Gustatory Sensation and Perception in Anorexia Nervosa

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Abstract

Anorexia nervosa, an eating disorder characterized by an abnormally low body weight and a refusal to eat, is closely connected to the sense of taste. Although results are inconsistent, psychophysical analyses of taste sensitivity tend to demonstrate alterations in identification and intensity ratings in anorexia, which can improve after recovery. Taste sensitivity deficits are non-specific and may arise from micronutrient deficiencies, reduced papillae density, or self-induced purging. The "liking" and "wanting" of taste stimuli also impact eating behaviors in anorexia. Brain imaging studies indicate an altered hedonic set point for pleasant stimuli in the insula, or primary taste cortex. Likewise, anorexia promotes hypersensitive responses to taste in the dopaminergic reward system, regardless of valence, explaining a generalized decrease in the desire to consume palatable foods. Research continues to expand with regard to somatosensory sensation in the oral cavity and taste reception in extraoral receptors of the gastrointestinal tract. Understanding of the altered gustatory sensation and perception in anorexia is critical to the development of effective treatments, as gustatory interventions could help create a fuller and more positive food experience for individuals struggling with anorexia. Additionally, it will improve our general understanding of the relationship between taste, food consumption, diet, and weight loss. This review highlights the unique perceptual experience of gustation in anorexia while expanding the knowledge base on gustatory processing in both the oral cavity and the central nervous system.

Keywords: anorexia nervosa, taste, sensation, perception

Contents

Anorexia Nervosa and Taste

Anorexia nervosa, commonly referred to as anorexia, is an eating disorder characterized by restriction of energy intake and a significantly low body weight. Individuals suffering from anorexia express intense fear of weight gain and persistently engage in behaviors that interfere with weight gain, without acknowledging the seriousness of their low weight (Brown et al., 2014). The ideal body weight and diet in anorexia fall far under healthy recommendations and can lead to malnutrition. The lifetime prevalence of anorexia is about 0.6%, but the disorder disproportionately affects females, with a 0.9% prevalence, compared to only 0.3% prevalence in males (Hudson et al., 2007). There are two main subtypes of anorexia nervosa, restrictive subtype (AN-R) and binging purging subtype (AN-BP). The binging purging subtype is defined by frequent episodes of binge eating followed by vomiting, while the restrictive subtype presents solely through restricted food intake (Brown et al., 2014). Anorexia is drastically impacted by social and cultural influences, including unrealistic societal standards for body image and social media platforms promoting food restriction (Bardone-Cone & Cass, 2006). Alongside societal pressures, individuals with anorexia may experience altered taste sensations that contribute to their food restriction and negative experiences with food.

Research on altered gustatory processes has grown in the past few decades, as newer technological developments, such as functional magnetic resonance imaging (fMRI), have allowed for assessment of taste function throughout the gustatory pathway. From the body of research available, it's evident that taste perception is different in anorexia than in healthy controls. Previous research has demonstrated potential malfunctions at multiple levels of the gustatory system, including taste sensitivity and discrimination, hedonic assessment, and reward processing. Nonetheless, there are inconsistent results throughout the literature, and the exact

gustatory deficits experienced by individuals with anorexia require continued investigation and inquiry. This review summarizes and analyzes the available literature on alterations in the gustatory processing of anorexia.

Taste Sensitivity

Taste begins with the binding of a chemical, known as a tastant, to the taste receptor cells on the taste buds. Taste buds are located on papillae throughout the oral cavity, including the tongue, soft palate, and cheeks. The atypical taste processing of anorexia may begin at the level of the taste bud, with altered sensitivity to all or a few of the five basic tastes: sweet, salty, bitter, sour, and umami. Fat has additionally been proposed as a sixth basic taste (Keast & Costanzo, 2015) and has also been studied in the anorexic population. Taste sensitivity is measured through two main mechanisms: identification and intensity.

Taste identification measures an individual's ability to recognize and pinpoint the presence of one of the five basic tastes. Solutions of the five tastes can be applied to the oral cavity through a variety of methods including sprays, strips, and filter paper. The most common method used among modern investigations is taste strips, however. Taste strips are submerged in varying concentrations of the different tastes and are placed on the participant's tongue (Mueller et al., 2003). The taste modalities of salty, bitter, sour, sweet, and umami are normally administered as sodium chloride, quinine hydrochloride, citric acid, sucrose, and monosodium glutamate, respectively.

