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Review Article

Nutrition and taste and smell dysfunction

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Abstract Food selection plays a pivotal role in maintaining adequate nutrient intake, thus elucidating drivers of food choice is a meaningful strategy to maintain health and manage disease. Taste and smell are key determinants of food choice and warrant careful consideration. In this review, we first discuss how sensory stimulation influences food selection and metabolism. We then review the evidence regarding the relationship between taste and smell dysfunction and food preferences and selection, with attention given to contexts of certain chronic diseases. We conclude with brief recommendations for the management of chemosensory disorders. While sensory abilities influence food selection, the effect of taste and smell dysfunction on long-term consumption patterns and health status must be considered in light of environment, exposure, and culture.

Introduction

Of the many interacting influences on food selection, sensory inputs are often the primary driver.[1] Sensory signals also affect the metabolism of ingested nutrients. Through these functions, the chemical senses (taste, smell and chemical irritation) play a role at all stages along the continuum from health to disease. Concurrently, the function of these sensory systems is modified by an individual's health status. The sensory properties of foods interact with the sensory capabilities of consumers to generate sensations that are measured by their detectability, intensity, quality, duration, and hedonic valence. The first four dimensions are the substrate for hedonic judgements and the latter exerts the most important influence on food choice under conditions of an available, varied diet.

Sensory influences on diet selection

In addition to serving as a warning system for potentially toxic substances, sensory systems may also have evolved as

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a way to detect energy and key nutrients.[2] Here, we review evidence surrounding the chemosensory detection of the macronutrients (carbohydrates, protein, and fat) and sodium, and their relation to nutrient and food selection.

Dietary carbohydrates are often consumed in the form of starch and sugars. Although increasing evidence indicates complex carbohydrates may be detected by the taste system,[3] sweetness is the sensory attribute most commonly associated with carbohydrates, and for which the most data are available. Sensitivity to sweetness is present in utero and influences sucking behavior in pre-term infants.[4,5] Despite the biological predisposition for sweet taste, the preference for and intake of sweetened foods depends heavily on culture.[6,7] Exposure, more than functional dimensions of sensory abilities such as threshold sensitivity or perceived intensity ratings, is related to sweet preferences. For example, frequent exposure to sweetened soft drinks increases the preferred sucrose concentrations among individuals who originally preferred lower concentrations.[8] However, relationships between exposure to selected sugary foods and acceptance cannot be generalized to all sweetened foods. Exposure to sugar-sweetened water during the first six months after birth is associated with greater intake of sweetened water at six months of age, but not with consumption of sugar-sweetened fruit drinks at two years of age.[9] Other studies have failed to find significant associations between intake of sweet foods and hedonic ratings of a test item.[10] Overall, the sweetness of some carbohydrate sources promotes intake of these compounds and foods that contain them, but there is no biological determinism that overwhelms dietary experience and cultural norms.

Intact proteins are generally weak chemosensory stimuli. Their constituent amino acids as well as short peptides have varied taste qualities.[11] Umami, best exemplified by mono-sodium glutamate, is considered by many as a basic or primary taste quality. The quality is sub-served by a unique receptor and is not replicated by other "primary" taste sensations. Although protein hydrolysates are generally regarded as unpalatable, their acceptance is heightened in populations with low or marginal protein status, suggesting the presence of a body or taste wisdom to ensure adequate intake.[12,13] Additionally, healthy individuals on low-protein diets show increased protein intake and preference for savory high-protein foods.[14] In some instances, savory taste modulates food preferences more than sweet taste.[15] Furthermore, preference for high protein foods decreases more following consumption of a savory meal rather than a sweet meal.[16] Together with sensory explanations for a protein-specific appetite, others have proposed that protein is the primary physiological signal driving total energy intake, a theory derived from observations of low variability in protein intake cross-culturally and within cultures over time. This view is termed the "protein leveraging hypothesis."[17] It is postulated that diets low in protein would be consumed in larger quantity to achieve a needed level of protein intake, and diets high in protein would be ingested in lower quantities as protein needs would be met more easily. However, several studies have directly tested this hypothesis and have not provided consistent support. Although some have demonstrated a change in energy intake in response to altered dietary protein, none has consistently shown a convergence towards an optimal level of protein intake when presented both higher and lower protein diets.[18–21] The taste of protein, i.e., amino acids and peptides, may serve more as a hedonic modifier than a fundamental controller of ingestive behavior.

