Neurobiology of Feeding, Eating, Food Addiction, and Binge Eating Disorder

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Abstract

Binge eating disorder (BED) is an autonomous DSM-5 mental health and eating disorder diagnosis characterized by discrete, rapid consumption of objectively large amounts of food associated with loss of control and distress that occur >3/wk. for >3 months. The disorder has high lifetime prevalence rates, low treatment rates, and high rates of treatment dissatisfaction, early discontinuation of care, and recurrence. Moreover, it is characterized by a complicated and costly health sequelae that includes a host of whole-systems health carries, including childhood and lifetime adversity and trauma, impaired cognitive function and emotion regulation, anxiety and depression, trauma and post-traumatic stress disorder (PTSD), low self-esteem, substance-related and addictive disorders (SRADs), overweight and obesity, hypercholesterolemia and hyperlipidemia, diabetes, cardiovascular disease, and (all together) cardiometabolic disorder, and overall significantly impaired quality of life. Emerging research highlights the role of reward dysregulation and food/eating addiction in the pathophysiology of binge eating disorder, especially in the ~30-50% of individuals with binge eating disorder who do not respond to conventional treatment approaches that advocate cognitive behavioral awareness and endorse body acceptance and an “all foods fit” model of eating. However, despite a robust body of supportive and validating preclinical and clinical research literature, the topic of food or eating addiction remains controversial among clinicians and clinical researchers and poses questions for treatment models. Here, we provide an overview of existing literature findings on the clinical and neurobiological underpinnings of food and eating, binge eating disorder, and food addiction. We address several limitations in this literature and identify areas where this literature proposes challenges to the field, and particularly to clinicians. We address the issue of nomenclature and use of the word “addiction” as being unpalatable in many clinical perspectives. We provide a harmonious perspective on how these findings can be applied to clinical treatment approaches and advocate for research funding that enables the development and exploration of empirically supported treatment interventions that may be particularly effective for individuals with binge eating disorder who self-report issues with reward regulation or screen positive for “Food Addiction” according to the Yale Food Addiction Scale v2.0. Overall, this review aims to help clinician-researchers, clinicians, and policy-makers alike identify, contemplate, and question their own biases around the topic of “food and/or eating addiction” in effort to form a more inclusive treatment perspective that may help improve current treatment outcomes and success rates while also advancing our understanding of this complex bio-psycho-social issue.

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# Introduction

## Binge Eating Disorder: An Autonomous DSM-V Diagnosis

Binge eating disorder (BED) is an autonomous DSM-V/DSM-V-TR mental health and eating disorder diagnosis1 characterized by recurrent binge eating episodes that occur at least once weekly for at least three months in the absence compensatory behaviors.2 These discrete (~2-hr) episodes involve rapidly consuming large amounts of food (more than others would under similar circumstances) with a sense of loss of control and marked distress about the binge eating, accompanied by feelings of embarrassment, guilt, shame, disgust, depression, isolation, and often physical discomfort.2,3

Between 4.5-31% of adults in the U.S. and globally will be diagnosed with binge eating disorder at some point in their lifetime,4,5 amounting to nearly 3 million adults in the U.S. alone.4 Moreover, studies find that 93.4–96.8%6,7 of individuals who meet DSM criteria for BED never receive a formal diagnosis and 67.3% do not perceive the need for formal treatment.4,6 These findings suggest that BED may have a much higher prevalence than has been previously estimated and may impact as much as 95% of the U.S. and global populations at some point in their lifetime.

BED also has a complex and costly8-12 health sequela that includes childhood and lifetime adversity and trauma,13-16 loneliness,17-22 impaired cognitive function and emotion regulation,17-22 anxiety, depression, and suicidality,14,16,23 trauma and post-traumatic stress disorder (PTSD),13-16 low self-esteem,13-15 substance-related and addictive disorders (SRADs),14,16,23 overweight and obesity,15,16,24,25 hypercholesterolemia and hyperlipidemia, diabetes,16,24 cardiovascular disease,26-29 and (all together) cardiometabolic disorder,16,24,30-36 and overall significantly impaired quality of life.8,9,37,38,4,14,16-22,39-44

## Standard Treatments for Binge Eating Disorder Have <50% Success Rates

Standard of care Guideline-approved interventions for BED include eating-disorder-focused cognitive behavioral therapy (CBT) or interpersonal therapy in individual or group formats.3,45-48 Medications (antidepressants and lisdexamfetamine // Vyvanse) are also suggested for those who prefer them or do not respond to psychotherapy alone.3,45-48

Nutritional counseling,45,49 behavioral weight loss,45 family-based therapy (FBT) and other psychodynamic therapies, 45,49 humanistic therapy,49 dialectical behavioral therapy (DBT),50,51. DBT and CBT guided self-help,50,51 alternative pharmacotherpies (including anticonvulsants, anxiolytics, other anti-obesity/weight loss medications),45 and complementary and integrative health interventions (e.g., mindfulness, meditation, yoga, acupuncture, and testing for dysregulations or deficiencies in hormones, micronutrients or gut microbes)52 are also used, empirically supported, and in some cases included in treatment guidelines internationally.3,45-48,52

Despite the array of options, these interventions generally have low success rates, high recurrence rates, high treatment dissatisfaction, and early discontinuation of care.4,40,48,53-55 Specifically, less than half of adults who receive standard treatment for binge eating disorder find a complete reversal of their symptoms ([38.3](https://pubmed.ncbi.nlm.nih.gov/23290497/)–[43.6](https://pubmed.ncbi.nlm.nih.gov/16815322/)%),4,40 and over half of those relapse ([49](https://pubmed.ncbi.nlm.nih.gov/21859185/)–[64](https://pubmed.ncbi.nlm.nih.gov/16815322/)%).4,53 Combining standard of care interventions does not seem to improve or enhance treatment outcomes.48,55 For example, CBT has a <50% success rate in fully alleviating BED symptoms.48,55 Pharmacotherapy for BED is less effective than CBT and does not enhance the success of CBT in alleviating BED symptoms.48,55 Moreover, studies find that 56.4–86.8% of individuals with binge eating disorder never receive or pursue standard treatment,4,6 which makes it difficult to estimate potential treatment outcomes for this population.

## Evolving Understanding & Acceptance of Binge Eating Disorder Pathology

Historically, there is a tendency to view binge eating disorder as resulting from overevaluation of body weight/shape/size leading to food/eating restriction and subsequent binge eating (e.g., transdiagnostic-, dietary restraint-, and dual pathway models).15,45,56-59 However, several alternative conceptualizations of binge eating disorder have gained attention in recent years.15,57 These include:

1. “Food/eating addiction" and reward dysregulation models/phenotypes thought to be driven by mechanisms implicit in substance-related and addictive disorders (e.g., hedonic/reward-based symptoms like impulsivity, obsesionality and compulsivity, craving and reward hyperresponsivity or issues with reward regulation).15,57,60-104
2. Self-regulatory models that focus on  dysregulated inhibitory control and include hypersensitivity, impulsivity, emotion//affect dysregulation, *and reward dysregulation*.15,57,105-108
3. Neurocognitive and neurobiological models that focus on neurobiological alterations and tend to endorse "food/eating addiction," reward dysregulation, and self-regulatory models described above.15,57,109-112

These models often align with- and support one another in a variety of ways.57,113

Research has increasingly focused on the role of reward dysregulation and food addiction in the pathophysiology of BED,114-116 especially in the ~57–62% of individuals with binge eating disorder who do not respond to conventional treatment approaches4,40,48,55 that advocate cognitive behavioral awareness and endorse body acceptance and an “all foods fit” model of eating within a standard consumer-driven diet.4,13,15,40,48,55

# Reward Dysregulation in Binge Eating Disorder

Reward dysregulation in binge eating disorder involves changes in brain pathways and neurotransmitter systems responsible for motivation and reinforcement,63,71,76,83,90,91,97,116-121 similar to those observed in substance-related addictive disorders.57,68,83,105-107,110,119,121-126-93,127-90,91,114,119-121,124,126,128-136

Preclinical and human neuroimaging studies have shown that binge eating of palatable foods leads to changes in dopamine (DA), acetylcholine (Ach), and opioid systems, and alterations in reward-related brain areas like the ventral striatum/nucleus accumbens (NAc), additional limbic regions like the amygdala, and hippocampus, frontal cortical regions like the orbitofrontal cortex (OFC), and regulatory processing regions like the prefrontal cortex (PFC).108,118,129,137-141-90,91,93,116,119-121,124,126-129,131-136,142-149