Identification of multiple tastes, including salty, bitter, sour, and sweet is impaired in both AN-R and AN-BP populations. A few studies have found "overall poorer gustatory function" and decreased taste identification across all modalities (Aschenbrenner et al., 2008;

Dazzi et al., 2013; Nakai et al., 1987). Contrastingly, other studies found preservation of most taste identification, with deficits in a specific taste only. Bitter and sweet, in particular, have shown the most frequent impairments and appear to be altered in instances where other taste modalities are unaffected (Dazzi et al., 2013; Fernández-Aranda et al., 2016). The varying methodologies and small samples sizes have led to contrasting results, however. A minority of studies have found no significant deficits in tastant identification for anorexic patients compared to healthy controls (Goldzak-Kunik et al., 2012; Jirik-Babb & Katz, 1988; Ortega et al., 2016). Research on anorexia as it relates to taste identification continues, with more emphasis on standardized techniques, such as the use of taste strips and methodology outlined by Mueller and colleagues (2003). Although the inconsistent results do not provide a clear solution upon immediate appraisal, the variable alterations in taste identification indicate that taste receptor cells and signaling pathways specific to one taste are not modified. Rather, functional change in the oral epithelium that impacts all five tastes is more likely.

Subjective taste intensity serves as another measure of taste sensitivity in the oral cavity. Taste intensity requires participants to rank different taste stimuli based on the perceived intensity of the taste quality. Generally speaking, estimations of sweetness and fattiness do not differ between AN-R and AN-BP patients and healthy controls (Drewnowski et al., 1987; Schebendach et al., 2014; Simon et al., 1993). As magnitudes of tastes increase, however, a difference starts to develop. At high concentrations, anorexic patients start to estimate significantly lower concentrations than controls (Jirik-Babb & Katz, 1988). Poor gustatory sensitivity starts to surface at higher tastants concentrations, implying that individuals with anorexia may have a dulled sense of taste for stronger tastants. Weakened sensation of

"powerful" tastants, or tastants of a high intensity, in anorexic patients may contribute to a general reduced appeal to taste stimuli and food consumption.

Despite the inconsistencies in the data regarding the development of taste sensitivity deficits, the trend for taste sensitivity recovery is much clearer: taste sensitivity improves with recovery from anorexia. A small proportion of taste sensitivity deficits in anorexia may endure long-term, but a majority of changes in taste sensitivity resolve after full recovery from anorexia. Research conducted by Aschenbrenner and colleagues (2008) indicated significant improvement in identification of all taste modalities in anorexic patients after remission and release from the hospital. The improvement was substantial, but did not completely repair taste sensitivity to the levels seen in individuals who had never previously suffered from an eating disorder. The partial recovery of taste sensitivity and the variable reduction across all five taste modalities suggests wide-spread, nonpermanent sources of taste sensitivity deficits.

Decreased Papillae Density

One proposed source of taste sensitivity deficits in anorexia is a decrease in the number of fungiform papillae and their associated taste buds and taste receptor cells. Fungiform papillae are mushroom-shaped papillae distributed throughout the oral cavity; they are the most abundant form of taste papillae, are mainly concentrated on the anterior two-thirds of the tongue, and are critical to proper taste perception (Miller, 1987). Taste bud density influences both taste perception and sensitivity (Essick et al., 2003; Miller & Reedy, 1990). More specifically, there is an inverse correlation between the number of fungiform papillae and taste sensitivity (Zhang et al., 2008). Two studies have identified modifications to papillae in individuals with anorexia. Patients with anorexia have a decreased density of fungiform papillae and a concurrent decrease

in bitter sensitivity (Wöckel et al., 2008; Wöckel et al., 2007). Sensitivity for the other four basic tastes was not directly assessed in the studies, but the decreased papillae density has been proposed as a potential mechanism for decreased sensitivity of sweet, sour, salty, and umami tastes in other studies. Reductions in taste papillae are potential indicators of altered taste perception, and more specifically, taste sensitivity, in individuals with anorexia.

