Provo, UT). Participants were recruited from undergraduate Psychology
203 students and via advertisements on social media. Psychology students were given course
204 credit for participation. The questionnaire took approximately 30-40 minutes to complete.
205 Following completion, participants were given the option of leaving their email address on a
206 separate secure webpage should they wish to be contacted with the results of the study and if
207 they were interested in completing a subsequent study. Ethics clearance was obtained through
208 the University's Behavioural and Social Sciences Ethical Review Committee.

209 **Measures**

210 **The Sensitivity to Reward Scale** (SR; Torrubia, Avila, Molto, & Caseras, 2001) was
211 used to assess reward sensitivity. The SR scale consists of 24 dichotomously-scored items and
212 includes situations in which individuals may strive for reward (e.g., "Does the prospect of
213 obtaining money motivate you strongly to do some things?"). Positively endorsed scores are
214 summed to create a total score. Internal consistency for the scale was .80.

215 **The Power of Food Scale** (PFS; Lowe et al., 2009) was used to assess hedonic eating.
216 This 15-item questionnaire differentiates between motivations and drive to obtain food from
217 the tendency to over-eat. All questions are answered on a 5-point Likert scale ranging from 1
218 (Strongly Disagree) to 5 (Strongly Agree). A total mean score represents a greater
219 responsiveness to the food environment. Three subscale scores can be derived: 1) Food
220 availability, e.g., “It seems like I have food on my mind a lot”, 2) Food Present, e.g., “ If I see
221 or smell a food I like, I get a powerful urge to have some.”, and 3) Food tasted, e.g., “Just
222 before I taste a favorite food, I feel intense anticipation”. Cronbach's alphas in the current
223 study were (total = .82; Food available = .89; Food present = .88; Food Tasted = .82). Mean
224 scores for the three subscales (Food available = 2.03; Food present = 2.63; Food Tasted =
225 2.48) were higher than that found in Cappelleri, Bushmakin, Gerber, Leidy, Sexton, Karlsson,
226 et al. (2009) web-based survey of non-obese participants, although the mean total score (2.33)
227 was similar to Lowe (2009).

228 **The Dutch Eating Behavior Questionnaire** (DEBQ; Van Strien, Frijters, Bergers, &
229 Defares, 1986) was used to assess external and emotional eating. The external eating subscale
230 consists of 10 items using a 5-point Likert scale from 1 (never) to 5 (very often). The scale is a
231 measure of disinhibited eating triggered by external cues such as taste, smell and others
232 behavior (e.g., “If you see or smell something delicious, do you have a desire to eat it?”). The
233 emotional eating scale consists of 13 items and is a good measure of eating cued by emotional
234 events (e.g., “Do you have a desire to eat when you are feeling lonely?”). Mean scores were
235 used to assess responsiveness to external food cues and using food to manage negative
236 emotions. Cronbach's alphas in the current study were .85 for external eating and .96 for
237 emotional eating.

238 **The Binge Eating Questionnaire** (BEQ; Halimi, Falk, & Schwartz, 1981). The five
239 items of the BEQ that assess binge eating (rather than purging) were used in the current
240 study. This was done to help better capture the study's goals of measuring eating behavior.
241 Example items include, "Are there times when you are afraid you cannot stop voluntarily
242 eating. Cronbach's alpha in the current study was .76.

243 **Yale Food Addiction Scale** (YFAS; Gearhardt et al., 2009). The 25-item YFAS was
244 used to assess food addiction symptoms. Similar to the DSM-IV substance-dependence
245 criteria, a diagnosis of food addiction can be given if the respondent experiences three or more
246 symptoms over the past year, and if the "clinically significant impairment" criterion is met. A
247 continuous, symptom count score is obtained by summing the number of symptoms endorsed,
248 and can range from 0 to 7. Kuder-Richardson test of internal reliability in the current study
249 was .83. Using the diagnostic scoring, 5.5% of the sample ($n = 20$) met criteria for food
250 addiction, which is lower than that typically found in normal weight samples (Pursey,
251 Stanwell, Gearhardt, Collins, & Burrows, 2014). However, the mean (1.56) was similar to the
252 mean found in non-clinical populations (1.70, Pursey et al., 2014).