Although increasing evidence suggests that fat is detectable via gustation as well as other sensory systems, data supporting a role for fat taste on dietary behavior is mixed.[22] The primary form of fat in the diet is triacylglycerol, a large molecule without documented efficacy as a taste stimulus. However, its constituent fatty acids are potent olfactory stimuli and effective, albeit more subtle, taste signals. Their chemosensory properties are generally unpleasant, and foods containing high quantities are rejected (except in selected cases where a liking develops through dietary exposure and cultural norms, e.g., appeal of strong cheeses). Thus, the food industry expends considerable effort to ensure fatty acids remain below detection levels so products are viewed favorably. In this regard, fat taste is a powerful determinant of intake. Early hypotheses held that the increasing fat content of breast milk over a feed was a cue used by nursing infants to terminate a feed. Evidence related to this view is mixed, but generally negative.[23–25] High fat foods are often viewed as desirable by consumers, but this is likely attributable to non-olfactory and gustatory properties. Rather, the contribution of triacylglycerols to the mouthfeel of foods (e.g., lubricity, creaminess) are primarily responsible for hedonic appeal. Some have suggested an association between low fat detection, high intake of fatty foods, and elevated BMI or disinhibited eating behavior.[26–30] However, findings from a recent meta-analysis do not support a relationship between fat detection or intensity ratings and body weight.[31]

Taste sensitivity to salt develops at approximately 4–6 months of age and generally elicits a positive response.[32,33] However, children quickly learn cultural norms regarding where sodium is appropriate in the diet.[34] Indeed, a twin study demonstrated that environment was more influential than genetics on salt taste.[35] Others have reported that dietary intake influences salt preferences, as reduced sodium intake lowered salt preferences independent of changes to salt taste detection.[36,37] Earlier work indicated increased or decreased dietary salt is associated with higher and lower preferred salt concentrations in foods, respectively.[36,38]

Salt taste has been proposed as a mechanism to regulate physiological needs for sodium. Sodium depletion increases salt sensitivity and preference for salty foods.[39,40] However, the association is not symmetrical: high levels of sodium consumption do not blunt preferences, and may even augment them.[38] Exercise may also alter sensory perception and preference for sodium.[41,42] However, a more recent placebo-controlled cross-over study failed to show an effect of encapsulated sodium or potassium supplementation on salt detection thresholds, or desire to eat salty foods.[43] Given the health concerns related to sodium intake, resolution of this mixed literature warrants further study. Taken together, current evidence suggests salt preferences are primarily determined by exposure, rather than innate sensory abilities.

Impacts of sensory stimulation on physiology

In addition to influencing food choice, sensory stimulation also affects food digestion, and the absorption and metabolism of nutrients through the elicitation of cephalic phase responses.[44–47] These are vagally-mediated physiological responses to sensory stimulation. Cephalic phase responses include, but are not limited to, saliva flow and composition, gut motor activity and enzyme release, endocrine and exocrine secretions, thermogenesis, as well as cardiovascular and renal effects.[45] These responses generally mimic those occurring as food is processed in the GI tract, but they occur within minutes of food exposure, are of short duration, and of low magnitude. They are viewed more as the triggers that initiate and modulate the actual digestion, nutrient absorption, and ultimately metabolism of foods.