Zinc Deficiency

To date, very little research has been conducted to investigate the link between nutritional status and taste. Anorexia is defined by a significant decrease in nutrients and calories, generating a wide array of nutritional deficiencies, including deficiencies in micronutrients, like vitamins and minerals. Micronutrient deficiencies are infrequently explored and considered in the development of eating disorders. Nonetheless, the link between micronutrients and the precise functioning of taste cells may provide insight into the taste deficits of anorexia. Zinc is a micronutrient that has shown the most promise in its connection to anorexia. According to Greenblatt and Delane (2018), “altered sensory mechanisms may represent the most direct explanations for the relationships between zinc and food avoidance in anorexia nervosa.”

Zinc’s connection to anorexia was first discovered through its effectiveness as a treatment. Zinc supplementation significantly improves myriads of symptoms in anorexia patients (Casper et al., 1980). The exact mechanisms through which zinc alleviates anorexia symptoms are unknown, but research indicates a link to taste. The zinc molecule supports the structural integrity of taste papillae. In rodent models, zinc deficient diets result in a decreased number of taste buds per papilla and a decreased average area of taste buds (Chou et al., 2001). In addition to a general reduction in taste bud frequency, more recent data in animal models has

revealed that zinc also impacts the abundance of tastant-specific receptor proteins. Zinc deficient diets generate a decreased frequency of a class of bitter receptors, TAS2Rs, and salty receptors, ENaCs (Ikeda et al., 2013).

Zinc's role in the development and treatment of anorexia is promising. Zinc supplementation restores gustatory sensation in anorexia (Greenblatt & Delane, 2018), matching the reversibility trends seen in previous examinations of taste sensitivity. Likewise, the loss of taste bud density and area during zinc deficiency matches the generalized decrease in taste sensitivity observed across all taste modalities in anorexia. The exact functions of zinc at the level of the taste receptors are still not fully understood and continued study is required.

Taste Differences in AN-R and AN-BP Populations

The two subtypes of anorexia, AN-R and AN-BP, may give rise to different taste alterations. The self-induced vomiting and binging that is unique to AN-BP may impact taste differently than restriction alone. Nevertheless, it is difficult to differentiate between the two subtypes from the available research body, in which explicit distinctions are limited. Moreover, around 62% of individuals with AN-R will develop AN-BP during the course of their disordered eating, making the isolation of taste in each subtype even more challenging (Goyal et al., 2012). Of all the taste sensitivity research, only the study conducted by Aschenbrenner and colleagues (2008) limited their participant pool to individuals with AN-R. Additionally, many earlier studies in the 1980s and 1990s, such as Jirik-Babb & Katz (1988), only defined their participants as "anorexic", failing to specify either subtype.

The second study conducted by Wöckel et al. (2008) uncovered a distinct difference in the taste alterations of AN-BP and AN-R. The decreased density of fungiform papillae was

unique to the AN-R population, and the AN-R patients showed significant decreases in fungiform papillae density relative to both controls and AN-BP patients. For the first time, research suggested a fundamental difference in the loss of taste sensitivity in AN-R and AN-BP patients. The underlying reasons for the differences in the groups remain unknown, but may be related to the increased activation of taste receptors during binging episodes of AN-BP.

Taste buds are directly impacted by the increased acidity of vomit following a purging episode in AN-BP. Although there are no independent investigations of taste sensitivity in the AN-BP population, studies of taste sensitivity changes in bulimia nervosa shed light on potential taste alterations from self-induced vomiting. Purging behaviors in both bulimia and AN-BP project vomit onto the palate. Like the tongue, the palate contains a variety of taste buds and receptor cells. These taste receptor cells are the most damaged from purging behaviors, resulting in a spatial impairment of sour, bitter, sweet, and salty taste intensity perception in bulimic patients (Rodin et al., 1990). Although Wöckel and colleagues (2008) demonstrated decreased fungiform papillae in AN-R, the research focused solely on the tongue. Without analyzing papillae on the palate, it is difficult to know if taste papillae density in other areas of the oral cavity could relate to taste differences in the AN-BP subpopulation. Future research necessitates a clear distinction between these subgroups of anorexia, as their behaviors distinctively impact the first line of gustatory processing, the taste papillae and taste receptor cells.