253 **Covariates.** Depressed mood, stress, and anxiety are frequently associated with eating
254 problems, including food addiction (e.g., Davis et al 2011), and thus were assessed as possible
255 covariates. The 21-item, Depression, Anxiety and Stress Scale (DASS; Lovibond & Lovibond,
256 1995) includes a depression scale, an anxiety scale, and a stress scale. Higher scores reflect
257 higher levels of psychological distress and is well established for use in research. The internal
258 reliability of the scales in the present study were: Depression = .87, Anxiety = .74, Stress =
259 .86.

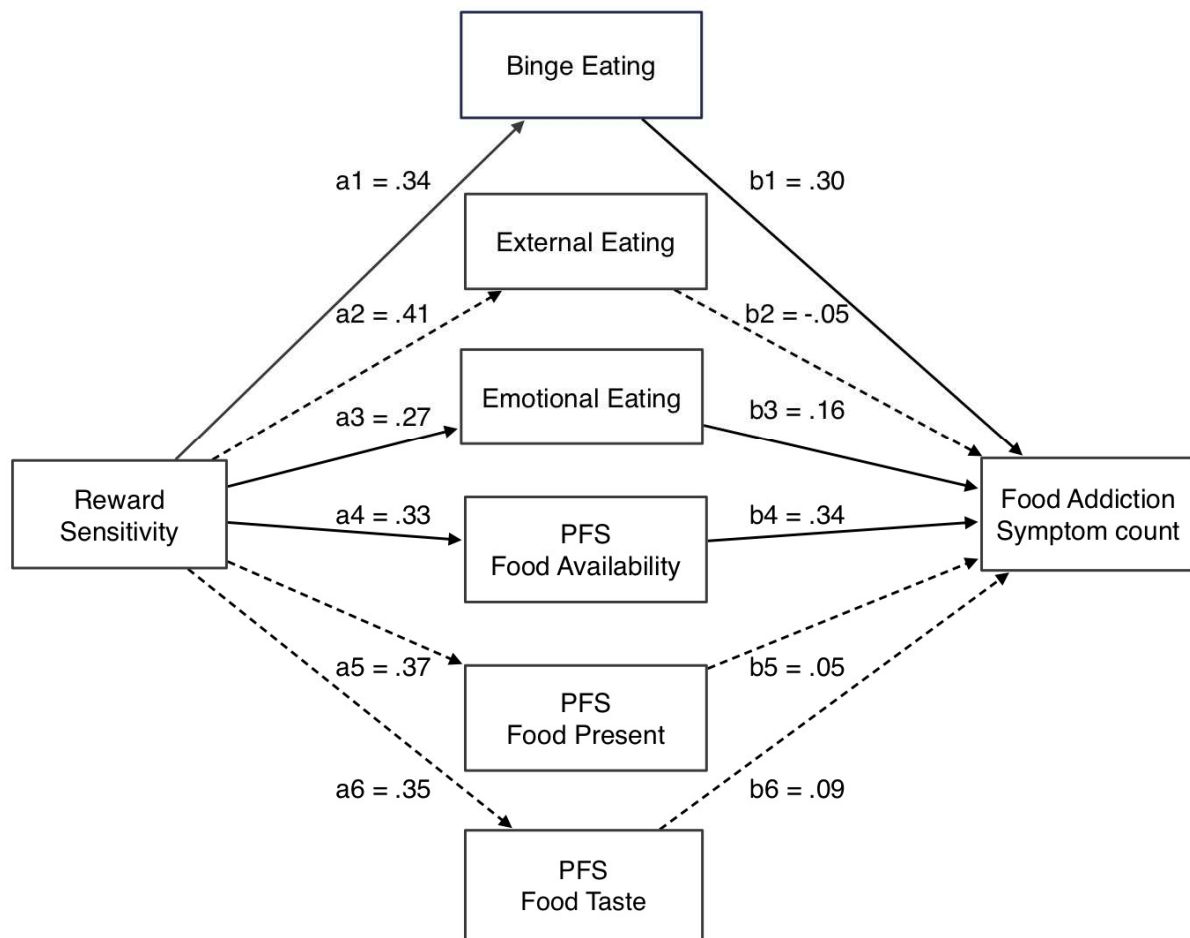
260 While reward sensitivity has previously been referred to as "impulsivity" there is
261 consensus that reward sensitivity is conceptually and neurologically distinct from impulsivity

262 as typically conceptualized (e.g., Dawe & Loxton, 2004). However, given there is some
263 overlap between these traits (typically correlating .3), we also assessed "trait impulsivity" as a
264 potential covariate. The total score of the 30-item Barratt Impulsiveness Scale (BIS-11;
265 Patton, Stanford, & Barratt, 1995) was used to measure "trait impulsivity". Alpha for this
266 scale was .82.