These alterations may contribute to the compulsive eating behaviors observed in binge eating disorder.57,68,83,105-107,110,119,121-126-93,108,118,127,129,137-141-90,91,93,116,119-121,124,126-129,131-136,142-149-83,90,91,97,106,116,117,119-121,124,126,129,130,132,134,149,150

It bodes mentioning that at the time of this publication, a large portion of the neurobiological findings that support the overlapping underpinnings that exist in binge eating disorder and substance-related addictive disorders come from the Director of the U.S. National Institute on Drug Abuse (NIDA), Nora Volkow,77,91,119,128,132,135,138-141,147,151-161 and U.S. National Institute on Alcohol Abuse and Alcoholism (NIAAA) Director George Koob.91,97,121,133,143,144,146,162-169

# “Food Addiction

The concept of “food addiction” in BED is controversial. While “food addiction” is not a formal DSM-V diagnosis, it *is* an operationally-defined construct that is well-supported by preclinical and clinical research.60,63,65-67,70-73,76,90,115,131----40,54,60,63,64,68,69,71,72,74-76,78-88,90-92,94-97,114-121,128-133,170-187 Broadly, the construct of “food addiction” describes addictive-like responses to highly palatable foods, similar to those evoked by substances abuse.[include Gearhardt citation]76,83,85,95 Preclinical and clinical studies find that certain foods, especially those high in sugar and fat, can trigger the brain's reward and pleasure centers, leading to compulsive, addictive-live patterns of consumption.60-63,65-67,70-73,76,90,98,115,131,187-{Studies also find that like substance-related and addictive disorders (SRADs),188 binge eating disorder often presents as a chronically relapsing disorder (standard of care interventions have relapse rates ranging from [49](https://pubmed.ncbi.nlm.nih.gov/21859185/)–[64](https://pubmed.ncbi.nlm.nih.gov/16815322/)%)4,53 characterized by preoccupation and craving, impaired control of consumption (e.g., loss of control, a diagnostic criteria of binge eating disorder),1 social impairment, persistence despite risks, and aspects of impulsivity, compulsivity, sensitization, tolerance, withdrawal, and relapse, with environmental, genetic, and neurobiological factors.91,99,100,102,104,114,122,123,189

To better assess signs of addictive-like eating behavior, the Yale Food Addiction Scale (YFAS) was developed and validated in a large range of clinical and community samples.69,75,87,96,98,99,134 Now in its second version, the YFAS 2.0 applies the DSM-5 criteria for substance-related and addictive disorders (SRADs)188,190 to food/eating, replacing the terms “*drug” and “drug use”* with “*food(s),” “eating,” and/or binge eating*.*”*75,99,191

Using this criteria, the YFAS 2.0 finds that 10-20% of Americans meet the YFAS/DSM-V criteria for having a SRAD to food or eating,70,75 paralleling prevalence rates observed for substance related and addictive disorders.192

Studies find that in community samples, groups of individuals *with* food addiction have significantly greater rates of:

* Caucasian or “other” ethnicity (in a Brazilian sample):
  + Caucasian ethnicity: 53.3% vs. 44.9%; P<0.001.
  + Non-Caucasian, African American, “Mullato,” or Asian: 7.6% vs. 4.6%; P<0.001.
* Female gender orientation (87.6% vs. 70.6%; P<0.001)
* Comorbid mental health disorder:
  + Major depressive episode: 66.1% vs. 27.1%; P<0.001.
  + Bipolar spectrum disorder: 15.2% vs. 7.3%; P<0.001.
  + Skin picking disorder: 3.2% vs. 8.2%; P<0.001.
  + Suicidal ideation: 48.5% vs. 23.9%; P<0.001
* Family history of mental health disorder (51.2% vs. 43.3%; P<0.001)
* Adoption status/history (5.8% vs. 3.3%; P<0.001)
* Past or current use of psychotropic drugs (45% vs. 25%; P<0.001)
* Spiritist or agnostic religion:
  + Spiritist: 10.6% vs 8.0%; P = 0.027.
  + Agnostic: 20.6% vs. 15.5%; P = 0.027.

## Food Addiction Prevalence Rates

YFAS “food addiction” also has increased prevalence rates (above the 10-20% prevalence rates observed in the general population) in specific sub-populations and pathologies that also have increased prevalence and comorbidity rates in BED. These include:

* [Bulimia nervosa (81-98% YFAS food addiction prevalence)](https://pubmed.ncbi.nlm.nih.gov/35041154/).84,193,194
* Binge eating disorder (55-95%).70,73,84
* Morbid obesity and bariatric surgical patients (60%).195,196
* [Polycystic ovarian syndrome (PCOS, 55%)](https://pubmed.ncbi.nlm.nih.gov/37950975/).197
* [Anorexia nervosa (44-88%)](https://pubmed.ncbi.nlm.nih.gov/36415030/).84,193
* [Obesity (25-55%)](https://pubmed.ncbi.nlm.nih.gov/32855515/).194,195
* [Breast cancer (23-50%)](https://pmc.ncbi.nlm.nih.gov/articles/PMC9407804/pdf/ijerph-19-10299.pdf).198
* [Type 2 diabetes (30%)](https://pubmed.ncbi.nlm.nih.gov/39870489/).199
* [Tobacco, alcohol, cocaine, heroin, and cannabis use (12-30%)](https://link.springer.com/article/10.1007/s40519-020-00865-z).200
* [Depression (20%)](https://pubmed.ncbi.nlm.nih.gov/29368800/).92
* [Anxiety (16%)](https://pubmed.ncbi.nlm.nih.gov/29368800/).92
* [Adolescents (15-20%)](https://pubmed.ncbi.nlm.nih.gov/33403795/).201,202

Importantly, although the growing body of empirical inquiry finds that YFAS “food addiction” has high prevalence rates in both obesity194-196 and eating disorders,73,84,99,100,193,194 it is reliably distinct (different) bio-psycho-pathologically from these and all other known health issues,203 with the sole possible exception being substance-related and addictive disorders.62,192

Animal studies additionally find that while food addiction is predictive of obesity, propensity for obesity is *not* predictive of addictive like behaviors with food,204 suggesting that food substances (e.g., food additives, processing components of processed- and ultra-processed foods) play a greater role in “food addiction” and over eating than do genetic variables related to overweight or obesity.204

## Predictive Factors for Food Addiction

A large variety of factors have been identified that both correlate with *and predict* food addiction, including:

* Greater ultra-processed food consumption.62,192,205,206
* Trait impulsivity (β = 0.06, 95% CI = 0.05–0.06).
* Social anxiety (β = 0.41, 95% CI [0.30, 0.52]).207
* Depressive Disorder (β = 0.60, 95% CI [0.49, 0.72]).207
* Isolation/social withdrawal (β = 1.56, 95% CI [1.24, 1.87]).207
* Poor academic performance (e.g., failed or below average in past year).207
* Monthly or past-month substance consumption (β = 0.29, 95% CI [0.19, 0.38]).207
* Social media addiction (β = 1.71, 95% CI [1.43, 1.98]).207
* Internet gaming disorder (β = 1.10, 95% CI [0.96, 1.24]).207
* Doxing (β = 0.28, 95% CI [0.18, 0.38]).207
* Sleep insufficiency (<6.5 hrs./night).207
* Online self-harm challenge engagement (β = 0.52, 95% CI [0.33, 0.70]).207
* Reduced likelihood of daily fruits or vegetable consumption.207

## “Food Addiction” in Binge Eating Disorder

YFAS studies also find that between 42–92% of adults73,84 and 55-95%99,100 of all individuals with BED99,100 meet the DSM-V/YFAS criteria for “food/eating addiction” (as addressed above). By contrast, ~27% of individuals with BED have a co-occurring DSM-V SRAD,206 though more research is needed to disentangle the temporal sequence of this comorbidity. More importantly, odds ratios and regression models show that YFAS “food addiction” increases the odds for – and is often also predictive of – binge eating disorder, bulimia nervosa, anorexia nervosa, and other eating and feeding disorders.73,84,193,208 Moreover, food addiction also predicts lower/worse responses to eating disorder treatments (e.g., lower rates of full remission and higher rates of dropout).209 These and other findings affirm that while “food addiction” and binge eating disorder are certainly not synonymous.203