The functionality of cephalic phase responses in digestion was demonstrated over 100 years ago by Pavlov when he observed that sham feeding improved digestion during intragastric intubation in dogs.[48] Numerous examples of functional cephalic phase responses have also been documented in humans at all sites within the GI tract. Visual cues to sour foods, chewing, and sour taste stimulate saliva release.[49–51] Gastric motility and acid secretion is enhanced by palatable foods compared to less preferred items.[52] Pharmacological inhibition of the first (cephalic) phase insulin response leads to higher and more prolonged post-prandial glucose concentrations.[53,54] Likewise, administration of insulin during the pre-absorptive period results in improved glucose control in obese subjects.[55] Similarly, oral fat exposure alone is sufficient to alter plasma triacylglycerol levels in healthy humans, independent of cognitive or sensory influences.[56] A dose-response relationship between the molarity of an oropharyngeal and laryngeal misting solution and urine volume and osmolality has also been observed.[57] Others have demonstrated that sensory stimulation is sufficient to decrease cardiac output, heart rate, and blood pressure[58,59] and increase thermogenesis.[60]

Smell and taste dysfunction

Taste and smell disorders can range from complete loss of function (ageusia and anosmia, respectively) to degrees of loss (hypogeusia and hyposmia, respectively). In some cases, individuals also experience inappropriate sensations for a given stimulus, termed dysgeusia (taste) and dysosmia (smell). Although the majority of individuals with chemosensory complaints identify both taste and smell loss, olfactory dysfunction is primarily responsible for most complaints.[2,61]

Due to variability in defining and evaluating taste and smell function, estimates of chemosensory dysfunction differ widely. A recent cross-sectional analysis of NHANES data reported taste quality and smell confusion in approximately 26.3 million (17.3%) and 20.5 million (13.5%) adults over 40 in the United States, respectively.[62] Other studies have suggested an incidence of severe olfactory miscoding at 2.7%–3.8%,[63,64] and severe gustatory miscoding at 14.8%.[64] However, in clinical populations, the incidence of olfactory disorders is much higher than that of gustatory disorders.[61] The incidence of chemosensory disorders has been associated with ethnicity (smell and taste) and gender (smell only).[62] The majority of taste and smell disorders are attributable to upper respiratory tract infections (19%–26%), head trauma (14%–18%) and nasal and paranasal sinus disease (15%–21%).[61,65] However, many (22%) also have no identifiable cause or are considered idiopathic.[61,65]

Despite the common observation that sensory properties influence food choice, evidence supporting an association between taste and smell function and nutritional status is limited.[61,63,66] Most individuals with taste and smell dysfunction report a loss of appetite, but maintain adequate dietary intake.[67] Although dysgeusic patients commonly report distorted tastes for common foods such as meats, fresh fruits, coffee, eggs, and carbonated beverages, their overall nutrient intake is not necessarily altered.[68,69] Others have noted no association between olfactory function and fruit and vegetable intake.[63] However, certain eating behaviors may be altered in some cases of chemosensory dysfunction, such as increased seasoning and sugar use in anosmic individuals.[66] Changes in related culinary practices, such increased salt, sugar, and fat use, could complicate issues with hypertension, diabetes and cardiovascular disease, respectively. More generally, some individuals with chemosensory disorders increase food intake to compensate for decreased sensory stimulation and gain weight, while other patients decrease food intake due to lower food appeal, resulting in weight loss.[69] Either response occurs in only a small subset of patients.

As with physical health status, limited data support a significant impact of chemosensory function on mental health. While decreased chemosensory function may affect the quality of life, there is no clear relationship between olfactory function and psychiatric disorders.[63,64,70–72] A recent systematic review of the literature relating olfactory function and depression found inconsistent evidence for altered smell detection, sensitivity, and identification; despite concluding that the majority of studies found differences in some indicator of olfactory function, the nature of the disruption was inconsistent.[73] Large variability in measurement and definition of olfactory function was noted as a significant limitation.[73] Although the majority of individuals with chemosensory dysfunction cope appropriately, there are some reports of concerning mental health consequences for a meaningful minority.[74]

Chemosensory function and aging

While dysfunction in chemosensory abilities is commonly associated with elderly populations, questions remain regarding the independent effect of age on taste and smell.[75] Differences in chemosensory abilities in elderly populations are often difficult to attribute solely to sensory function, as many age-associated factors such as overall health status, denture use, education, medication use, and other environmental insults can influence taste and smell responses.[76] In studies that have observed differences, the effect varies widely among individuals and stimuli. Furthermore, the size of detected differences in the elderly may be clinically irrelevant in terms of influencing food choice or health status.[76] After adjusting for potential

confounders, recent cross-sectional studies have failed to find a significant relationship between olfactory abilities and nutritional status in the elderly.[77,78] In light of the variety of etiologies contributing to chemosensory dysfunction and nature of the complaints in the elderly, current evidence does not support a universal strategy (e.g., flavor fortification, treatment with zinc) to improve nutritional status through sensory-related interventions.