267 **Analysis plan**

268 Associations between reward sensitivity, food addiction, binge-eating, hedonic eating,
269 external eating, and emotional eating were first tested using bivariate correlations. To test
270 binge-eating, external eating, and hedonic eating as mediators of reward sensitivity and food
271 addiction, a multiple mediation model was conducted according to procedures described by
272 Hayes (2013). Binge-eating, hedonic subscales, emotional and external eating were entered as
273 mediators as shown in Figure 1. Bias-corrected bootstrap confidence intervals ($n = 10000$,
274 confidence intervals set at 95%) were used to assess the significance of the indirect effects. An
275 advantage of the bootstrapping approach relevant to the current study is that the assumption of
276 normality is not required. The SPSS "PROCESS" macro, model 4, v2.16 (Hayes, 2013) was
277 used to test the significance of the overall indirect effects. The absence of zero within the
278 confidence intervals suggests a significant indirect effect. This approach provides an estimate
279 of the overall indirect effect of the mediators as a group (analogous to R in multiple
280 regression) as well as estimates of each mediator (controlling for the other mediators;
281 analogous to b weights in multiple regression, e.g., in Figure 1 the product of a_1 and b_1 is the
282 specific indirect effect of reward sensitivity on food addiction via binge-eating, controlling for
283 the other mediators).

284



285

286 *Figure 1. Indirect effects of reward sensitivity and YFAS symptom count via binge-eating,*
 287 *external eating, emotional eating, and hedonic eating.*

288 *Note.* All values are standardized regression coefficients. Each 'a' path is the effect of reward
 289 sensitivity on the mediating variables. The 'b' paths represent the associations between the
 290 mediating variables and YFAS symptom score. Solid lines represent significant indirect effects.
 291 Dashed lines represent non-significant indirect effects.

292

293

Results

294 **Descriptives**

295 While there was positive skew in all the eating variables (as expected in a community
296 sample) this is accounted for in the bootstrapped tests and thus were not transformed.

297 Descriptive statistics and correlations between all variables are shown in Table 1. Reward
298 sensitivity was significantly associated with food addiction, binge-eating, emotional eating,
299 external eating, and hedonic eating subscales. The correlations between the PFS subscales and
300 the DEBQ external eating scale were of a similar magnitude to that found in Lowe et al
301 (2009). Reward sensitivity was moderately correlated with the total PFS score ($r = .38$).
302 YFAS scores were significantly associated with age ($r = -.12$), BMI ($r = .20$), trait impulsivity
303 ($r = .21$), anxiety ($r = .34$), depression ($r = .34$), and stress ($r = .37$). As such we tested the
304 mediation model without and without these covariates.

305 **Tests of Indirect Effects on YFAS symptom scores**

306 As shown in Figure 1, binge-eating, emotional eating, externally-driven eating, and
307 hedonic eating subscales were entered as parallel mediators. Table 2 provides the total and
308 specific indirect effects when using the YFAS symptom scores. The overall total indirect
309 effect of reward sensitivity and food addiction via the mediating variables (i.e., the indirect
310 effect via the six mediators combined) was significant. However, when controlling for the
311 shared variance between the mediators (i.e., the specific indirect effects), only the binge-items
312 of the BEQ, the DEBQ Emotional Eating subscale, and the “Food Availability” subscale of
313 the PFS were significant. There was no difference in the magnitude of the significant indirect
314 effects. The overall model (reward sensitivity, hedonic eating subscales, binge-eating,
315 emotional and external eating) accounted for over 48% of the variance in food addiction
316 symptom count. See Figure 1 for standardized coefficients. When using the total PFS score
317 rather than the three subscale scores in the model, there was a significant indirect effect of

318 reward sensitivity and YFAS symptom count via overall hedonic eating, controlling for binge-
319 eating, external, and emotional eating (unique indirect effect = .05; SE = .01; 95CI = .03; .07).