## “Food Addiction” Correlates Associated with Binge Eating Disorder

A large-scale, multi-center 2022 study of 8,755 middle and high school students found that YFAS “food addiction” has statistically significant correlations with each of the comorbidities and predictive factors identified above as well as a variety of factors highly correlated with binge eating disorder and central to BED psychopathology.13-15,39,62,192 These include:

* Reduced cognitive performance and function.74
* Reduced ability for emotion regulation (contributing to a host of other psychological issues that often require professional treatment).203
* Greater interpersonal sensitivity.210
* Greater likelihood of early life trauma, including physical, psychological, and sexual abuse.210
* Reduced sleep quality.211
* Stress sensitivity.211
* Reduced physical, psychological, social, and environmental quality of life.210
* Overweight infancy in offspring of mothers with food addiction.207

## “Food Addiction” Increases Odds of Binge Eating Disorder Correlates

YFAS food addiction also increases odds (and is often predictive) of a variety of additional conditions that are either directly associated or highly comorbid with binge eating disorder, including:

* [Greater consumption of ultra-processed foods](https://pdf.sciencedirectassets.com/272489/1-s2.0-S0195666322X00093/1-s2.0-S0195666322003518/main.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEMn%2F%2F%2F%2F%2F%2F%2F%2F%2F%2FwEaCXVzLWVhc3QtMSJIMEYCIQD0qMyr7WfxS4i9V2Nn32mHiHA4Q9UCzWljrPTwRpl8QQIhAJIYXWkWV4ZiyBUCCMwcZxMj94T02iCkokvzyEr4pUxfKrsFCOL%2F%2F%2F%2F%2F%2F%2F%2F%2F%2FwEQBRoMMDU5MDAzNTQ2ODY1Igx9DfHnclSOlB8jhOEqjwXWtSBpAoq%2BudigZ0U3Wvy5adUtdnXcx6NAVve4SGSnfiz2%2FYjZhObAkcIRm4K%2BtjrqHLyMew5%2FNcflBOEoKEFL%2FBC3pJI%2BcTMEumkpsbUprFZVdyYXGELc6AonUyCE%2B1uLCkxrfucMPLzVVLLD7Q0%2Bxg2ibg%2Fj163y7TZwBdiTKwCHWATbcmgcDDfS6pDmiJC6HU4KP9cEFLxTTdbUEeZY%2FHkeNoqa1jJOMU467j1%2B9GdumypbDnkY1w59%2BHgvR58Qg1iEzabhi7qGCOdOkrbsQARBkWlUPg8IuL48w%2Bq3MA4Bqd49VZ5dVpnAOJhhEN0KHjwzKvTxCtxF1X5ZrPWbm2HL2Hyt4KbW3YBSek0%2FF%2FZc78qFx4RSbgBU%2BEjpx%2BGOSi7ULWzgGPhgnrS3DWluDnwFnXIBLHZxvlH28vkt2Dv1qvLIzoIU9ZQeAMeG1qykNBkUtKTFzhtUxNul%2BnG%2BhhVpQSomNCng3FwIA0fObGKTOpN%2BDV%2FDcgxIOIAqFqCby%2FS6wM6ExAhOWdCyXVvxUoudDNOcL62IoYnD0kU7gkl3n%2BrfKQjLXBa0Y59%2BtcU5KK3%2FXaqKqSZ5lMTeI%2FXj60PbiYz6P%2BzGJ3OHyZ5SD9GdIWpBqFtrFZW9gD%2FbXc5RqPhe2VEPuy%2BvVp4ICW9nDgCN8JOxkdRvZ%2BP1RPSThKWBat5wXoXllGup1pJ%2FcXSNJtKGPTxUdBizpVANDa5Oiy4797yZe6UwufY8bZYjcIMzRJ8SuE8FzExgZ2qCMxhHryN6rgJlCPMXftl5bkS2IRTLVgFSRlHHFRMJ03v5FZnfIa0blkT%2B9OHJDOIPmeNiUnF7tDswPQ84IEKRrk46ybMr24gyMy%2FlqZcbcXcFMMzdr70GOrABNOE89r3MIGB39vjTBWrxs7TUyYEv0JuyMHjmIsxabfzpAt%2FtwI%2BpHNIY9K3QnZjm6U6Ko8Ff3VzaTBjGqKv8QNAJuIL0Ry6Pso1ulSuasPSrXO8UEvF9ElGO383kS7PgO7SzQltQN3530T406j7bzZA86czbh9TkPxJK6cyIqXi9JGp%2FZ7Q674epyQjJLQaMtGMUXN5V%2FQSt6pDIVzaQUp714aQ01BzhR6GrwOUHHqM%3D&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20250212T020332Z&X-Amz-SignedHeaders=host&X-Amz-Expires=299&X-Amz-Credential=ASIAQ3PHCVTYXZCOSJ7Q%2F20250212%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=e3ce207b2747f6afbdf90c8c73e98b704734c35ad4546f670ff846d9e1e68726&hash=c6a5b0e22aff889abde5295e6eeb45543eb666e01bcef37659de31d2facaab41&host=68042c943591013ac2b2430a89b270f6af2c76d8dfd086a07176afe7c76c2c61&pii=S0195666322003518&tid=spdf-381f3ca0-4a92-4c73-add1-5d44a6afb234&sid=a7675db54badd8401c1aa6e3e4abe7f197abgxrqa&type=client&tsoh=d3d3LXNjaWVuY2VkaXJlY3QtY29tLm5jbm0uaWRtLm9jbGMub3Jn&ua=14135b515459565500&rr=910900b4ad5c8102&cc=us) (in [humans](https://www.sciencedirect.com/science/article/abs/pii/S0195666322003518?fr=RR-2&ref=pdf_download&rr=91097aefefa87b27) and [rodents](https://pubmed.ncbi.nlm.nih.gov/36209772/)).204,212
* Weight dysregulation
  + Underweight.213
  + Overweight and obesity.70,73,204,213
  + Infant risk for obesity (e.g., in the case of maternal UPF addiction).214
  + BMI (in University students): OR 8.32; 95% CI: 3.81-18.15.215
  + *[Lower responses to obesity treatments (e.g., less weight loss)](https://pubmed.ncbi.nlm.nih.gov/39415327/).62,192*
* Diabetes (aOR = 2.01; 95%CI: 1.39; 2.64).199
* [Mood disorders](https://pubmed.ncbi.nlm.nih.gov/37571411/), including:
  + Anxiety *or* depression (in college students: aOR = 7.79; 95% CI: 3.29-18.42)
  + Major depressive episode (PHQ-9): aOR = 4.41; 95% CI: 3.46-5.62 (P<0.001).210
  + Anxiety: β=0.53; SE=0.06; p< 0.0001208,210
  + Skin picking disorder (SPSQ): aOR = 2.02; 95% CI: 1.31-3.09.210
  + Bipolar spectrum disorder (HCL-32): aOR = 1.98; 95%CI: 1.43-2.75; P<0.001.210
  + Suicidal ideation (PHQ-9): aOR = 1.254; 95% CI: 0.963 – 1.634; P<0.001.210
  + Psychopathological dimensions (SCL-90R):
    - Interpersonal sensitivity: aOR = 2.013; 95% CI: 1.588 – 2.551; P<0.001.210
    - Depression: aOR = 1.429; 95% CI: 1.114 – 1.832; P = 0.005.210
    - Hostility: aOR = 1.298; 95% CI: 1.096 – 1.538; P = 0.002.210
    - Paranoid ideation: aOR = 0.776; 95% CI: 0.622 – 0.969; P = 0.025.210
* Early life Trauma (ELISR-SF):
  + Psychological abuse: aOR = 1.106; 95% CI: 1.027 – 1.190; P = 0.008.210
  + Sexual abuse: aOR = 1.094; 95% CI: 1.023 – 1.169; P = 0.008.210
* Reduced quality of life (QoL), including:
  + Physical QoL: ηp2 = 0.342; P < 0.001.210
  + Psychological QoL: ηp2 = 2 = 0.451; P < 0.001.210
  + Environmental QoL: ηp2 = 0.241; P < 0.001.210
* Poor lifestyle habits:
  + Difficulty sleeping: aOR = 3.24; 95% CI: 1.04–10.13; P < 0.05.215
  + Sedentary lifestyle: aOR = 2.44; 95% CI: 1.04 = 5.71; P < 0.05.215
* Propensity for relapse (shown in humans and [rodents](https://pubmed.ncbi.nlm.nih.gov/36209772/)).62,192,204,209,212

# Neurobiology of Food and Eating

At a neurobiological level, feeding and eating behaviors are thought to involve complex interactions between neural, enteric, and physiological systems associated with energy homeostasis, hunger/satiety mechanisms, appetitive and consummatory ingestive processes, and hedonic/reward/reinforcement-based mechanisms (which often become dysregulated in feeding and eating disorders).90,106,216,217

The brain regions, neurotransmitters, and hormonal signals that regulate energy homeostasis and food intake are thought to involve primarily the hypothalamus and brainstem.