Hedonic Processing of Taste

The inconsistent findings on altered taste sensitivity in anorexia prompt investigation of taste preference. Modern research indicates that both “liking” and “wanting” processes may be modified in taste perception in anorexia (Frank et al., 2012). Liking describes the hedonic

assessment of a taste stimuli, or the subjective pleasantness of a taste stimuli. Wanting, on the other hand, describes the motivational desire to obtain the taste stimuli. In 2009, K.C. Berridge developed a framework specific to taste-reward associations. According to his framework, the rewarding properties of a taste require both the "liking" and "wanting" components. If only one element is fulfilled, there is a partial, unsatisfying reward rather than a full, gratifying reward (Berridge, 2009). A partial reward generates decreased enjoyment and desire to consume food and may lead to the fasting and restrictive eating seen in anorexia.

Consumption of fatty and sweet foods are of particular interest in anorexia, as these are the categories of food most commonly avoided in the population. When anorexic patients are asked to self-assess palatable taste stimuli, they consistently report lower pleasantness scores (Szalay et al., 2010). Increased fat concentrations, in particular, generate further reductions in self-perceived pleasure (Simon et al., 1993). After recovery from anorexia, and most likely a simultaneous and partial recovery of gustatory sensitivity (Aschenbrenner et al., 2008; Nakai et al., 1987), patients continue to report significantly lower perceived pleasantness of gustatory inputs, especially of fatty and sweet stimuli (Drewnowski et al., 1987). If the taste sensitivity has at least partially recovered, then these major differences in pleasantness ratings must be rooted in higher order taste processes. In a review of gustatory processing in anorexia, Keating and colleagues (2012) make this argument for hedonic assessment of the gustatory sensations. The researchers argue that individuals with anorexia do not have permanent deficits in their ability to assess the quantity or presence of taste stimuli. Rather, their "liking" of certain taste modalities decreases, as seen through decreased hedonic value (Keating et al., 2012).

Insular Activity in Hedonic Processing

After gustatory signals leave the tongue through a series of cranial nerves, they pass through the ventral posterior nucleus of the thalamus to the primary taste cortex, located within a cortical structure known as the insula. The primary sensory cortex then projects to the secondary taste cortex, located in the orbitofrontal cortex, or OFC. The insula and OFC code the sensory-hedonic elements of taste and classify the pleasantness and hedonic value of gustatory stimuli (Kaye et al., 2013; Small, 2001). Alterations to activity in both the OFC and insular regions could suggest dysregulated hedonic processing of taste and have been investigated in the anorexic population. The insula is the first and more well-established region in the pathway, however, so it is the most commonly studied.

In 2008, Wagner and colleagues conducted one of the first studies on higher order taste processing in recovered anorexic patients. Previous research had investigated higher order taste processes with non-gustatory images of food (Uher et al., 2003). Using an fMRI, the researchers focused on physiological responses in primary and secondary taste cortices to blind administration of a pleasant taste, sugar, and a neutral taste, water. Anorexic patients showed lower activation of the insula upon administration of both the water and sugar (Wagner et al., 2008). The lower activation is suggestive of an "altered set point" between sensory and hedonic processing, making it so that very few gustatory inputs actually generate subjective feelings of pleasantness (Kaye et al., 2013). Alongside the objective fMRI data, the researchers also collected subjective pleasantness ratings to confirm that participants' brain activity matched their subjective perception. As insular activity increases, one would expect a concurrent increase in pleasantness ratings. Healthy controls showed this correlation; as their insular activity increased, so did their subjective pleasantness ratings. Strangely, anorexic patients did not show this same

trend and had no significant correlation between subjective pleasantness ratings and insular activity (Wagner et al., 2008). Even when the insula responded properly to palatable stimuli, with an increase in neural activity, in other words, the patients did not change their subjective perceptions. This suggests that anorexic patients do not properly interpret changes in insular activity. These misinterpretations of insular signaling could result from malfunctions in second and third order gustatory structures, which receive signals from the insula. In addition, it is possible that other external factors, such as anxiety, could interfere with interpretations of insular activity.