Chemosensory abnormalities associated with chronic diseases

Alterations in taste and smell function may also occur as a consequence of other disorders. Due to specific dietary needs in many of these conditions, taste and smell function have been proposed as a strategy to influence food intake.

Cancer

Because maintaining adequate energy and nutrient intake in cancer patients is important for effective treatment, strategies to increase dietary compliance are needed.[79] In untreated cancer patients receiving palliative care, 86% report some sort of chemosensory complaint.[80] The nature of complaints among cancer patients is highly variable, as dysgeusia, dysosmia, and heightened and diminished sensitivity to specific taste qualities or odors have all been reported.[80–83] Although earlier studies failed to find an association between chemosensory complaints and appetite, food preferences, and body weight,[84,85] more recent research has associated chemosensory function with lower energy intake, appetite, BMI, quality of life, and protein intake in cancer patients.[80,83,86]

Chemosensory dysfunction is frequently associated with anti-cancer therapies. Radiation therapy reduces the number of taste buds, and tongue exposure is related to taste impairment.[87,88] Patients undergoing radiation therapy exhibit diminished taste sensitivity relative to pre-treatment levels.[89] Although some report that taste sensitivity recovers to baseline levels following radiation therapy, others continue to observe alterations six months post-treatment.[89,90]

Chemotherapy treatment also commonly induces changes in sensory function, with 56%–76% of patients reporting dysgeusia or some form of taste alterations.[81,91,92] Dysgeusia incidence may be related to cancer type.[81,92] Cyclical effects of chemotherapy on taste function, as demonstrated by quality-specific decreases in taste identification abilities, liking, and appetite in early, but not later, treatment cycles, have also been observed.[86] While the nature of gustatory disturbances in cancer patients are incompletely characterized, recent evidence suggests that taste alterations during chemotherapy may be related to specific macronutrients (e.g., protein) rather than specific tastes.[93] Diminished olfactory sensitivity has also been reported in patients undergoing chemotherapy treatment.[94] Changes induced by chemotherapy treatment are often transitory and recover within six months post-treatment.[93,94] Alterations in chemosensory function in cancer patients undergoing chemotherapy can impact food preferences and practical and social aspects of everyday life.[95] Practitioners are advised to inform patients of potential alterations to their taste and smell perception prior to chemotherapy treatment.[96]

Hypertension

Associations between sodium intake and blood pressure have prompted investigations of the relationship between salt taste, salt intake and blood pressure. Although some have proposed that decreased salt taste sensitivity would lead to high salt use, it could also be argued that decreased salt taste leads to lower salt use due to lack of reward value.[97] Additionally, higher salt sensitivity could lead to reduced intake, as less would be more impactful, or greater intake, as it would be more rewarding. Because of a lack of clear evidence, such claims are descriptive rather than mechanistic. The preponderance of evidence does not support any difference in sodium chloride sensitivity or liking between normotensive and hypertensive patients.[98–101] Examination of individuals classified as "salt sensitive" or "insensitive" has also failed to reveal meaningful differences of salt taste sensitivity, intensity perception, or liking.[100] It should be noted that hypertensive drug treatment regimens may alter taste.[97,102] In such cases, alternate medications should be considered.

