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Neuroimaging and Eating Disorders

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Abstract

Purpose of Review—Eating disorders are severe psychiatric disorders with a suspected complex bio-psycho-social etiology. The purpose of this review is to synthesize the recent literature on brain imaging in eating disorders.

Recent Findings—Food restriction as well as binge eating and purging behaviors are associated with lower regional brain volumes or cortical thickness, but those changes largely return to normal with normalization of weight and eating behavior. Computational modeling has started to identify patterns of structural and functional imaging data that classify eating disorder subtypes, which could be used in the future diagnostically and to better understand disorder specific psychopathology. The prediction error model, a computational approach to assess dopamine related brain reward function, helped support a brain based model for anorexia nervosa. In that model, the conscious motivation to restrict conflicts with body signals that stimulate eating, which causes anxiety and drives a vicious cycle of food restriction.

Summary—Novel brain research supports the notion that eating disorders have distinct neurobiological underpinnings. This new knowledge can be used to describe disease models to patients and develop novel treatments.

Keywords

Eating Disorder; Brain; Imaging; Neurobiology

Introduction

Eating disorders (EDs) are severe psychiatric illnesses with complex biological, psychological and social underpinnings (1). Anorexia nervosa (AN) is characterized by a body weight below of that expected for age and height, feeling fat despite being underweight, an intense fear of gaining weight and a disturbance how one's own body weight and shape are experienced. A restricting type marked by food restriction and commonly over-exercising, has been distinguished from a binge-eating/purging type, where afflicted individuals eat large amounts of food in a relatively short period of time ("binge eating"), or engage in behaviors to counteract weight gain, such as self-induced vomiting or

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Conflicts of interest

None.

use of laxatives or diuretics (“purging”). Individuals with bulimia nervosa (BN) are usually at normal weight, and engage in recurrent binge eating and purging behavior at least once a week for at least three months. Binge eating disorder (BED) is also characterized by regular binge eating episodes that are followed by guilt and shame feelings, but without compensatory behaviors to counteract weight gain. Other EDs that are described in the feeding and eating disorders section of the Diagnostic and Statistical Manual of Mental Disorders (DSM–5) (1) are avoidant restrictive food intake disorder (ARFID), pica and rumination disorder.

Over the past two decades brain research in EDs has increased dramatically. Earlier studies found in EDs that alterations in serotonin and dopamine neurotransmitter systems were associated with high anxiety, especially the temperamental trait harm avoidance. More recent studies that investigated brain function and behavior found that pathways that process rewarding, or salient stimuli frequently showed either elevated or reduced brain response. Tying altered brain response to ED behavior or models that explain the etiology of EDs has been difficult as studies tend to be heterogeneous and results have often been inconsistent (2). Several advances, however, have been made recently in understanding brain function in EDs and the aim of this article is to review the past 18 months of published work in this field to provide an up to date insight.

Methods

The US National Library of Medicine National Institutes of Health database PubMed was searched separately for “anorexia nervosa”, “bulimia nervosa”, “binge eating disorder”, “avoidant restrictive food intake disorder”, “pica” and “rumination disorder”. The search terms “imaging”, “functional magnetic resonance imaging”, “fMRI”, “brain volume”, “brain structure”, “gray matter”, “white matter”, “cortical thickness”, “positron emission tomography” and “connectivity” were subsequently entered in the search engine together with eating disorder diagnostic terms, In addition, the search term imaging was entered together with the search terms reward, cognition, emotion, eating, behavior, binge-eating or purging, and subsequently together with one of the 6 diagnosis terms. Identified studies were screened and suitable manuscripts were downloaded. This search resulted in 80 articles on brain imaging across AN, BN or BED. No suitable articles for other feeding or eating disorders were identified. The most important articles are reviewed in this article.

Structural MRI Studies

Several advances in structural imaging in AN have emerged in the past year. Studies by King and Nickel, showed that state of illness, such as acute food restriction, is associated with lower brain volume but this can normalize within weeks after starting weight restoration (3, 4). Accordingly, lower cortical folding (gyrification) normalized with weight restoration in AN as shown by Bernardoni (5). Furthermore, Olivo found in so-called atypical AN, food restriction and body image distortion but without the AN typical underweight, normal brain volumes compared to controls (6). Altogether those results suggest that underweight may be directly related to changes in brain volume. Research by Seitz, using an AN animal model for structural brain changes showed that loss of astrocytes, cells that provide structure and

support to neurons, may be responsible for the observed volume losses in AN (7). The mechanism how those cells quickly recover with weight gain remains unclear.

