3-2016

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Cordelia Running
Purdue University, crunning@purdue.edu

Recommended Citation

Running, Cordelia, "Human oral sensory systems and swallowing" (2016). *Department of Nutrition Science Faculty Publications.* Paper 15.
https://docs.lib.purdue.edu/fnpubs/15

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Cordelia A Running, PhD

crunnin@purdue.edu, Department of Nutrition Science, Purdue University, West Lafayette IN 47907; Department of Food Science, The Pennsylvania State University, University Park, PA 16802

Author background

Dr. Cordelia Running is a food scientist and nutritionist with research interests in saliva, oral processing, and food sensations. These topics inherently overlap with the study of swallowing function, which lead to her interest in the field. This review is intended first to familiarize the reader with the basic functions of sensory systems for flavor perception, and second to summarize the research that has been conducted on interactions of sensation and swallowing function. Hopefully, this overview will draw to light some of the new potential areas for research to improve swallowing function and dietary quality/compliance for individuals with dysphagia.

Abstract

Numerous oral sensations contribute to the flavor experienced from foods. Texture is sensed throughout the mouth by nerve endings in the oral epithelium. Chemesthetic sensations, including irritation, spiciness, and chemical burn or cooling, are sensed by these same nerves. Tastes are sensed by taste buds, primarily on the tongue, which transduce information through the gustatory nerves. Even after placing food in the mouth, odor is still experienced through retronasal olfaction, the air that passes through the rear of the oral cavity into the nasal passages. All of these sensations combine to give an overall experience of flavor. In individuals with dysphagia, these oral sensory systems can be used to improve swallowing function. Texture is the most common current approach, but the other oral sensations, particularly chemesthesis, may also hold potential for making sensory modified foods for dysphagia management. However, modifying any of these sensory properties also alters the overall food flavor, which can lead to decreased liking of the food.

1. Introduction

A multitude of sensations are experienced as a part of food flavor. Long before ingestion, food is evaluated through vision and odor. These cues contribute to expectations for palatability and flavor. Taste, texture, and odor combine to create overall food flavor inside the mouth. This flavor is again evaluated for palatability. The mouth thus acts not only as a control point for acceptance or rejection of food but also as an initial point of direct physical contact with food. Orthonasal odor (odor that passes through the nostrils) and appearance of a food may be assessed from a distance, but taste and texture are assessed during contact of the food with oral surfaces. Additionally, retronasal odor (odor that passes through the rear of the mouth and into the nasal passages) contributes heavily to food flavor and is predominantly sensed after foods have been placed inside the oral cavity. Stimulating specific senses in the mouth may either prepare the body for ingestion of nutrient yielding substances or assist in expectorating and clearing potentially noxious substances. As oral sensory information is experienced prior to swallowing, research shows potential for targeting these sensations to improve swallowing function in individuals with dysphagia. The principal sensory systems in oral perception of food are the trigeminal (texture/touch, temperature, and chemesthesis), gustatory (taste), and olfactory (odor) systems. This review will describe how these systems function in humans and briefly summarize the current research on how sensation may be used to manage dysphagia.

However, many of sensory interventions discussed in this review have not been extensively evaluated for long-term management of dysphagia. Data on sensory modifications for dysphagia in pediatric populations is extremely limited, so almost all of the information in this review pertains to adults. Limited data are also available on the types of dysphagia for which these treatments may be most effective. Further, many of the sensory modifications result in less palatable foods. This may lead to poor compliance to modified diets in the long-term. Future work will hopefully find ways to use these sensations to improve swallowing while maintaining palatability.

2. Trigeminal: Texture

2.1. Innervation and physiology

Texture, temperature, and chemesthesis (feelings of irritation, spiciness, pungency, etc), overlap in the mechanisms by which they are detected. All are sensed in the oral cavity predominantly through the trigeminal nerve (cranial nerve V). Thus, these sensations are often referred to collectively as the “trigeminal” sensations, though the vagus (cranial nerve X) and other cranial nerves may also carry irritant and temperature sensations (Green & Lawless, 1991). Nerve endings from the trigeminal nerve are ubiquitous in the oral and nasal cavities, and the receptors located on these nerve fibers detect a wide range of sensations. The classes of receptors feeding the trigeminal sense include mechanoreceptors (texture), nociceptors (pain and chemical irritation), thermoreceptors (temperature), and proprioceptors (location, position).

2.2. Sensation

Food textures are dynamic. While texture can be analytically assessed before entering the oral cavity, the multitude of processes that alter food structure inside the mouth make analysis of oral food texture extremely challenging. The food industry can create a plethora of foods of certain thickness or hardness or melting characteristics, but the food then interacts with both soft (cheeks, lips, tongue, etc) and hard (teeth, hard palate) tissue. Additionally, the foods mix with saliva, which is also constantly changing (Bradley, 1991; Dawes & Jenkins, 1964). These factors make assessment of “in mouth” food texture extremely complex (Stokes, Boehm, & Baier, 2013).