In a follow-up study, using sucrose and sucralose, a non-caloric sucrose alternative, the researchers isolated the impact of calories on hedonic assessment. Compared to controls, recovered anorexic individuals had significantly decreased activation in the insula in response to both the caloric sucrose and the non-caloric sucralose alternative (Oberndorfer et al., 2013), continuing to support the general trend of an altered set point for hedonic processing in anorexia. Insular activation was higher for sucralose than for sucrose within the anorexia participant pool, however. These results could relate to differences in taste sensitivity or caloric value. Sucrose and sucralose activate the same sweet taste receptors in the oral cavity, T1R2 and T1R3 (Nie et al., 2005). Although sucralose binds to the same taste receptors in the oral cavity, taste sensitivity to the two molecules may not be identical, as sucralose has a higher affinity for the receptors than sucrose (Servant et al., 2010). Higher affinity could generate the increased activity in the insula, producing the differences seen in the anorexic patients. Nonetheless, the fact that insular activity and associated hedonic value differ between two sweet stimuli that share the same receptors suggests that hedonic value may be influenced by caloric content too. The stimulus of

the taste modality alone, in this case sweetness, may not tell the entire story of how individuals with anorexia assess the "pleasantness" of a tastant.

The studies conducted by Oberndorfer and colleagues (2013) and Watson and colleagues (2008) both demonstrated decreased insular activity in anorexic patients in response to food intake. This directional relationship has not persisted in all research. Another research group conducted two studies that showed increased activity in the insula and OFC in the anorexic population (Frank et al., 2012; Frank et al., 2016). The directional change in insular activity most likely results from methodological differences. Whereas previous studies (Frank et al., 2012; Frank et al. 2016) examined random, blinded administration of tastants, Frank and colleagues' methodology used associative learning tasks and gave participants advanced notice of tastant identity. According to Oberndorfer and colleagues (2013), the "explicit expectation phase" of the learning task in Frank and colleagues' studies likely explains the differences seen (Oberndorfer et al., 2013). The exact mechanism through which the learning task influences insular activity remains unexplored. Nonetheless, it seems that the expectation of food plays a critical role in the hedonic value assigned to tastants in anorexia. In real-life contexts, anorexic patients view, smell, and make decisions about food prior to tasting it, so the expectation phase represents a more realistic representation of the schema of tasting behaviors and may be more typical of responses outside of laboratory settings.

Furthermore, there is still research that demonstrates other separate factors that may be at play in hedonic taste assessment. Investigation of swallowing of the food, rather than solely tasting the food has been shown to impact hedonic assessment, for example. In anorexic patients, when sucrose solutions are swallowed, hedonic pleasantness is rated much lower than when they are spit out (Eiber et al., 2002). Fear of gaining weight and swallowing the solutions, therefore,

may be relevant in subjective hedonic assessment rather than an actual decreased ability to experience the pleasantness of the tastants.

Reward Processing of Taste

The reward pathway works in combination with hedonic processing to increase or decrease the pleasantness of a taste stimulus. Logically, without "liking" a food and its taste, an individual will have no drive, desire, or want to consume it. The reward system drives the "wanting" for rewarding stimuli, like sweet and fatty foods.

Early research on reward processing in anorexia indicated a general increase in dopamine receptor binding in the striatum of the reward pathway (Frank et al., 2005). In the more recent past, there have been more intense investigations to determine the exact effects of this increased dopamine receptor binding on taste preferences and eating behaviors in anorexia. Individuals with anorexia have a hypersensitive response to tastes in their reward systems, seen by increased activation of the ventral striatum in response to pleasant tastes (Cowdrey et al., 2011). They are more perceptive of the rewarding effects that palatable foods provide, in other words (Frank et al., 2012). With increased reward perception, individuals with anorexia may partake in fasting and restrained eating to reduce the perceived overstimulation of reward.

The directional relationship between striatal activation and gustatory stimulation does not remain consistent across the literature. Wagner and colleagues (2008) discovered decreased striatal activity in recovered anorexia patients in response to sucrose. Cowdrey and colleagues (2011) suggest that the decrease in striatal activity was a result of expectation. Wagner and colleagues' (2008) blocked methodology resulted in a more predictable administration of tastants

compared to other studies. This explanation seems logical at first, but future studies conducted by Frank and colleagues (2012) directly contradict this proposition. In associative learning tasks, where participants knew which tastant to expect, individuals with anorexia showed significant increases in striatal activity (Frank et al., 2012), rather than decreases, as would be predicted by Cowdrey and colleagues' (2011) hypothesis. Therefore, expectation may not explain the underlying directional changes in striatal activity and reward assessment. Rather, the complexity of a tastant may impact its salience. Wagner and colleagues (2008) and Frank and colleagues (2012) used a simple tastant, sucrose. In contrast, Cowdrey and colleagues (2011) used a more complex tastant, chocolate milk. The differential salience of simple and complex tastants requires further study.