There continues to be high heterogeneity across studies though and this was reflected in recent studies on cortical thickness in AN. Lavagnino showed in AN higher cortical thickness in the right orbitofrontal cortex when ill and after recovery, and greater cortical thickness in bilateral insula after recovery (8). Those regions have been associated with higher drive for thinness and bulimia symptom levels previously (9). Castro-Fornieles however, showed lower cortical thickness in the post central gyrus in AN when ill and after recovery, suggesting that the field needs to come together and adhere to common methods to create more reliable results to be able to define pathophysiology (10, 11).

Studies on brain structure in BN, one by Westwater and the other by Berner, found that higher binge eating and purging frequency were associated with lower cortical thickness in frontal, parietal or cingulate cortices (12, 13). Those results highlighted that not only food restriction but also binge eating and purging may directly alter brain structure. Those effects are non-specific though with respect to affected region, and their impact on ED behavior is uncertain.

Another advancement have been studies by Lavagnino and Vaughn that used machine learning, a statistical method to identify patterns of regional brain volumes to distinguish control from ED groups (8, 14). While classification accuracy in those studies was only between 70 and 80% for diagnostic purposes, those studies allow generating hypothesis about brain regions and circuits, such as insula and frontal cortical regions to be involved in ED pathophysiology and define subgroups.

White Matter Tract Diffusion Imaging

White matter tracts link functionally connected brain regions and could contribute to pathological behavior, including food restriction or binge eating and purging via altered information processing. Past studies suggested reduced fractional anisotropy (water flow along the axon as a measure of white matter tract integrity) across many regions, which was thought to be a result from malnutrition, while elevated tract numbers after long term recovery could be a potential compensatory mechanism (15). Several white matter studies were conducted in AN in the past year. Phillipou and Hu found in independent studies lower white matter integrity in AN versus controls widespread across the brain (16, 17). However, those study have to be viewed with caution. A recent report by Kaufmann indicated that so-called “free water” such as from enlarged ventricles or other cerebrospinal fluid spaces that are adjacent to white matter tracts could lead to artificially lower white matter integrity values (18). This may indicate that previous studies should be reanalyzed. Similarly, to brain volume studies, weight restoration and recovery from AN are associated with white matter integrity normalization. Atypical AN showed normal white matter integrity, highlighting the impact of food restriction and underweight on white matter integrity (19–21). No white matter diffusion studies have recently been published in BN or BED.

Brain Connectivity Studies

Several recent studies identified brain network organization differences between AN and control groups. Geisler found that individuals recovered from AN had more nodes (functionally relevant regions) compared to controls across the brain, which mirrored ill AN findings, suggesting that this pattern could be a trait marker (22). Haynos found reduced functional connectivity between reward processing and executive regions in AN, while Olivo reported a more mixed picture of reduced connectivity between basal ganglia, occipital cortex and cerebellum, but higher connectivity in temporo-parietal-occipital circuits (23, 24). Whether these are state factors due to malnutrition and whether these are relevant for illness progression and recovery remains to be further studied (25).

Rangaprakash presented fear inducing pictures and saw that the AN group lacked expected connections between the prefrontal cortex and the amygdala, connections that are important for emotion regulation (26). This result suggests a possibly underlying mechanism for the often exaggerated fear or anxiety response in AN that is poorly modulated by frontal cortical input.

Two studies investigated functional connectivity related to binge eating. Stopyra found that anterior cingulate (salience network, reward processing, emotional arousal), and medial frontal cortex (default mode network, monitoring of physical and emotional states) were less active in BN and BED groups compared to controls implicating reward and executive function circuits in those disorders and associated especially with food intake control and binge eating (27). Domakonda on the other hand found no altered network connectivity across controls and BN, suggesting that larger, more definitive studies are needed to resolve questions about network involvement in those EDs (28).