A common approach to measure the texture of liquid and semi-solid foods is with rheology, and these properties are of great interest to the field of dysphagia. Oral rheology is the characterization of how a food flows, or more technically, how stress (force applied) affects strain (how the object is deformed) (Koç, Vinyard, Essick, & Foegeding, 2013). This includes attributes such as viscosity (resistance to flow, which contributes to perception of thickness), but also attributes regarding how the food responds to shearing forces, such as stirring a drink or the moving the tongue through a liquid. Some foods are Newtonian, which have the same viscosity regardless of how much shear is applied or how long that shear is applied. Examples of Newtonian fluids include water, honey, milk, and oils. Other foods are non-Newtonian, which means their viscosity is not linearly related to the shear force. The majority of foods have non-Newtonian properties. Examples include ketchup, cheese, custards, milkshakes, butter, many pureed foods, starch/water mixtures, and many more (Stokes, 2012a). One example of non-Newtonian behavior is how ketchup behaves like a solid in the bottle until force is applied, which makes the ketchup behave more like a liquid and flow out of the container. Similar, many spreads are solid-like until the force of a knife smears them (they are now liquid-like) across a surface. When the force of the knife is removed, the spread again behaves like a solid.

Rheology is not the only textural measure of foods, however. Tribology is another important property of the texture of foods. This property deals with the behavior of thin films or lubrication of surfaces, such as when the tongue smears a food against the teeth or the palate. Tribological properties of foods are still not well understood or well characterized, and research continues to try to connect these properties to actual oral sensations (Stokes, 2012b; Stokes et al., 2013). Much of the complexity in studying food tribology is because this property is influenced by not only the food itself but also by the properties of the oral surfaces. A wide variety of surface textures are present in the mouth, and very few of these textures are accurately represented by hard metal or plastic instruments common to most machinery used for analytical assessment of texture. In theory, the tribological interactions between a food bolus and oral epithelium during swallowing could be of great importance to successful swallows; i.e., we want the food to remain a cohesive bolus, but we want the surface of that bolus to slide easily across the oral epithelium and into the esophagus. As measures of tribology that are relatable to actual oral food properties are still being developed and fine-tuned, the field of tribology and dysphagia remains an important target for future research.

2.3. Role in swallowing

Thickening of thin liquids is the most common sensory modification used for management of oropharyngeal dysphagia. For individuals with trouble swallowing thin liquids, thickeners improve measures of aspiration and penetration but also increase the residue left behind after swallowing (Steele et al., 2015). There are numerous types of thickeners available, and consistent, systematic evaluation of these thickeners and their rheological properties *in vivo* is still being conducted. Considering the aforementioned difficulties in relating food texture before entering the mouth to actual in-mouth texture, the challenge in developing thickeners with consistent, predictable properties is understandable. Data on viscosity of samples with various concentrations of added thickener may help in initial selection of a product, and yet the actual viscosity of that sample upon entering the mouth, or how that viscosity changes when the food mixes with saliva and when forces are applied by the tongue, could vary among individuals and types of foods/beverages.

Notably, the textural modification approach to managing dysphagia may be effective, but patient compliance is a strong limiting factor. Texture is a strong driver of food aversions (Scott & Downey, 2007) as well as food acceptance (Guinard & Mazzucchelli, 1996), and when food texture does not match expectation (e.g., juice is not supposed to feel like pudding), consumers are more likely to reject the food. Thus, researchers have been investigating using other sensory properties, such as irritation and taste, to improve swallowing function.

3. Trigeminal: Chemesthesis

3.1. Innervation and physiology

Chemesthesis (irritancy, pungency, spiciness, tingling, chemical burning or cooling) is innervated by the same physiological system as texture, described above. These sensations are sensed throughout the oral and nasal passages, from the lips and nares all the way to the back of the throat. Actually, these sensations are not specific even to the oral and nasal cavities, but can be detected by free nerve endings in epithelial layers throughout the body (Green, 2000, 2012).

3.2. Sensations

Chemesthetic sensations are caused by a variety of food ingredients, such as capsaicin (spiciness of peppers), cinnamaldehyde (heat of cinnamon), carbon dioxide (irritancy of carbonated beverages), and menthol (coolness of mint). Research shows that these sensations are detected independently of taste and odor (Green, Alvarez-Reeves, George, & Akirav, 2005), but that tastes, temperatures, and fat concentrations can interact with the chemesthetic sensation to augment or suppress intensity (Baron & Penfield, 1996; Bennett, Zhou, & Hayes, 2012; Green, 1986; Prescott, Allen, &

Stephens, 1993; Prescott & Stevenson, 1995). Further, frequency of consumption of spicy foods can lower ratings of intensity for the burn of compounds like capsaicin (Prescott & Stevenson, 1995). Culture, which influences how often a person is exposed to these chemesthetic sensations in foods, can therefore strongly influence perception of chemical irritancy and acceptability of spiciness in foods.