320 **Covariates**

321 To assess whether the associations between reward sensitivity, YFAS, and the
322 mediating variables were due to shared variance in negative affect (i.e., depression, anxiety,
323 stress), trait impulsivity, age, or weight, a subsequent model was tested in which DASS
324 depression, anxiety, and stress, BIS-11, age, and BMI, were included as covariates. There was
325 virtually no change to any coefficients and the indirect effects via binge-eating, emotional
326 eating and PFS food availability remained significantly different from zero.

327 **Ancillary Tests of Indirect Effects using YFAS diagnosis scores**

328 Although there were relatively few participants who met diagnostic criteria for food
329 addiction ($n = 20$) we ran ancillary analyses to assess whether the same pattern of results was
330 found for the association between reward sensitivity and YFAS diagnosis status as the
331 outcome variable. Reward sensitivity was significantly higher in the YFAS diagnosis group
332 ($M = 12.30$) than the no YFAS diagnosis group ($M = 8.36$; $t[365] = 4.10$, $p < .001$). In the first
333 model with the PFS subscales, binge-eating, external eating, and emotional eating as the
334 mediators, the overall total indirect effect of reward sensitivity and food addiction via these
335 variables was still significant (indirect effect = .18, SE = .10, 95CI: .07; .30). However, when
336 controlling for the shared variance between the mediators only the binge-eating showed a
337 significant unique indirect effect (95CI: .02; .26). Unlike in the previous analysis, there was
338 no significant effect via emotional eating (95CI: -.10 ; .09). The indirect effect via PFS Food
339 Availability subscale (95CI: -.02; .20) also dropped to non-significance. The external eating
340 scale and other PFS subscales remained non-significant. In a second model using the total PFS

341 score instead of the subscales, there was a significant indirect effect via hedonic eating (95CI:
342 .03; .21) as well as via binge-eating (95CI: .04; .24).

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344 Table 1

345

346 *Descriptive statistics and correlations among the variables*

	<i>M</i>	<i>SD</i>	1	2	3	4	5	6	7
1. Reward Sensitivity	8.58	4.26	-						
2. Binge Eating	1.23	1.43	.33***	-					
3. External Eating	3.06	.60	.41***	.35***	-				
4. Emotional eating	2.54	.95	.27***	.52***	.53***	-			
5. PFS: Food Available	2.03	.95	.33***	.61***	.57***	.63***	-		
6. PFS: Food present	2.63	1.02	.37***	.49***	.72***	.52***	.74***	-	
7. PFS: Food tasted	2.48	.92	.35***	.35***	.54***	.32***	.66***	.69***	-
8. Food Addiction Symptoms	1.56	1.34	.31***	.56***	.37***	.49***	.61***	.50***	.42***

347 *Note.* PFS = Power of Food Scale. *** $p < .001$

348 Table 2

349 *Unstandardized Indirect effects of reward sensitivity and food addiction symptom scores via*
 350 *binge eating, external eating, emotional eating, and hedonic eating subscales*

	Bootstrap estimate	SE	BC 95% CI lower	BC 95% CI upper
Binge eating	.028*	.007	.015	.044
External eating	-.013	.008	-.031	.002
Emotional eating	.014*	.006	.005	.027
PFS: Food Available	.032*	.010	.016	.055
PFS: Food Present	.006	.008	-.009	.023
PFS: Food Tasted	.008	.006	-.003	.021
Total Indirect effect	.076*	.013	.051	.102

351 *Note.* PFS = Power of Food Scale. Based on 10000 bootstrap samples. BC = bias corrected;
 352 CI = Confidence Interval,

353 * Indirect effect is significantly different from zero. Unstandardized indirect effect reported.

354

355

Discussion

356 The results of the study supported the hypothesis that reward sensitivity was associated
 357 with greater food addiction symptoms. Further, tests of indirect effects found the relationship
 358 between reward sensitivity and food addiction to be uniquely mediated by binge-eating,
 359 emotional eating, and hedonic eating (notably, food availability). These indirect effects held
 360 even when controlling for BMI, anxiety, stress, depression, and trait impulsivity. When using
 361 YFAS diagnostic status as the outcome, binge-eating and hedonic eating (as a total score)
 362 mediated the association between reward sensitivity and food addiction.