Task Based Functional Brain Imaging Studies

Executive function, emotion processing, body perception, and reward processing may be relevant for ED pathophysiology and brain circuits related to those behaviors could be part of specific pathophysiology that drives illness related behaviors.

Bernardoni applied a decision making task during brain imaging and while brain response did not differ between group, AN had elevated learning rate compared to controls; this highlighted that certain types of learning are well preserved if not better in AN (29). In a study by Neveu on food choice and decision making, individuals with BN and controls rated food items for tastiness and healthiness during brain scanning and then chose food items based on what they deemed more important, taste or health (30). Individuals with BN used food unhealthiness and tastiness to make food choices while healthy controls used only food tastiness, supporting the clinical observation that individuals with BN “allow” themselves unhealthy foods during binges. The BN group activated the dorsolateral prefrontal cortex more than controls during food choice based on health, suggesting stronger mental effort in BN. Cyr et al studied a conflict resolution paradigm (“Simon Task”) where participants ill with or recovered from BN and controls had to respond with button presses to visual stimuli that appeared variably on each side of a computer screen (31, 32). Brain activation patterns

could distinguish healthy controls from individuals with BN. Interestingly, individuals who had recovered from BN showed the highest activation compared to controls, which led to the hypothesis that high brain response might compensate for executive function deficits found previously in BN.

A study by Berner that induced negative emotions by breathing in and holding the breath, suggested a state of hyper-arousal in AN across cortical and subcortical regions in AN (33). McAdams found in a social interaction task that individuals ill with AN had a negative bias toward how they interacted with others and this externalizing bias correlated with insula and frontal cortical brain activity, implicating those areas in difficulties in social perception in AN (34).

Body image distortion in AN continues to be an enigma and there is ongoing debate whether this is a cognitive emotional problem or whether there are neuronal factors that interfere with body integration or perception (35). Burke found that when comparing one's own body with that of another person, women activated stronger than men striatal, medial prefrontal and insula regions, suggesting a sex specific brain response that could be related to the higher prevalence of eating disorders in women compared to men (36). Furthermore, the insula integrates interoceptive stimuli and that study raises the question whether intense self-perception in AN is mediated by insula hyper-sensitivity. In treatment, patients with AN have a low threshold for being triggered by other patients' thin body shape, causing fear of being heavier and it is possible that insula over-activation mediates this behavior response. That study, however, is in contrast to Via's report that showed a lack of response when comparing oneself with others in AN (37). In summary, the pathophysiology that underlies body image perception continues to be poorly understood and more effort needs to be made to better understand this key element of AN.

Several functional studies in the past year have applied reward paradigms. In a study that presented pictures of food during brain imaging, Boehm showed that adults with AN had higher brain response to subliminal food cues in visual areas (38). Horndasch found higher cerebellar activation to both high and low calorie food images versus controls in adult AN, but adolescents had a mixed pattern of higher response in mostly frontal and parietal regions. A study by Aviram-Friedman that focused on presenting high and low-calorie food images in binge eating disorder found elevation of brain response across multiple regions (39). How to interpret results from those studies that presented visual food cues and use clinically continues to be difficult, as studies vary greatly and the neurotransmitters involved are uncertain (40). One study though indicated that amphetamines may be able to normalize exaggerated brain response to food images in BED and reduce binge eating, further implicating the dopamine and noradrenaline system in binge eating pathophysiology (41). A very elegant task by Mueller that *depleted* catecholamines in the blood prior to a monetary reward earning task in BN and a control group, found that the dopamine related reward circuitry is desensitized in BN, consistent with earlier studies (42). Interestingly, in controls higher brain response was associated with higher monetary earnings, but this relationship was disrupted in the BN group, which suggested a disruption between neurotransmitter function and behavior.