* The hypothalamus, particularly the arcuate nucleus (ARC), plays a central role in detecting nutritional status and regulating appetite through the actions of agouti-related protein (AgRP)/neuropeptide Y (NPY) neurons and pro-opiomelanocortin (POMC) neurons. AgRP/NPY neurons promote feeding by responding to hunger signals such as ghrelin, while POMC neurons inhibit feeding by responding to satiety signals like leptin.
* Additionally, the brainstem, including the nucleus of the solitary tract (NTS), integrates peripheral signals and contributes to the regulation of feeding behavior.
* The hypothalamus communicates with higher-level brain regions involved in reward processing, including those in the mesolimbic reward pathway, to regulate feeding behaviors. The mesolimbic reward pathway, including the ventral tegmental area (VTA) and nucleus accumbens (NA), is critical for the hedonic aspects of eating, promoting the pleasure and reward associated with food consumption. Other brain regions, such as the prefrontal cortex (PFC), play a role in executive control and decision-making related to eating behaviors.

Neurochemically, the regulation of feeding involves various neurotransmitters and hormones.{Chen, 2025 #12799}

* Dopamine, a key neurotransmitter in the mesolimbic reward pathway, plays a crucial role in the hedonic aspects of eating by promoting the pleasure and reward associated with food consumption.
* Serotonin and norepinephrine are also involved in modulating appetite and satiety.
* Hormones such as insulin, leptin, and ghrelin act on the hypothalamus and other brain regions to regulate energy balance and food intake.
* The gut-brain axis, involving the vagus nerve and gut hormones like glucagon-like peptide-1 (GLP-1), also plays a significant role in signaling hunger and satiety to the brain.

# Neurobiology of Binge Eating Disorder

Neurobiologically, BED involves dysregulation in brain regions associated with reward processing, emotion regulation, and executive function. Broadly, the hypothalamus, particularly the lateral hypothalamus, plays a role in appetite regulation through the release of peptides such as orexin that are thought to become dysregulated in BED. The mesolimbic reward pathway, including the VTA and NA, is implicated in the heightened reward sensitivity and compulsive eating behaviors observed in BED.

The hypothalamus, particularly the lateral hypothalamus, plays a role in appetite regulation through the release of peptides such as orexin. The mesolimbic reward pathway, including the ventral tegmental area (VTA) and nucleus accumbens (NA), is implicated in the heightened reward sensitivity and compulsive eating behaviors observed in BED.

Alterations in the connectivity and functioning of the default mode network (DMN) and salience network (SN) contribute to impaired self-regulation and increased reward sensitivity.

* The DMN, which is involved in self-referential processing and introspection, shows altered connectivity in individuals with BED, affecting their ability to regulate eating behaviors.
* The salience network, which detects and filters salient stimuli, is also dysregulated in BED, leading to heightened reactivity to food-related cues.

Neurochemically, BED is associated with alterations in dopamine signaling, which contributes to the increased reward sensitivity and food-seeking behaviors. Additionally, dysregulation of serotonin and norepinephrine systems may contribute to the emotional dysregulation and impulsivity observed in BED. Genetic factors also play a role in BED, with heritability estimates ranging from 41% to 57%.{Donnelly, 2024 #12800}

[Mapping Treatment Advances in the Neurobiology of Binge Eating Disorder: A Concept Paper (mdpi.com)](https://www.mdpi.com/2072-6643/16/7/1081)

[Neurobiology of Binge Eating Disorder - A Synopsis (psychscenehub.com)](https://psychscenehub.com/psychinsights/neurobiology-of-binge-eating-disorder/)

[Advances in the Neurobiology of Food Addiction | Current Behavioral Neuroscience Reports (springer.com)](https://link.springer.com/article/10.1007/s40473-021-00234-9)

[Frontiers | Editorial: Neurobiology of food addiction (frontiersin.org)](https://www.frontiersin.org/journals/behavioral-neuroscience/articles/10.3389/fnbeh.2023.1285557/full)

# Neurobiology of YFAS Food Addiction

Neurobiologically, food addiction involves similar pathways and mechanisms as those involved in substance-related and addictive disorders. The mesolimbic reward pathway, including the VTA and NA, is activated by palatable foods, leading to the release of dopamine and the experience of pleasure. This activation reinforces food-seeking behaviors and contributes to the compulsive nature of food addiction.

Neurochemically, food addiction is associated with alterations in dopamine signaling, similar to substance addiction. Additionally, changes in the expression and sensitivity of dopamine receptors may contribute to the development of addictive-like eating behaviors. The involvement of other neurotransmitter systems, such as serotonin and norepinephrine, further modulates the reward and emotional aspects of food addiction. Preclinical and clinical research findings support the role of these neurobiological mechanisms in both animal models and human studies.

In animal models, high-fat and high-sugar diets have been shown to induce alterations in the mesolimbic reward pathway, leading to increased dopamine release and changes in receptor sensitivity. These findings suggest that the consumption of palatable foods can produce neurobiological changes similar to those observed in substance addiction. In human studies, individuals with food addiction exhibit increased activation of the mesolimbic reward pathway in response to food-related cues, supporting the role of this pathway in the development of addictive-like eating behaviors.

These insights into the neurobiology of feeding, BED, and food addiction highlight the complex interplay of brain regions, neurotransmitters, and hormonal signals that regulate eating behaviors and contribute to disordered eating patterns.

[Ten Years of the Yale Food Addiction Scale: a Review of Version 2.0 | Current Addiction Reports (springer.com)](https://link.springer.com/article/10.1007/s40429-019-00261-3)

# Neurobiology of Food and Eating

physiological and neural systems associated with hunger/satiety mechanisms, ingestive (homeostatic/appetitive and consummatory) mechanisms, and hedonic/reward/reinforcement-based mechanisms 90,106,216,217 (Figure S1).

Implicated neural circuitry includes the **mesostriatal dopamine system**, **nigrostriatal dopamine system, corticolimbic system**,and **frontoparietal control system.**90,91,104,106-108,123,189,217-219

* The **mesostriatal dopamine system** (AKA the ventral pathway) includes the ventral tegmental area (VTA), ventral striatum/nucleus accumbens (NAc), and ventral pallidum (VP).220-223 This pathway is associated with reward salience, motivational drive, impulsivity, and consummatory behaviors (e.g., consumption, cue-induced feeding, taste reactivity, and food preference)([Figures 1](#_Figure_1); [Figure 2](#_Figure__2); Supplementary Figure S3).220-223
* The **nigrostriatal dopamine system** (AKA the **dorsal pathway**) includes the VTA, dorsal striatum (e.g., caudate nucleus and putamen), paraventricular nucleus of the thalamus (PVN/PVT), thalamus, and **orbitofrontal cortex (OFC)**.112,224-229 This pathway is associated with reward sensitization and compulsivity, orchestrating goal-directed- and habitual decision-making, integrating homeostatic and hedonic feeding signals with physiological and environmental stress signals, anticipatory feeding needs, and cognitive inputs to regulate food-seeking and consumption, and the development of habit formation from previously goal-directed behaviors, possibly contributing to compulsivity ([Figures 1](#_Figure_1); [Figure 2](#_Figure__2); Supplementary Figure S4 and S5).112,224-229
* The **corticolimbic system** includes the amygdala, hippocampus, prefrontal cortex (PFC), OFC (within the PFC), insula, thalamus, hypothalamus, and brainstem/pons.217,230-235 This system is associated with sensory input integration (e.g., taste, smell, touch, vision, sound), learning/reversing associations between stimuli and their outcomes (e.g., foods and their salient/rewarding properties/pleasantness), and adapting to changes in food value, thus contributing to reward- and punishment-based decision-making processes that drive eating and binge eating behaviors ([Figures 1](#_Figure_1); Supplementary Figures S6A–C).217,230-235
* The **frontoparietal executive control system/network (ECN)/central executive network (CEN)** includes the OFC and middle frontal gyrus in the PFC, the anterior cingulate cortex (ACC), posterior parietal cortex (PPC), middle cingulate gyrus (mCG), thalamus, caudate nucleus head, dorsal precuneus, posterior inferior temporal lobe, and hippocampal system) is associated with executive functioning, decision-making, coordinating goal-driven behaviors, self-regulation, regulating appetitive responding, and regulating the hedonic/reward/reinforcement-based corticolimbic and mesostriatal dopamine circuits, and integrating reward information with spatial and action-related information, connecting rewards to actions and reward-cues and storing reward memories **(**[Figures 1](#_Figure_1); Supplementary Figures S7**)**90,91,104,106-108,123,189,217-219,236-241.