Hypothyroidism

Taste and smell function are commonly altered in hypothyroidism, with reports of both dysgeusia (50% of patients) and dysosmia (39% of patients).[103–105] The nature of taste disruption in hypothyroidism may be quality-specific, as decreased taste function has been detected for bitterness and sweetness, but not other qualities.[104,106] Others have reported that only bitterness is altered.[105] Lower odor threshold, discrimination, and identification scores have also been reported in patients with hypothyroidism.[104,105] The mechanisms responsible for taste and smell alterations in hypothyroidism are unclear, but may involve changes in secretions in the nasal cavity, alterations of the olfactory epithelium or olfactory bulb function, or neural conductivity.[67] Pharmacological treatment often resolves chemosensory disturbance in patients with hypothyroidism.[104,105] Individuals with hyperthyroidism may also experience quality-specific taste alterations, as hyperthyroid patients report lower salty and bitter intensities.[106]

Obesity

Relationships between sweet and fat detection and body weight have been explored in populations that are lean and obese to elucidate the concomitant rise in the availability of palatable, energy-dense foods and obesity. However, the evidence base does not support systematic differences in taste sensitivity and preferences among people who are lean or have high percent body fat.[67,107,108] Very limited data suggest a higher prevalence of olfactory impairment in extremely overweight individuals.[109,110] Although some evidence indicates a difference in high-fat food preference in obese populations.[111,112] other studies have failed to find a relationship.[113,114] Furthermore, a prospective study reported no difference in hedonic responses based on body

size and adiposity.[115] While bariatric surgery appears to have little effect on smell function,[116] others have noted increased sweet taste sensitivity.[117,118] Evidence supporting a relationship between weight loss due to energy restriction and taste function are mixed, as weight loss interventions have resulted in no change, impairment, and improvement of sweet taste abilities.[117,119,120]

Diabetes

Decreased sweet taste sensitivity is the most consistently reported chemosensory disturbance in diabetic patients. Chemosensory dysfunction has been reported in over 60% of diabetes patients and is likely related with associated comorbidities and complications.[121] Studies comparing taste and smell function of uncomplicated diabetic patients and healthy controls have failed to detect significant differences in sensory abilities.[122,123] Furthermore, others have found positive relationships between the degree of neuropathy and severity of gustatory symptoms, taste function, and olfactory function.[124–126] Disease duration and the presence of additional complications is also associated with chemosensory dysfunction in diabetic patients.[123,125] Taken together, the evidence suggests that reported changes in sweet taste function in diabetic patients are likely due to peripheral neuropathy rather than defects of glucoreception.

Strategies for management of chemosensory disorders

As there is no single cause of chemosensory dysfunction, recommendations must be adapted to individual circumstances. In some cases, surgery or steroids may be appropriate for treatment of olfactory disorders.[129,127] In other cases, taste and smell function recover spontaneously or when the medical disorder responsible for the disturbance is resolved.[2] To determine the impact of chemosensory function on overall health, practitioners are first advised to understand how an individual's dietary intake is affected by their patient's taste and smell dysfunction, as the evidence does not currently support a single management strategy.[67]

As current evidence does not support a role of nutrient deficiency in the majority of chemosensory disorders, dietary supplementation is not typically recommended as a treatment strategy. Although nutrient deficiencies may play a role in some chemosensory disorders, they are rare and often not the primary cause.[69] The use of zinc supplementation, for example, has generally had limited efficacy.[61,128] Although other micronutrients (e.g., vitamin A, B vitamins, vitamin E, copper, iodine, and iron) have been associated with chemosensory function, the overall evidence does not support the use of supplements to treat taste and smell disorders.[2]

Selective flavor fortification may be a useful strategy for a subset of individuals with diminished taste and smell function, but its effectiveness is limited in ageusic or anosmic patients, or in those cases where sensory function is not the underlying cause of altered food intake.[67] Other strategies have been proposed to alter taste perception in specific medical conditions, such as the use of plastic utensils, chewing slowly, and ice chips in cancer patients.[129,130,127] Emphasizing spiciness or non-chemosensory food attributes such as appearance or texture provide additional avenues for management.

Conclusion

Taste and smell function play an important role in diet selection and metabolism. However, the effect of sensory function on habitual food intake and ultimately health status must be considered within the context of several other factors such as environment, exposure, and culture. Consequently, dietary management of patients with chemosensory complaints should be individualized.

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