Our lab published a multi-modal brain imaging study in adolescents with AN and controls, where the AN group showed hyper-activation in the caudate head, nucleus accumbens and insula compared to controls during a classical conditioning paradigm that has been associated with dopamine function. Orbitofrontal brain response in AN was positively related to the anxiety trait harm avoidance and striatal-hypothalamic connectivity, but negatively with change in body mass index during treatment (43). This suggested that altered reward brain response in adolescent AN may be due to disturbed dopamine function in response to food restriction, may have a key role in AN's specific pathophysiology and should be explored as a target for biological treatments. There is also evidence for genetic underpinnings that alter reward prediction error response, which needs to be further explored (44). Based on those data we developed a model, where we propose that there is a conflict between the conscious motivation to restrict food, and a body-homeostasis driven motivation to approach food in response to weight loss. These opposing motivations trigger anxiety, which maintains the vicious cycle of ongoing energy restriction and weight loss (45). Such a top-down control over eating was supported by a study from Hildebrandt that showed elevated frontal control network response to food cues (46). Another study from our group analyzed brain response and value that individuals with EDs attribute to sweet taste (47). We found that in AN when ill, the expected value for receiving sucrose is strongly associated with anterior cingulate activation, which correlated negatively with body mass index (BMI, weight in kg / height m^2) across groups. This suggests that excessive food intake and resulting BMI change brain circuitry and reduce value attribution to the stimulus. The notion that extremes of food intake alter brain function was also suggested in a study by Joutsa that found lower mu-opioid receptor availability in obese individuals with and without binge eating (48). Previous research has demonstrated that food intake can directly alter neurotransmitter receptor expression and those recent brain imaging data are further supporting that extremes of food intake have profound effects on brain function and stimulus processing (49).

Conclusion

Brain structure and function are altered in response to extremes of eating and this can be used clinically to motivate patients to cease those behaviors. White matter studies indicated altered axon integrity, but methods need to be developed further to control for potential confounds. Altered functional connectivity in AN between amygdala and frontal cortex could account for poor emotion regulation. The dopamine system associated reward prediction error brain response is elevated in AN compared to controls and relationships between prediction error, anxiety and hypothalamus connectivity suggest that this signal drives anxiety and food restriction. The dopamine system can me modulated pharmacologically (50), and could become a target for intervention.

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References

1. American Psychiatric Association Desk reference to the diagnostic criteria from DSM-5. Washington, DC: American Psychiatric Publishing; 2013 xlviii, 395 p. p.
2. Frank GK. Advances from neuroimaging studies in eating disorders. CNS Spectr. 2015;20(4):391–400. [PubMed: 25902917]