363 The association between reward sensitivity and food addiction symptom scores, and
364 the higher reward sensitivity score in those meeting food addiction diagnosis is in accord with
365 research showing an association between food addiction and a genetic profile linked to reward
366 responsiveness (Davis et al. 2013). Reward sensitivity has also been consistently found to be
367 associated with overeating (Bijttebier et al., 2009) and mid-brain responsiveness to appetitive
368 food cues (Beaver et al., 2006). This association, however, is somewhat at odds with two
369 previous studies that have found minimal association between YFAS scores and reward
370 sensitivity (Clark & Saules, 2013; Gearhardt et al., 2009). This may be due to differences in
371 the measures used to assess reward sensitivity. Both earlier studies used the total BAS scale
372 score from the Carver and White (1994) BIS/BAS scale, whereas in this study we used the
373 Torrubia et al. (2001) Sensitivity to Reward Scale. The BIS/BAS scale consists of a single
374 Behavioural Inhibition System (BIS) scale (a measure of punishment sensitivity) and three
375 BAS scales (fun-seeking, drive, reward responsiveness). Confirmatory factor analyses have
376 consistently supported the use of separate subscale scores, rather than a total BAS score (e.g.,
377 Heubeck, Wilkinson, & Cologon, 1998; Jorm et al., 1999). More importantly, the BAS
378 subscales also tend to correlate differentially with over-eating, hazardous drinking, and illicit
379 drug use (Loxton & Dawe, 2001; Loxton et al., 2008; May et al., 2016; Voigt et al., 2009). For
380 example, Loxton and Dawe (2001) found only two of these subscales (fun-seeking and drive)
381 to be associated with hazardous drinking and only one subscale (fun-seeking) to be associated
382 with dysfunctional eating. Voigt et al. similarly found the fun-seeking scale to be associated
383 with greater alcohol and drug use, and the reward responsiveness scale to be associated *lesser*
384 alcohol and drug use. Using the total BAS score may therefore miss significant associations
385 with specific subscales. Future research may benefit from using measures that include BAS
386 subscales to compare results.

387 A recent analysis of current measures of reward sensitivity found that a (short version)
388 of the Sensitivity to Reward Scale captures trait impulsivity as well as reward sensitivity
389 (Krupić, Corr, Ručević, Križanić, & Gračanin, 2016). As such, the associations we find
390 between the Sensitivity to Reward Scale and YFAS may reflect both reward sensitivity and
391 trait impulsivity. However, even when we controlled for trait impulsivity, the model still held
392 suggesting that impulsivity alone does not account for the association found in the current
393 study. Nevertheless, in future studies alternative measures of reward sensitivity (e.g., Corr &
394 Cooper, 2016) may assist in better understanding the association of reward sensitivity and
395 food addiction.

396 This is the first study to examine the association between reward sensitivity and the
397 subscales of the Power of Food scale (Davis et al., 2011; 2013). Reward sensitivity was
398 moderately associated with all three subscales and the total score. While the indirect effect via
399 hedonic eating was supported using the total score, when using the subscale scores only the
400 "food available" subscale showed a significant unique indirect effect. This subscale assesses
401 the tendency to be aware of and drawn towards food that could be obtained but is not currently
402 present. The use of the multiple mediation approach is similar to the use of multiple regression
403 whereby there was a unique indirect effect of "food availability" when controlling for the
404 other mediators. This adds to the literature on hedonic eating and food addiction with the more
405 distal component (i.e., being aware of the availability of food) playing a unique factor in food
406 addiction symptoms in generally normal weight women. Given this is the only study to
407 explicitly examine the PFS subscale, these findings need replication.

408 In an earlier study we found reward sensitivity to be associated with external and
409 emotional eating (Hennegan et al., 2013). In that study the association between external
410 eating, but not, emotional eating, was mediated via the expectations that eating is rewarding.