These systems are illustrated in [Figures 1](#_Figure_1) and [2](#_Figure__2) and in the **Supplementary Figures S1–S16** 90,91,104,106-108,123,189,217-219,242-248.

These systems work together in several relevant networks, including the basal ganglia network (BGN, the reward network), default mode network (DMN, the “resting state”/self-referential processing/introspection network), frontoparietal executive control system, and salience network.91,107,122,217,218,244

* **The basal gangliar network (BGN)** is a group of subcortical nuclei that are most commonly associated with motor control and motor learning but are also critically involved in executive functions and emotional behaviors.249,250 The BGN also plays a significant role in reward processing and habit formation, which can influence feeding behaviors. Indeed, the BGN is implicated in motivational drive for reward-based eating and sensitivity to food rewards and rewarding foods.240,249-255-256-262 and BGN dysregulation has been associated with both obesity and compulsive eating.240,250,255-262 Specifically, alterations in the BGN are thought to impact reward sensitivity and habit formation, contributing to the compulsive nature of binge eating episodes.240,250,255-262(Supplemental Figure 8, Supplemental Figures 9–17**)**.
* **The default mode network (DMN)** is a “task-negative” network of interconnected brain regions that show increased activity during internally-oriented, self-referential, introspective, and unfocussed thought/mentation (e.g., thinking about one’s self, others, the future or past, daydreaming, mind-wandering, and meditation; when the focus is *not* on the external environment) as well as memory encoding and retrieval and social reasoning.239,240,263 The DMN has nodes in the medial prefrontal cortex (mPFC), posterior cingulate cortex (PCC), lateral parietal lobes, hippocampus, and inferior parietal cortex240 and is typically deactivated by the salience network (SN) during stimulus-driven cognitive processing.239,264 It is often associated with maintaining the “resting state” of activity in the brain. The DMN’s role in self-referential processing and introspection are thought to influence eating behaviors, with disruptions in DMN activity/connectivity implicated in altered food cue reactivity and eating behaviors, particularly in the context of social isolation and mental health symptoms.265-268 Binge eating disorder is associated with reduced connectivity in the dorsal anterior cingulate cortex (dACC) of the salience network (SN, resulting in disinhibition of the DMN) and increased connectivity in the PCC and mPFC of the DMN.269 These alterations in connectivity are in turn associated with impaired self-regulation and increased reward sensitivity, contributing to the loss of control over eating (a diagnostic feature of binge eating disorder) and binge frequency. 267,269.265,266,268
* **The frontoparietal executive control system (ECN)/**central executive network (CEN) is regarded as a “task-positive network” associated with cognitive control and high-level executive cognitive functioning (e.g., goal-oriented thinking, decision-making and complex problem-solving, planning, impulse control, controlling and sustaining attention, and working memory.239,240,270 The ECN has nodes in the dorsolateral and lateral PFC, posterior parietal cortex (PPC), ACC, and paracingulate cortex (PCC).239,240,264 It is considered crucial for goal-directed behavior and decision-making, which can influence eating behaviors by regulating self-control and impulse control.270 Specifically, impairments and reduced connectivity within the ECN and between the ECN and other networks (specifically the salience network and BGN) are associated with impaired self-regulation and decision-making and increased impulsivity (a central feature of BED), leading to loss of control over eating behaviors (a core diagnostic feature of BED).269217,271
* **The salience network (SN)** is a large-scale brain network that has nodes in the dorsal anterior cingulate cortex (dACC) and anterior insular cortex.239,240,272 It is involved in detecting, processing/filtering, and orienting to salient external and internal stimuli. This is done largely through its ability to engage relevant functional networks like the ECN (and disengage the DMN) to attend and respond to important, goal-oriented (salient) stimuli, which can include salient food cues.239,272-274 Dysregulation of this network can result in altered food cue sensitivity (hypersensitivity) and responsivity (hyper-reactivity) as well as altered eating behaviors.240,269 In binge eating disorder specifically, alterations in the salience network (e.g., diminished connectivity in the dACC) can result in hyper-sensitized responses to food/eating cues and food/eating.269 This can contributing to the loss of control over eating that is a core diagnostic feature of binge eating disorder.1,269 This can also contribute to the persistent prioritization of food/eating cues and rewards over other daily life activities, life goals, and harms associated with engaging in food/eating cues and activities, a core feature of substance-related and addictive disorders.188,240,269
* diminished connectivity in the dorsal anterior cingulate cortex within the salience network and increased connectivity in the posterior cingulate cortex and medial prefrontal cortex within the DMN.

Notably, the DMN, ECN, and BGN have been identified as crucial neural substrates that can explain the roles of self-referential processing (e.g., records of bodily sensation and self), executive functioning (e.g., inhibitory control), and reward processing (e.g., reward sensitivity) in the development and maintenance of eating disorders (as addressed further in section 2.1 below)240,254,275-279. A popular model of psychopathology (e.g., the triple network model) also identifies the DMN, ECN, and SN as three primary resting networks associated with attention and cognitive control that are also implicated in a variety of psychopathologies, including eating disorders 240 as well as depression and anxiety (which are highly comorbid with eating disorders 14)239.

At the neurochemical level, **opioid** and **dopamine** systems within these circuits are primarily responsible for mediating three predominant aspects of reward and reinforcement-based eating: “liking,” associated with hedonic impact/reward value; “wanting,” associated with motivation/incentive salience; and “learning” implicit in cue association and reward predictions[[1]](#footnote-1) 90,107,137,189,218. These systems are thought to be inherent to all reinforcing processes, including those that drive overconsumption, BED, obesity, substance-related and addictive disorders (SRADs, formerly substance use disorders, SUDs), and “food and eating addictions,” 80,90,91,102-104,107,108,110,123,189,218,219,281. Additional neurotransmitters, neuropeptides, and neurohormones associated with these processes include dopamine, opioids, serotonin, orexigenic and anorexigenic peptides/hormones, glutamate, endocannabinoids, and glucocorticoids 127,217,282,283, as well as inhibitory gamma-aminobutyric acid (GABAergic) systems, leptin, insulin, ghrelin, glucagon-like peptide 1 (GLP-1), melanin-concentrating hormone, (MCH) oxytocin, and corticotrophin-releasing factor/hormone (CRF/CRH) 90. Notably, these systems largely overlap with those involved in substance-related and addictive disorders (SRADs, formerly termed substance use disorders, SUDs) as addressed in section 2.1 below.

## Neurobiological Alterations Associated with Binge Eating Disorder

Neuroimaging studies have provided insights into the functional organization of brain networks involved in reward processing in BED.85,90,91,117-121,128,129,131,132,179 For example, BED is often characterized by elevated sensitivity to food salience/reward138,217,284,285 and increased impulsivity[[2]](#footnote-2) and compulsivity[[3]](#footnote-3)102,103,217,287-291 (**Figure 2**) that are associated with aberrant/deficient “top-down” cognitive control and dysregulated interactions between executive self-regulatory prefrontal circuits and more primitive mesolimbic circuits associated with behavioral engagement.107,217,286,291,292

These alterations are thought to result in food/eating-related impulsions and compulsions overriding homeostatic and cognitive regulation systems,279,293,294 thought to result in dysregulated reward processing in BED.85,90,91,117-121,128,129,131,132,179 For example, resting state functional magnetic resonance imaging (rs-fMRI) studies find hypoconnectivity of striatal networks in individuals with BED,240,277 which may contribute to difficulties in self-regulation and reward processing.110,277

At the same time, fMRI studies also find reduced activity in the vmPFC, inferior frontal gyrus, and insula in individuals with BED during neurocognitive testing designed to assess executive functioning.[[4]](#footnote-4)295 The result is a diminished capacity to curb or self-regulate binge eating behaviors.279,295 Notably, the observed activity patterns in the right insular cortex have also been identified as having diagnostic accuracy for distinguishing BED from bulimia nervosa and healthy controls, implicating the insula in the food stimuli processing.125