3. King JA, Frank GKW, Thompson PM, Ehrlich S. Structural Neuroimaging of Anorexia Nervosa: Future Directions in the Quest for Mechanisms Underlying Dynamic Alterations. Biol Psychiatry. 2018;83(3):224–34. [PubMed: 28967386] (** This is a detailed review of structural brain imaging in anorexia nervosa that lays out future directions of research.)
4. Nickel K, Joos A, Tebartz van Elst L, Matthis J, Holovics L, Endres D, et al. Recovery of cortical volume and thickness after remission from acute anorexia nervosa. Int J Eat Disord. 2018.(* This manuscript supports the notion of reversible changes in brain structure in anorexia nervosa.)
5. Bernardoni F, King JA, Geisler D, Birkenstock J, Tam FI, Weidner K, et al. Nutritional Status Affects Cortical Folding: Lessons Learned From Anorexia Nervosa. Biol Psychiatry. 2018;84(9): 692–701. [PubMed: 29910027] (* The manuscript extends state related structural changes in anorexia nervosa to cortical folding.)
6. Olivo G, Solstrand Dahlberg L, Wiemerslage L, Swenne I, Zhukovsky C, Salonen-Ros H, et al. Atypical anorexia nervosa is not related to brain structural changes in newly diagnosed adolescent patients. Int J Eat Disord. 2018;51(1):39–45. [PubMed: 29215777] (* The manuscript supports the notion that structural brain changes are related to severe underweight.)
7. Seitz J, Konrad K, Herpertz-Dahlmann B. Extend, Pathomechanism and Clinical Consequences of Brain Volume Changes in Anorexia Nervosa. Curr Neuropharmacol. 2018;16(8):1164–73. [PubMed: 29119931] (* This manuscript provides a model for potentially underlying causes for volume alterations in anorexia nervosa.)
8. Lavagnino L, Mwangi B, Cao B, Shott ME, Soares JC, Frank GKW. Cortical thickness patterns as state biomarker of anorexia nervosa. Int J Eat Disord. 2018;51(3):241–9. [PubMed: 29412456] (* One of the few studies that investigated pattern analyses.)
9. Wallace GL, Richard E, Peng CS, Knodt AR, Hariri AR. Subclinical eating disorder traits are correlated with cortical thickness in regions associated with food reward and perception. Brain Imaging Behav. 2019.
10. Castro-Fornieles J, de la Serna E, Calvo A, Pariente J, Andres-Perpina S, Plana MT, et al. Cortical thickness 20 years after diagnosis of anorexia nervosa during adolescence. Eur Arch Psychiatry Clin Neurosci. 2019.
11. Frank GKW, Favaro A, Marsh R, Ehrlich S, Lawson EA. Toward valid and reliable brain imaging results in eating disorders. Int J Eat Disord. 2018;51(3):250–61. [PubMed: 29405338] (* The manuscript provides guidance for imaging study set up and abalysis in eating disorder research.)
12. Westwater ML, Seidlitz J, Diederen KMJ, Fischer S, Thompson JC. Associations between cortical thickness, structural connectivity and severity of dimensional bulimia nervosa symptomatology. Psychiatry Res Neuroimaging. 2018;271:118–25. [PubMed: 29150136]
13. Berner LA, Stefan M, Lee S, Wang Z, Terranova K, Attia E, et al. Altered cortical thickness and attentional deficits in adolescent girls and women with bulimia nervosa. J Psychiatry Neurosci. 2018;43(3):151–60. [PubMed: 29688871]
14. Vaughn DA, Kerr WT, Moody TD, Cheng GK, Morfini F, Zhang A, et al. Differentiating weight-restored anorexia nervosa and body dysmorphic disorder using neuroimaging and psychometric markers. PLoS One. 2019;14(5):e0213974.) [PubMed: 31059514]
15. Frank GK, Shott ME, Riederer J, Pryor TL. Altered structural and effective connectivity in anorexia and bulimia nervosa in circuits that regulate energy and reward homeostasis. Transl Psychiatry. 2016;6(11):e932 [PubMed: 27801897] (* This is the first study that showed altered hypothalamic connecivity across various eating disorders.).