Taken together, the hypersensitivity of the reward system and the altered set point of the hedonic system demonstrate altered "wanting" and "liking" of taste stimuli in anorexia. Individuals struggling with anorexia may restrict food intake (1) because taste stimuli are less pleasant and (2) to compensate for the hyper-functioning of the reward system.

Taste, Hunger, and Satiety

To maintain proper nutritional homeostasis, external sensory stimuli must be evaluated with regard to the internal states of hunger and satiety. States of hunger and fullness have previously been shown to influence both the hedonic and rewarding value of gustatory food stimuli (Uher et al., 2006). The pleasantness and subjective liking of foods increases in a hungry state, and tastant preferences can even become associated with positive post-ingestive feelings of fullness (Mobini et al., 2007). Likewise, the pleasantness and hedonic value of tastes decreases in

a satiated state (Berridge, 1991). Satiety can also be specific to certain gustatory stimuli. In a phenomenon known as sensory-specific satiety, the pleasantness of a recently consumed food decreases relative to non-consumed foods (Rolls et al., 1981). Many studies of food preference and pleasantness ratings in anorexia focus solely on differences in a satiated state, so as to eliminate extraneous influences (Oberndorfer et al., 2013; Wagner et al., 2008). Nevertheless, the interconnected nature of gustation, hunger, and satiety cannot be understated in the pathology of anorexia.

Anorexic patients show altered taste preferences in satiated and hungry states. Early research determined that anorexic patients can override sensory-specific satiety signals and consume the same low-calorie, low-fat foods repetitively in order to avoid aversive high-fat options (Hetherington & Rolls, 1989). Modern research, using neuroimaging such as fMRIs, has continued to confirm the influence of satiation in the altered gustation of the anorexic population. In 2011, Vocks and colleagues studied a population of recovered anorexics in hopes of uncovering hunger- or satiation-dependent changes in higher order hedonic processing. Regardless of hunger state, anorexic individuals rated the valence of a chocolate milk stimulus as significantly less appealing than the controls did, consistent with previous data (Drewnowski et al., 1987; Simon et al., 1993; Szalay et al., 2010). In the hunger state, however, anorexic patients had increased amygdala activity compared to controls (Vocks et al., 2011). The amygdala has been shown to be activated in response to aversive gustatory stimuli, and signals decreased hedonic value (Wang et al., 2018; Zald, 1998). In a hungry state, in other words, food appeared to be especially aversive for anorexic patients. Additional research has been conducted to uncover hunger- and satiation-dependent changes in reward processing too. In one study, anorexic patients were resistant to increased activation of reward pathways in a hungry state

(Wierenga et al., 2015). Even in a hungry state, in other words, food may not be as rewarding for anorexic patients as it is for healthy individuals. Generally speaking, in healthy individuals, food becomes more rewarding and pleasant when an individual feels hungry, giving them additional incentive to eat. Evidence from Vocks and colleagues (2011) and Wierenga and colleagues (2015), however, demonstrates that anorexic patients do not perceive the reward or pleasantness of food stimuli any differently when they are hungry or full. The lower reward and pleasantness during hunger in anorexia could contribute to the decreased drive to eat, even during lengthened periods of fasting.

Mouthfeel, Fat Content, and Reduced Consumption

Although the activation of taste receptors is a key component of taste sensitivity, hedonic value, and reward processing in gustation, there are other elements that contribute to the overall "taste" experience of food. After ingesting food, the tactile elements of texture, referred to as mouthfeel, impact perception (Guinard & Mazzucchelli, 1996). Scientifically, these texture elements are associated with somatosensation, but during consumption of food these texture elements impact what one typically perceives as "taste". Compared to other "tastes", fat has a distinctive lubricating and creamy texture and indicates the consumption of energy dense foods (Drewnowski, 2009). The pleasantness and hedonic value of taste stimuli are impacted by the mouthfeel of fat (De Araujo & Rolls, 2004). Although fat is not traditionally considered a basic taste quality, recent research also indicates that fat may be detected through chemoreception on the taste receptor cells (Keast & Costanzo, 2015). In addition, there are distinct populations of neurons in the OFC, "fat texture-sensitive" neurons, that support the recognition of fatty substances in the mouth (Verhagen et al., 2003).