BED is also associated with a shift from impulsivity to compulsivity that is thought to involve neuroplastic changes in the mesolimbic dopamine system (esp. in the NAc) and in prefrontal systems, including the extended amygdala,152 as well as dopamine desensitization in the dorsal striatum (of the nigrostriatal dopamine system) that accelerates the development of habit formation from previously goal-directed behaviors.112,227-229

The glucocorticoid stress system is also thought to be implicit in these dysregulated changes.106,127,282,283

Resting-state functional magnetic resonance imaging (rs-fMRI) studies suggest BED is associated with significantly reduced baseline functional connectivity both within and between the DMN, ECG, SN, and BGN relative to weight-matched controls (P<0.05).240,277 This includes reduced connectivity in the dorsal cingulate cortex in the SN, dmPFC in the DMN, right caudate to right angular gyrus, right middle frontal gyrus (MFG), and bilateral superior frontal fyrus (SFG) in the ECN, and between the right thalamus/caudate/putamen and right inferior frontal gyrus (IFG) in the BGN 240,277. This also includes significantly reduced functional connectivity between the ECN and DMN (specifically reciprocally between the right caudate in the ECN and the PCC, bilateral parahippocampal gyrus, right middle occipital gyrus (MOG), and right SFG/MFG in the DMN), BGN and DMN (between the right thalamus/caudate/putamen in the BGNand same DMN regions as identified previously); and the ECN and BGN (between the same regions as identified previously)(p < 0.05)240. Additionally, loss of control eating – a central feature of BED – was significantly correlated with reduced all-mean within-network and between-network connectivity and body image concern was significantly correlated with reduced mean connectivity between the ECN and DMN and between the BGN and DMN (*p* < 0.05).240 These findings suggest that SN activity in the ACC (responsible for reward salience processing and emotional arousal) and caudate (responsible for orchestrating goal-directed and habitual decision-making 112,224,225) and DMN activity in the medial frontal cortex (responsible for monitoring physical and emotional states) are reduced in BED, further implicating reward and executive function circuits (e.g., the salience network and DMN) in BED and especially in control of food intake and binge eating 110,277.

Binge eating has also been associated with significantly increased dACC activity and connectivity with the insula, cerebellum, and supramarginal gyrus in response to high-calorie food cues (P<0.05 vs. healthy controls and vs. low-calorie food cues in binge eaters)296. These findings suggest dACC hyper-responsivity and hyperconnectivity with the insula, cerebellum, and supramarginal gyrus may be associated with hyper-responsivity and hypersensitivity to food cues in BED 296. Similar studies have also found increased blood oxygen level-dependent (BOLD) activity in the insula, ACC, PCC, Brodmann areas (BA) 19 & 32, inferior parietal lobule (IPL), and lingual, postcentral, middle temporal, and cuneate gyri (emotional, motivational, and somatosensory brain regions) in response to food images (p≤0.005; k≥88 vs. non-food-cue responses and vs. weight-matched individuals without BED)and increased BOLD activity in inhibitory brain regions (BA6, middle and superior frontal gyri) in response to high-calorie processed foods (p<0.01; k≥119 vs. low-calorie unprocessed food responses and vs. weight-matched controls)297. These findings also provide neurobiological support for previous theories that food cues elicit attention bias, emotion dysregulation, and disinhibition in individuals with obesity and BED (as indicated by increased BOLD activity in the cuneate and PCG, BA 19 and 32, and MFG, BA6, and SFG respectively)297.

## Similarities Between Binge Eating Disorder and Substance-Related and Addictive Disorders

Many of the CIH interventions reviewed below have empirical support in the context of substance-related and addictive disorders (SRADs, e.g., substance use disorders, SUDs). This support is relevant given the neurobiological, psychopathological, physiological, behavioral, and genetic similarities between SRADs/SUDs and BED 90,91,102,104,107,108,123,137,189,218,219, which we will summarize here.

### Epidemiological and Diagnostic Support

Like SRADs, BED has been described as a chronic relapsing disorder characterized by preoccupation and craving, impaired control of consumption (e.g., loss of control), social impairment, persistence despite risks, and aspects of impulsivity, compulsivity, sensitization, tolerance, withdrawal, and relapse, with environmental, genetic, and neurobiological factors 91,99,100,102,104,114,122,123,189. To better assess signs of addictive-like eating behavior, the Yale Food Addiction Scale Version 2.0 (YFAS 2.0) uses the DSM-V diagnostic criteria for a substance-related and addictive disorder but replaces the term “*drug”* with “*food or binge eating”* 75,99,191. Using this criterion, between 42–92% of adults diagnosed with binge eating disorder meet DSM-V diagnostic criteria for an SRAD/SUD (in which the substance/addiction is related to food/eating)99,100. BED also has a 27% incidence of comorbidity with true DSM-V SRADs 206. Research is needed to disentangle the temporal sequence of this comorbidity.

### Preclinical and Clinical Research Support

A variety of research demonstrates that processes mediating feeding behaviors can become linked to neurobiological processes that underlie reinforcement and addiction 90,219,281. For example, certain types of foods (e.g., high-sugar, high-fat, highly-palatable, and highly-processed foods)83,90,187, food cue exposure 102, stressors and emotional reactivity 90,102, and changes in weight or eating patterns 90,298-300 can induce compulsive patterns of binge-like consumption, akin to those seen in BED and SRADs (in rodents and humans). Neuroimaging studies reinforce overlapping mechanisms in the neurobiological underpinnings of BED and SRADs/SUDs. For example, the hedonic/reward/reinforcement-based neural systems and processes described above (section 2.1 and [Figures 1](#_Figure_1) and [2](#_Figure__2) ) are thought to be inherent to all reinforcing processes, including those that drive SRADs and those that drive overconsumption, obesity, BED, and “food and eating addictions,” 80,90,91,102-104,107,108,110,114,122,123,189,218,219,281. Food- and drug- related cues and the craving cascade are associated with increased activation in the same brain regions – the NAc/striatum, OFC, insula, caudate, hippocampus, and amygdala – in YFAS-validated “food addicts” and drug-users respectively 102,110,262,301,302. The hedonic/reinforcement systems can also become hypersensitized, particularly in response to cues (e.g., food cues) and in the context of stress, which can result in cue hyper-reactivity, excessive cravings, behavioral urges to seek/consume associated rewards, and appetitive, reward-seeking behaviors 107. At the same time, alterations in functional activity and connectivity of the PFC, OFC, insular cortex, and striatum are similar in BED and SRADs/SUDs 290,303. Human genetics and animal studies also demonstrate that SRADs and BED are associated with similar neurotransmitter network changes, including alterations in dopaminergic and opioid systems 290,303. Additionally, the transition from impulsive, reward-driven behaviors to compulsive, habit-driven behaviors (**Figure 2**) has been associated with the development of both SRADs and BED alike 107,114,122,123,189,217,218 and a greater degree of similarity to SRAD processes (e.g., “food addiction 304-307” or “hedonic,” addictive-like eating81,105,106,308,309) has been associated with greater severity of binge eating and BED (306,310-312 as cited in 217). Together, these and other findings suggest that interventions effective for SRADs may be effective in alleviating BED symptoms 94,102,116,132,313-315, although this possibility has not yet been demonstrated.