16. Phillipou A, Carruthers SP, Di Biase MA, Zalesky A, Abel LA, Castle DJ, et al. White matter microstructure in anorexia nervosa. Hum Brain Mapp. 2018;39(11):4385–92. [PubMed: 29964345]
17. Hu SH, Feng H, Xu TT, Zhang HR, Zhao ZY, Lai JB, et al. Altered microstructure of brain white matter in females with anorexia nervosa: a diffusion tensor imaging study. Neuropsychiatr Dis Treat. 2017;13:2829–36. [PubMed: 29200856]
18. Kaufmann L-K, Baur V, Hänggi J, Jäncke L, Piccirelli M, Kollias S, et al. Fornix Under Water? Ventricular Enlargement Biases Forniceal Diffusion Magnetic Resonance Imaging Indices in Anorexia Nervosa. Biological Psychiatry: Cognitive Neuroscience and Neuroimaging. 2017;10.1016/j.bpsc.2017.03014:1–8.(** A very interesting stiudy that suggest that free water needs to be taken into consideration for white matter diffusion analysis.)
19. von Schwanenflug N, Muller DK, King JA, Ritschel F, Bernardoni F, Mohammadi S, et al. Dynamic changes in white matter microstructure in anorexia nervosa: findings from a longitudinal study. Psychol Med. 2018:1–10.
20. Bang L, Ro O, Endestad T. Normal white matter microstructure in women long-term recovered from anorexia nervosa: A diffusion tensor imaging study. Int J Eat Disord. 2018;51(1):46–52. [PubMed: 29120488]
21. Olivo G, Swenne I, Zhukovsky C, Tuunainen AK, Saaid A, Salonen-Ros H, et al. Preserved white matter microstructure in adolescent patients with atypical anorexia nervosa. Int J Eat Disord. 2019;52(2):166–74. [PubMed: 30676658]
22. Geisler D, Borchardt V, Boehm I, King JA, Tam FI, Marxen M, et al. Altered global brain network topology as a trait marker in patients with anorexia nervosa. Psychol Med. 2019:1–9.(*)
23. Haynos AF, Hall LMJ, Lavender JM, Peterson CB, Crow SJ, Klimes-Dougan B, et al. Resting state functional connectivity of networks associated with reward and habit in anorexia nervosa. Hum Brain Mapp. 2019;40(2):652–62. [PubMed: 30251758]
24. Olivo G, Swenne I, Zhukovsky C, Tuunainen AK, Salonen-Ros H, Larsson EM, et al. Reduced resting-state connectivity in areas involved in processing of face-related social cues in female adolescents with atypical anorexia nervosa. Transl Psychiatry. 2018;8(1):275. [PubMed: 30546060] (*)
25. Frank GK. What causes eating disorders, and what do they cause? Biol Psychiatry. 2015;77(7): 602–3. [PubMed: 25766685]
26. Rangaprakash D, Bohon C, Lawrence KE, Moody T, Morfini F, Khalsa SS, et al. Aberrant Dynamic Connectivity for Fear Processing in Anorexia Nervosa and Body Dysmorphic Disorder. Front Psychiatry. 2018;9:273. [PubMed: 29997532]
27. Stopyra MA, Simon JJ, Skunde M, Walther S, Bendszus M, Herzog W, et al. Altered functional connectivity in binge eating disorder and bulimia nervosa: A resting-state fMRI study. Brain Behav. 2019;9(2):e01207. [PubMed: 30644179]
28. Domakonda MJ, He X, Lee S, Cyr M, Marsh R. Increased Functional Connectivity Between Ventral Attention and Default Mode Networks in Adolescents With Bulimia Nervosa. J Am Acad Child Adolesc Psychiatry. 2019;58(2):232–41. [PubMed: 30738550] (* This is one of the very few studies that investigated connectivity in bulimia nervosa)
29. Bernardoni F, Geisler D, King JA, Javadi AH, Ritschel F, Murr J, et al. Altered Medial Frontal Feedback Learning Signals in Anorexia Nervosa. Biol Psychiatry. 2018;83(3):235–43. [PubMed: 29025688] (*)
30. Neveu R, Neveu D, Carrier E, Gay A, Nicolas A, Coricelli G. Goal Directed and Self-Control Systems in Bulimia Nervosa: An fMRI Study. EBioMedicine. 2018;34:214–22. [PubMed: 30045816]
31. Cyr M, Fontaine M, Stefan M, Terranova K, Kopala-Sibley DC, Attia E, et al. A longitudinal functional magnetic resonance imaging study of task control circuits and bulimic symptoms over adolescence. J Child Psychol Psychiatry. 2018;59(7):752–62. [PubMed: 29114852]
32. Cyr M, Yang X, Horga G, Marsh R. Abnormal fronto-striatal activation as a marker of threshold and subthreshold Bulimia Nervosa. Hum Brain Mapp. 2018;39(4):1796–804. [PubMed: 29322687] (* An interesting study in bulimia nervosa that highlights that brain function is related to state of illness)