Myriads of studies report aversion and disgust responses to fatty foods amongst anorexic patients. Anorexia patients consistently rank the pleasantness of fatty substances lower than controls (Drewnowski et al., 1987; Simon et al., 1993; Szalay et al., 2010) and have lower self-reported preferences for foods high in fat content (Schebendach et al., 2019). As a result, they also consume less fat and a smaller percentage of calories from fat (Schebendach et al., 2019). Even after restoration of weight and normal eating behaviors, a general aversion to and disliking of fat persists in recovered anorexics (Sunday et al., 1992). Mouthfeel may contribute to decreased eating in anorexia through its effects on the reward system. Mouthfeel and texture of fat increase reward responses in the brain (Grabenhorst et al., 2010), so the hypersensitivity to the reward generated by fat could explain the aversion seen in anorexia. Future studies should be conducted to try and isolate the impacts of mouthfeel and fat chemoreception on food preferences and consumption in anorexia.

Taste, the Gastrointestinal Tract, and Consumption

Traditionally, taste receptors were believed to be isolated to the tongue and oral cavity. In 1996, researchers first discovered that the same taste receptors in the oral cavity are also found throughout the gastrointestinal tract, or GI tract (Hofer et al., 1996). Sweet and umami TAS1R receptors and bitter TAS2R receptors have all been discovered in the GI tract (Dyer et al., 2005; Wu et al., 2005). Until recently, however, the exact impacts of these so-called extraoral taste receptors were not understood. The taste receptors in the GI tract "taste" sweet, umami, and bitter tastants in the same manner as those of the oral cavity. The binding of tastants to receptors in the GI tract, however, generates slightly different effects. Binding initiates the release of metabolic hormones, including glucagon-like peptide-1 (GLP-1), which directly impacts satiety-

hunger signaling, feeding behaviors, and reward pathways (Jang et al., 2007; van Bloemendaal et al., 2014). The taste receptors of the gut have preliminarily been presented as a promising recourse for treatment of many pathological conditions (Depoortere, 2014).

Individuals do not have cognitive awareness of the "taste" in their GI tract, as they do with taste in the oral cavity, so analogous assessments of subjective taste sensitivity are not possible. Changes in hormone release, however, may be indicative of an improper functioning of these taste receptors in anorexia. Levels of GLP-1 and ghrelin, for example, are altered in the anorexic population (Holsen et al., 2014; Tomasik et al., 2002), suggesting improper responses in the taste receptor cells. Research on taste in the GI tract is relatively novel, and to date, the literature is extremely limited with regard to eating disorders and anorexia. Future research will continue to address the potential pathological role of GI taste receptors in anorexia.

Concluding Remarks

Anorexia nervosa is an eating disorder defined by reduced food consumption and excessive weight loss. Anorexia has been connected to taste dysfunction at many levels of gustatory processing: taste sensitivity, hedonic value, and reward pathways. Anorexic patients have wide-spread and non-permanent decreases in taste sensitivity, which may be attributed to lost taste papillae or micronutrient deficiencies. Furthermore, anorexic patients have an altered set point for hedonic assessment and a hypersensitive reward response to palatable gustatory stimuli. Research continues to expand on the role of satiation, mouthfeel, and extraoral taste receptors. The current body of research indicates a dysfunction in the connection between hunger, hedonic assessment, and reward in anorexia. The state of hunger does not increase the

pleasantness and rewarding properties of food in anorexic patients, which may contribute to a lower drive to consume food. The least amount of research is available on somatosensory inputs of mouthfeel and extraoral taste receptors, but the present research suggests that they may decrease fat consumption and proper hunger-satiety signaling, respectively. Continued investigation of taste in the pathology of anorexia will help expand basic research on gustation while simultaneously aiding in the development of efficacious treatments, so that anorexic individuals can start to have more positive and rewarding experiences with food.

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