### Neuroimaging Findings Associated with Binge Eating Disorder

Neuroimaging studies have provided insights into the functional organization of brain networks involved in reward processing in BED. For example, a study found hypoconnectivity of striatal networks in individuals with BED, which may contribute to difficulties in self-regulation and reward processing. 85,90,91,117-121,128,129,131,132,179

#### Electroencephalogram (EEG)

Electroencephalogram (EEG) studies demonstrate elevated resting-state beta wave activity (13–21 Hz) in fronto-central regions in individuals with obesity comorbid with binge eating disorder under fasted conditions (4 – 12h fast)111,284,285 and increased beta activity in food-cue conditions.111,285 The increased beta activity in resting-state and food-cue conditions has also been found to correlate positively with binge eating disorder psychopathology, as assessed using Binge Eating Scale (BES) summary scores and Bulimic Investigatory Test severity and symptom scores.111,285 Beta wave activity is typically associated with strong focus, conscious precision, heightened states of alertness, and the ability to solve problems.111 However, excessive beta activity is also found in many psychiatric disorders, including SRADs (both at rest and when in the presence of substances and substance cues), attention deficit disorder (ADD), obsessive-compulsive disorder (OCD), anxiety, and depression,111 all of which have high rates of comorbidity with binge eating disorder.14 These findings suggest that in a fasted state, individuals with obesity and binge eating disorder may respond similarly to individuals with SRADs who display heightened frontal beta wave activity when separated from substance use and when in the presence of substances and substance cues.111 These findings also suggest that heightened frontal beta wave activity at resting state “may depict a maintenance mechanism of binge eating disorder, leading to faster attentional engagement of food cues.”111

#### Magnetic Resonance Imaging (MRI)

BED is often characterized by elevated sensitivity to food salience/reward138,217,284,285 and increased impulsivity[[5]](#footnote-5) and compulsivity[[6]](#footnote-6)102,103,217,287-291 (**Figure 2**) that are associated with aberrant/deficient “top-down” cognitive control and dysregulated interactions between executive self-regulatory prefrontal circuits and more primitive mesolimbic circuits associated with behavioral engagement.107,217,286,291,292 These alterations are thought to result in food/eating-related impulsions and compulsions overriding homeostatic and cognitive regulation systems,279,293,294 thought to result in dysregulated reward processing in BED.85,90,91,117-121,128,129,131,132,179 For example, resting state functional magnetic resonance imaging (rs-fMRI) studies find hypoconnectivity of striatal networks in individuals with BED,240,277 which may contribute to difficulties in self-regulation and reward processing.110,277

At the same time, fMRI studies also find reduced activity in the vmPFC, inferior frontal gyrus, and insula in individuals with BED during neurocognitive testing designed to assess executive functioning.[[7]](#footnote-7)295 The result is a diminished capacity to curb or self-regulate binge eating behaviors.279,295 Notably, the observed activity patterns in the right insular cortex have also been identified as having diagnostic accuracy for distinguishing BED from bulimia nervosa and healthy controls, implicating the insula in the food stimuli processing.125

BED is also associated with a shift from impulsivity to compulsivity that is thought to involve neuroplastic changes in the mesolimbic dopamine system (esp. in the NAc) and in prefrontal systems, including the extended amygdala,152 as well as dopamine desensitization in the dorsal striatum (of the nigrostriatal dopamine system) that accelerates the development of habit formation from previously goal-directed behaviors.112,227-229

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Resting-state functional magnetic resonance imaging (rs-fMRI) studies suggest BED is associated with significantly reduced baseline functional connectivity both within and between the DMN, ECG, SN, and BGN relative to weight-matched controls (P<0.05).240,277 This includes reduced connectivity in the dorsal cingulate cortex in the SN, dmPFC in the DMN, right caudate to right angular gyrus, right middle frontal gyrus (MFG), and bilateral superior frontal fyrus (SFG) in the ECN, and between the right thalamus/caudate/putamen and right inferior frontal gyrus (IFG) in the BGN 240,277. This also includes significantly reduced functional connectivity between the ECN and DMN (specifically reciprocally between the right caudate in the ECN and the PCC, bilateral parahippocampal gyrus, right middle occipital gyrus (MOG), and right SFG/MFG in the DMN), BGN and DMN (between the right thalamus/caudate/putamen in the BGNand same DMN regions as identified previously); and the ECN and BGN (between the same regions as identified previously)(p < 0.05)240.

Additionally, loss of control eating – a central feature of BED – was significantly correlated with reduced all-mean within-network and between-network connectivity and body image concern was significantly correlated with reduced mean connectivity between the ECN and DMN and between the BGN and DMN (*p* < 0.05).240 These findings suggest that SN activity in the ACC (responsible for reward salience processing and emotional arousal) and caudate (responsible for orchestrating goal-directed and habitual decision-making 112,224,225) and DMN activity in the medial frontal cortex (responsible for monitoring physical and emotional states) are reduced in BED, further implicating reward and executive function circuits (e.g., the salience network and DMN) in BED and especially in control of food intake and binge eating 110,277.

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* fMRI150,277,279

#### Positron Emission Tomography (PET)

PET studies are limited to date.109 Wang et al., 2011 observed that in 8 fasted (x16 hours) subjects with BED and obesity, extracellular dopamine levels were significantly increased in the putamen and caudate in response to food stimulation (presentation of a warm, pungent meal the participant identified as liking, with cotton swab of the meal on patient’s tongue) after oral methylphenidate MPH administration (MPH blocks dopamine reuptake transports, thus amplifying dopamine signals).138 These increases were not observed in weight-matched controls. Further, the increase in caudate dopamine were found to correlate with binge eating disorder pathology and severity (e.g., BES scores) and with self-reported desire for food.138 Brain dopamine is generally attributed with regulating motivation for food intake.138 Dopamine increases in the dorsal striatum (e.g., the putamen and caudate) are typically associated with reward anticipation and positive reinforcement of reward-seeking and reward-producing actions. Therefore, the authors interpreted these findings to identify dopamine neurotransmission in the caudate as being of relevance to the neurobiology of binge eating disorder.138

Neurochemical studies further demonstrate that the administration of amphetamine (a potent dopamine and noradrenaline agonist) can normalize exaggerated brain responses to food images in BED and reduce binge eating, further implicating deficiencies or dysregulations in the dopamine and noradrenaline systems in binge eating pathophysiology and promoting the use of lisdexamfetamine dimesylate (Vyvanse®, a stimulant medication used to treat attention deficit hyperactive disorder (ADHD) and the only FDA-approved medication for BED at the time of this publication) to treat BED (Fleck et al., 2019 316 as cited in Frank et al., 2019 110). These findings support a view that episodic excessive food intake as occurs in BED corresponds with excessive episodic dopamine release that results in desensitization of the dopamine circuits *via* the downregulation of D2 dopamine receptors 279. In support of this possibility, alterations in the dopamine taste reward system coincide with an addictive-like model of craving for excessive food stimulation 271,279, as addressed further in section 2.2 below.

#### Preclinical Animal Models

* Animal studies.56,90,298

# Clinical Implications

Understanding the role of reward dysregulation and food addiction in BED has important clinical implications. Targeting these mechanisms through behavioral interventions, pharmacotherapy, and nutritional strategies may improve treatment outcomes for individuals with BED.78,84,85,116-118,129,132,133

# A Case for Research Funding for Holistic Health Interventions that Address Reward Dysregulation and/or Food/Eating Addiction in Binge Eating Disorder

Although empirical support for CIH intervention use in the context of BED treatment is growing, it is far from adequate. Given the low treatment rates 4,40, high recurrence rates 4,53, high rates of treatment dissatisfaction 54, and early discontinuation of care 54 associated with current conventional treatment options, there is a strong need for research that can identify, develop/standardize, and test new treatment options that may be effective in producing clinically meaningful outcomes in the ~56–62% of individuals with BED who do not respond to current treatment approaches. Moreover, ~93–97% of individuals who meet DSM criteria for BED never receive a formal diagnosis 6,7, 67% do not perceive the need for formal treatment 6, and between 56–87% of individuals with a formal diagnosis never receive or pursue standard treatment 4,6. These findings highlight the importance of identifying, developing, and testing new treatment options that overcome the treatment barriers addressed in Bray et al. 2022 and 2025 and can address reward regulation and food/eating addiction,100 especially in the estimated ~42.399 – 55%70 of individuals who meet diagnostic criteria for binge eating disorder *and* food addiction, as assessed using the Yale Food Addiction Scale.99,{Schankweiler, 2023 #10564;Escrivá-Martínez, 2023 #10567;Criscuolo, 2023 #10569;Saffari, 2022 #10568;Praxedes, 2022 #10570;Ben-Porat, 2022 #10566;Burrows, 2017 #10565}101

The ease of access to these interventions – including at-home delivery and low cost also removes or minimizes the treatment barriers of stigmatization (including stigmatization in the healthcare system and shaming from healthcare providers, as well as self-stigmatization, embarrassment, guilt, and self-denial), insurance coverage, lack of a formal diagnosis, and even lack of identifying BED within oneself. For example, an individual could elect to use yoga or acupuncture for movement, weight stabilization, or anxiety management and receive additional benefits pertaining to BED, even if BED is undetected or diagnosed within the individual.

In fact, a review on BED epidemiology noted that less than half of adults with BED are recognized within the healthcare system 16. These findings suggest a possibility that adults with BED may already be using – or have used – CIH interventions to manage BED symptoms outside of conventional healthcare systems, thus underscoring the need for current information on CIH use in general and in individuals with diagnosed and undiagnosed BED.