33. Berner LA, Simmons AN, Wierenga CE, Bischoff-Grethe A, Paulus MP, Bailer UF, et al. Altered interoceptive activation before, during, and after aversive breathing load in women remitted from anorexia nervosa. Psychol Med. 2018;48(1):142–54. [PubMed: 28714434]
34. McAdams CJ, Harper JA, Van Enkevort E. Mentalization and the left inferior frontal gyrus and insula. Eur Eat Disord Rev. 2018;26(3):265–71. [PubMed: 29464819]
35. Treasure J, Zipfel S, Micali N, Wade T, Stice E, Claudino A, et al. Anorexia nervosa. Nat Rev Dis Primers. 2015;1:15074. [PubMed: 27189821]
36. Burke SM, Majid DSA, Manzouri AH, Moody T, Feusner JD, Savic I. Sex differences in own and other body perception. Hum Brain Mapp. 2019;40(2):474–88. [PubMed: 30430680]
37. Via E, Goldberg X, Sanchez I, Forcano L, Harrison BJ, Davey CG, et al. Self and other body perception in anorexia nervosa: The role of posterior DMN nodes. World J Biol Psychiatry. 2018;19(3):210–24. [PubMed: 27873550]
38. Boehm I, King JA, Bernardoni F, Geisler D, Seidel M, Ritschel F, et al. Subliminal and supraliminal processing of reward-related stimuli in anorexia nervosa. Psychol Med. 2018;48(5): 790–800. [PubMed: 28832300]
39. Aviram-Friedman R, Astbury N, Ochner CN, Contento I, Geliebter A. Neurobiological evidence for attention bias to food, emotional dysregulation, disinhibition and deficient somatosensory awareness in obesity with binge eating disorder. Physiol Behav. 2018;184:122–8. [PubMed: 29128522]
40. Lloyd EC, Steinglass JE. What can food-image tasks teach us about anorexia nervosa? A systematic review. J Eat Disord. 2018;6:31. [PubMed: 30410758] (** An important review of food-image studies in anorexia nervosa.)
41. Fleck DE, Eliassen JC, Guerdjikova AI, Mori N, Williams S, Blom TJ, et al. Effect of lisdexamfetamine on emotional network brain dysfunction in binge eating disorder. Psychiatry Res Neuroimaging. 2019;286:53–9. [PubMed: 30903953] (** A study that points toward mechanism of action of lisdexamfetamine).
42. Frank GK, Reynolds JR, Shott ME, O'Reilly RC. Altered temporal difference learning in bulimia nervosa. Biol Psychiatry. 2011;70(8):728–35. [PubMed: 21718969] (* The first study in bulimia nervosa that used computational modeling.)
43. Frank GKW, DeGuzman MC, Shott ME, Laudenslager ML, Rossi B, Pryor T. Association of Brain Reward Learning Response With Harm Avoidance, Weight Gain, and Hypothalamic Effective Connectivity in Adolescent Anorexia Nervosa. JAMA Psychiatry. 2018;75(10):1071–80. [PubMed: 30027213] (** A large study in youth with anorexia nervosa that shows altered effective connectiivty and a connection between brain reward function and treatment outcome.)
44. Frank GKW, Shott ME, DeGuzman MC, Smolen A. Dopamine D2 -141C Ins/Del and Taq1A polymorphisms, body mass index, and prediction error brain response. Transl Psychiatry. 2018;8(1):102. [PubMed: 29795192]
45. Frank GKW, DeGuzman MC, Shott ME. Motivation to eat and not to eat - The psycho-biological conflict in anorexia nervosa. Physiol Behav. 2019;206:185–90. [PubMed: 30980856] (** A manuscript that integrates brain response, peripheral hormone findings and anorexia nervosa typical behavior and develops a model for illness development and maintenance.)
46. Hildebrandt T, Schulz K, Schiller D, Heywood A, Goodman W, Sysko R. Evidence of prefrontal hyperactivation to food-cue reversal learning in adolescents with anorexia nervosa. Behav Res Ther. 2018;111:36–43. [PubMed: 30292918]
47. Olsavsky AK, Shott ME, DeGuzman MC, Frank GKW. Neural correlates of taste reward value across eating disorders. Psychiatry Res Neuroimaging. 2018.
48. Joutsa J, Karlsson HK, Majuri J, Nuutila P, Helin S, Kaasinen V, et al. Binge eating disorder and morbid obesity are associated with lowered mu-opioid receptor availability in the brain. Psychiatry Res Neuroimaging. 2018;276:41–5. [PubMed: 29655552] (** One of the very few studies that investigated neurotransmitter receptors in binge eating and related to obesity.)
49. Johnson PM, Kenny PJ. Dopamine D2 receptors in addiction-like reward dysfunction and compulsive eating in obese rats. Nat Neurosci. 2010;13(5):635–41. [PubMed: 20348917]

50. Frank GK, Shott ME, Hagman JO, Schiel MA, DeGuzman MC, Rossi B. The partial dopamine D2 receptor agonist aripiprazole is associated with weight gain in adolescent anorexia nervosa. Int J Eat Disord. 2017;50(4):447–50. [PubMed: 28334444]

Key points

1. Food restriction as well as binge eating and purging behaviors are associated with lower regional brain volumes or cortical thickness, but those changes largely return to normal with normalization of weight and eating behavior.
2. Computational modeling has started to identify patterns of structural and functional imaging data that classify eating disorder subtypes.
3. The prediction error model, a computational approach to assess dopamine related brain reward function, helped support a brain based model for anorexia nervosa. In that model, `the conscious motivation to restrict conflicts with body signals that stimulate eating, which causes anxiety and drives a vicious cycle of food restriction.