411 In the current study, reward sensitivity was again associated with both external eating and
412 emotional eating. However, in this study only emotional eating showed a significant unique
413 indirect effect when using the YFAS symptom count score. The indirect effect was non-
414 significant when using diagnostic status. This reflects a previous study (Davis, et al., 2013)
415 where emotional eating did not show a unique indirect effect of a genetic profile score of
416 dopamine responsiveness and YFAS diagnosis. The difference in the finding that emotional
417 eating was associated with YFAS symptom count, but not YFAS diagnostic status may reflect
418 lower power when using the categorical clinical score relative to the continuous symptom
419 count - in both studies, the number of participants meeting diagnostic criteria was small (20 in
420 the current study, 21 in Davis et al.). Alternatively, emotional eating may be associated with
421 subclinical levels of addictive-like eating, but not in the development of clinically severe
422 levels of food addiction. To tease out these differences requires samples with larger numbers
423 of participants with clinical significant food addiction.

424 The association between external eating and food addiction has been mixed, with one
425 study of obese individuals finding no difference in external eating between those meeting
426 diagnostic criteria for food addiction and those that did not (Davis et al., 2011), while another
427 sample of obese patients undergoing bariatric surgery has found a difference (Pepino, et al.,
428 2014). In this study, there was an association between external eating and food addiction
429 symptoms. However, this became non-significant when controlling for the other eating
430 variables.

431 As previously found, reward sensitivity was associated with a measure of binge-eating
432 (Bijttebier et al 2009). Binge-eating was again supported as a mediator of an index of reward
433 responsiveness and food addiction. The current study adds further support to Davis's (2013a)
434 contention that "food addiction is a reward-responsive phenotype of obesity" and proposal of

435 "a reward-based process model whereby an inherent biological susceptibility contributes to
436 increased risk for overeating, which in turn may promote addictive tendencies toward certain
437 highly palatable foods" (p. 173). We extend this proposal by explicitly linking a biologically-
438 based personality trait as a phenotypic risk factor for binge-eating and hedonic-eating; eating-
439 related behaviors that may lead to food addiction (and potentially obesity).

440 **Limitations**

441 We note that this is the first study to find an association between reward sensitivity and
442 food addiction. In other studies in which this trait has been measured there have been non-
443 significant associations. While we have suggested that the difference may reflect the use of
444 different measures of reward sensitivity, another possibility is that the association found in
445 this study may be a spurious finding. However, in a number of other (unpublished) studies we
446 have performed using similar samples and the same measure, we have consistently found
447 associations of a similar magnitude. As noted, given the different measures of reward
448 sensitivity are used in the study of addictive-like eating, future research should include
449 additional scales to determine whether the association with food addiction is only found with
450 this specific measure.

451 As with any cross-sectional study, causal effects cannot be established and prospective
452 studies are required. This is critical in this area as there is evidence using animal models that a
453 diet of hyper-palatable foods changes the reward pathways in the mid-brain - the very region
454 underpinning individual differences in reward sensitivity. We also used an online survey that
455 was promoted as a study of "health in women", which may have targeted participants with an
456 interest in health more generally. We note that the prevalence of women who met criteria for
457 food addiction was lower than that have found in other samples collected in Australia (e.g.,
458 Pursey, Collins, Stanwell, & Burrows, 2015). We also note that the study only used women

459 and so the associations found in this study may not generalise to men. However, we note that
460 in our previous studies of a genetic index of reward responsiveness and food addiction that
461 there were no apparent differences between men and women (Davis et al., 2013).
462 Nevertheless, this is a significant limitation that would need to be addressed in future research
463 examining reward responsiveness and addictive-like eating.

464 **Conclusions**

465 This study further supports the argument that high levels of reward sensitivity may
466 offer a trait marker of vulnerability to excessive over-eating, beyond negative affect and
467 impulse-control deficits. That the hedonic properties of food (especially food availability) and
468 binge-eating behavior act as unique mediators suggest that interventions for reward-sensitive
469 women presenting with food addiction may benefit from targeting food availability. There is
470 growing evidence that public health interventions on obesity, such as provision of dietary
471 guidelines, are largely ineffective, in part, due to the failure to account for individual
472 differences in people's response to food availability and the promotion of unhealthy foods in
473 the environment. Binge-eating behavior also plays a key role in the development and
474 maintenance of food addiction symptoms. An impulsivity-focused treatment program has
475 recently been proposed (Schag et al., 2015). Such personality-targeted interventions have had
476 promising results in the reduction of binge-drinking and drug use in adolescents (e.g., Conrod,
477 Castellanos, & Mackie, 2008). Given the clear links between food addiction and traditional
478 addictions, such approaches may be effective with reward-driven over-eating.

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