Our findings highlight the importance of funding and resources to support research that can empirically test the use of different CIH interventions when used as a complement to (or integrated with) current standard BED treatments. The information we present here can be used to help identify CIH intervention candidates that can be used to target and treat specific aspects of BED pathology, both clinically and in preliminary safety and feasibility studies.

# Conflict of Interest

*The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest*.

# Author Contributions

Conceptualization, investigation, resources, data curation, and writing – original draft preparation: B.B.; writing—review and editing, B.B., A.J.S., H.Z. All authors have read and agreed to the published version of the manuscript. All authors agree to be accountable for the content of the work.

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# Tables

## Figure 1

A diagram of a brain

Description automatically generated

Fig 1: Neural circuitry proposed to be involved in eating and binge eating behaviors include **mesostriatal dopamine**- and **corticolimbic circuits** and structures associated with **reward** and motivation as well as **frontoparietal systems** associated with **decision-making, self-regulation**, and regulating appetitive responding 90,91,104,106-108,123,189,217-219. In the **mesostriatal dopamine circuit** (also termed the **ventral pathway** associated with impulsivity [see Fig. 2]), dopaminergic neurons in the medial **ventral tegmental area (VTA)** innervate the **ventral striatum** (mainly the medial **nucleus accumbens shell (NAc),** which sends GABAergic and dopaminergic projections to the **ventral pallidum (VP)** in turn, conveying the reward salience of pleasurable experiences and substances (e.g., food, drugs, etc.))220,221. The VP integrates accumbal inputs with dopaminergic inputs directly from the VTA to influence consummatory behaviors, including consumption, cue-induced feeding, taste reactivity, and food preference 221. In the nigrostriatal dopamine pathway (also termed the **dorsal pathway** associated with compulsivity), dopaminergic neurons in the VTA innervate the **dorsomedial and dorsolateral striatum**, including the **caudate nucleus** and **putamen**, which are essential for orchestrating goal-directed and habitual decision-making 112,224,225. The dorsal pathway largely involves a circuit by which dorsal striatal projections innervate the **paraventricular nucleus of the thalamus (PVN/PVT)**, which integrates homeostatic and hedonic feeding signals with physiological and environmental stress signals, anticipatory feeding needs, and cognitive inputs to regulate food-seeking and consumption 226. The thalamus (innervates the **orbitofrontal cortex (OFC)** in turn [described below], which feeds back onto the striatum 317. Additionally, preclinical findings demonstrate that dopamine sensitization in the dorsal striatum accelerates the development of habit formation from previously goal-directed behaviors 112,227-229, possibly contributing to compulsivity.

The **corticolimbic system** also contributes to reward and motivational processes, and includes the amygdala, hippocampus, and prefrontal cortex (PFC) 230. The VTA sends dopaminergic neurons to the **amygdala** and **hippocampus**, which are thought to be involved in learning and remembering reward cues and innervate the nucleus accumbens as part of the mesolimbic pathway. The **orbitofrontal cortex (OCF)** in the **prefrontal cortex (PFC)** is also thought to be involved in reward (and punishment) processing and reward-based decision-making 231-235. It receives and integrates various sensory inputs (e.g., taste, smell, touch, vision, sound) and learns (and reverses) associations between stimuli and their outcomes (e.g., foods and their salient/rewarding properties/pleasantness), adapting to valuation changes as needed (e.g., changes in food value), thus contributing to reward-based decision-making processes that guide behavior 231-235. The **insula** and **thalamus** (described above), **hypothalamus**, and **brainstem/pons** are also thought to be part of the corticolimbic circuitry that drives eating and binge eating behaviors 217.

**Frontoparietal systems associated with decision-making, coordinating goal-driven behaviors, self-regulation, and regulating appetitive responding** include the OFC (as described above) as well as the PFC at large and the **anterior cingulate cortex (ACC)**90,91,104,106-108,123,189,217-219,236,237. Specifically, the OFC sends projections and reward information to the ACC, which integrates spatial and action-related information from the parietal cortical areas, thus connecting rewards to actions and reward-cues, while the **posterior cingulate cortex (PCC)** projects to the hippocampus system, thus storing reward memories 241.

## Figure 2

A diagram of the brain

Description automatically generated

**Figure 2: Impulsivity and compulsivity in BED.** **A)** **Impulsivity** is associated with deficient inhibition of the **ventral/mesolimbic dopamine pathway** [Fig. 1], by which dopaminergic neurons in the medial **ventral tegmental area (VTA)** innervate the **ventral striatum** (mainly the medial **nucleus accumbens shell (NAc)**, which projects onto the thalamus, which projects onto the **anterior cingulate cortex (ACC)** [see Fig. 1 for description] which projects back onto the ventral striatum both directly and through the **ventromedial prefrontal cortex (vmPFC)**. The vmPFC is largely associated with exerting inhibitory control over the NAc and reward-seeking behaviors in turn 318,319, with decreased vmPFC thickness in binge eating and obesity thought to render this inhibitory system unable to prevent binge eating 222. The resulting disinhibition is thought to contribute to impulsivity, both in impulsive, disinhibited binge eating and in general 222,223.

**B)** **Compulsivity** is associated with the **dorsal/nigrostriatal dopamine pathway** [Fig. 1], by which dopaminergic neurons in the VTA innervate the **dorsomedial and dorsolateral striatum**, including the **caudate nucleus** and **putamen**, which are essential for orchestrating goal-directed and habitual decision-making 112,224,225. Dorsal striatal projections innervate the **paraventricular nucleus of the thalamus (PVN/PVT)**, which integrates homeostatic and hedonic feeding signals with physiological and environmental stress signals, anticipatory feeding needs, and cognitive inputs to regulate food-seeking and consumption 226. The thalamus innervates the **insular cortex** (the primary taste cortex involved in appetite, motivated behavior, emotional processing, and emotional, stress-driven eating 320) and **orbitofrontal cortex (OFC),** which are situated in junction to one another and both project back onto the striatum 317,320-322. The insular cortex also projects to the OFC as well as to the mPFC, amygdala, cingulate, and autonomic centers 322,323. The OFC then feeds back onto the striatum in turn 317. Preclinical findings demonstrate that dopamine sensitization in the dorsal striatum accelerates the development of habit formation from previously goal-directed behaviors 112,227-229, possibly contributing to compulsivity.

The shift from impulsivity to compulsivity involves neuroplastic changes in the mesolimbic dopamine system (esp. in the NAc) and in prefrontal systems, including the extended amygdala 152, as well as dopamine desensitization in the dorsal striatum (of the nigrostriatal dopamine system) that accelerates the development of habit formation from previously goal-directed behaviors 112,227-229.



1. It should be acknowledged that the role of dopamine in addiction processes has been disputed, as it does not seem to be the driving mechanism in some substance-related addiction disorders (ex: cannabis and opiates)[33]. Furthermore, additional hormones/neurohormones, neuropeptides, and neurotransmitters such as orexins, endocannabinoids, glutamate, GABA, leptin, insulin, ghrelin, glucagon-like peptide 1, melanin-concentrating hormone, oxytocin, serotonin, and corticotrophin releasing factor/hormone (CRF/CRH) are also involved. [↑](#footnote-ref-1)
2. Characterized by poorly conceived and prematurely expressed actions that are often risky or inappropriate to the situation and often result in undesirable consequences (Dalley et al., 2011; Boswell et al., 2021). [↑](#footnote-ref-2)
3. Characterized by perseverative behaviors that are often intrusive, unrelated to any long-term goals, and often also result in unwanted consequences (Dalley et al., 2011; Boswell et al., 2021). [↑](#footnote-ref-3)
4. E.g., the Stroop Test of selective attention, cognitive flexibility, processing speed, as compared to weight-matched and healthy-weighted controls. [↑](#footnote-ref-4)
5. Characterized by poorly conceived and prematurely expressed actions that are often risky or inappropriate to the situation and often result in undesirable consequences (Dalley et al., 2011; Boswell et al., 2021). [↑](#footnote-ref-5)
6. Characterized by perseverative behaviors that are often intrusive, unrelated to any long-term goals, and often also result in unwanted consequences (Dalley et al., 2011; Boswell et al., 2021). [↑](#footnote-ref-6)
7. E.g., the Stroop Test of selective attention, cognitive flexibility, processing speed, as compared to weight-matched and healthy-weighted controls. [↑](#footnote-ref-7)