3.3. Role in swallowing

Irritating stimuli may improve swallowing of thin liquids for individuals with oropharyngeal dysphagia. Capsaicinoids, pipirine, carbonation, and high concentrations of citric acid and sodium chloride (which have both taste and irritating qualities at high concentration) have all demonstrated improved swallowing parameters in dysphagic individuals by reducing oral and pharyngeal transit time as well as occurrences of aspiration and penetration (Bülow, Olsson, & Ekberg, 2003; Ebihara et al., 2005; C. Krival, 2007; Logemann et al., 1995; Loret, 2015; Pelletier & Lawless, 2003; Rofes, Arreola, Martin, & Clavé, 2013, 2014; Sdravou, Walshe, & Dagdilelis, 2012). In healthy populations, these sources of chemesthesis have also been shown to increase swallow pressure (Krival & Bates, 2012; Pelletier & Dhanaraj, 2006). Notably, barium contrast agents, used in many imaging studies on swallowing function, may decrease the intensity of chemesthetic sensation, at least for irritation from carbonation (Dietsch, Solomon, Steele, & Pelletier, 2014). Whether the decrease in perceived intensity of the chemesthetic sensation alters the potential for improved swallowing function is unknown.

4. Gustation

4.1. Innervation and physiology

Taste sensation (“gustation”) is detected throughout the oral cavity and even in the upper esophagus by taste cells, which are organized into taste buds. These taste buds are shaped like garlic cloves and have an apical side oriented toward the oral cavity. Hairs protrude from this apical surface of the cells and access the rest of the oral cavity through a small pore. The receptors responsible for detecting tastants are located on these gustatory hairs. Taste buds are found in greatest concentration in papillae on the tongue, which include circumvallate (large circular structures a couple millimeters in diameter located on the posterior of the tongue), foliate (vertical grooves located on the lateral sides of the posterior tongue), and fungiform (small mushroom like structures located mostly on the anterior tongue) papillae. Taste buds are innervated primarily by the glossopharyngeal nerve (cranial nerve IX) for the posterior third of the tongue and chorda tympani nerve (a branch of the facial nerve, cranial nerve VII) for the anterior two-thirds of the tongue. The vagus nerve (cranial nerve X) also carries some taste information from taste buds located in the epiglottis, extreme posterior tongue, and esophagus (Pritchard, 1991). Localized loss of taste function can occur in cases where the chorda tympani nerve is damaged, usually from repeated ear infection or surgery, as this nerve passes through the middle ear very close to the tympanic membrane (Miller & Bartoshuk, 1991; Sakagami, 2009). Because there is one branch of the chorda tympani nerve on each side of the face, this taste loss will lateralize to one half of the anterior portion of the tongue. Often, individuals who have damage or transection of this nerve are unaware of the localized loss of taste (Bull, 1965), as sensation from the rest of the tongue is adequate or even augmented in order to maintain taste perception (Kveton & Bartoshuk, 1994). Aging may also contribute to reduction in taste sensitivity, but these effects are generally very small and may also reflect a bias by younger individuals to rate all stimuli as more intense (Heft & Robinson 2014). In general, most individuals who believe they have lost “taste” sensation have actually lost ability to smell (Deems et al., 1991).

4.2. Sensations

The sense of taste has traditionally been limited to a set of “primary” tastes. The number of primary tastes is debated, but generally includes sweet, sour, salty, bitter, and umami (savory) and may be expanding to include other tastes such as “oleogustus” (taste of fatty acids, [Running, Craig, & Mattes, 2015]), calcium (Tordoff, Alarcon, Valmeki, & Jiang, 2012), and carbon dioxide (Chandrashekar et al., 2009). In general, to be considered a taste, a sensation should provide an ecological advantage to the organism, be stimulated by a definable class of compounds, activate taste cells and convey a message through taste nerves (primarily the glossopharangeal or chorda tympani), be unique from other tastes, and evoke a physiological or behavioral response (Mattes, 2011).

4.3. Role in swallowing

Several studies show promising results using intense tastes to improve swallowing function. In healthy populations, sweet, sour, and salty all improved swallow pressure (Pelletier & Dhanaraj, 2006). In individuals with dysphagia, the most promising candidate is intense sour taste, which is generally unpleasant and thus decreases patient compliance. Studies have shown decreased oral transit times and penetration/aspiration events with solutions such as 2.7% citric acid or 50/50 mix of lemon juice and barium sulfate solution (Logemann et al., 1995; Pelletier & Lawless, 2003). While at least one study attempted to improve the palatability of the sour solution by reducing the acid and adding sugar, this lemonade-like sample did not reduce occurrences of penetration and aspiration as the higher concentration of acid alone did (Pelletier & Lawless, 2003). Notably, high concentrations of sour compounds can also activate trigeminal sensors in the oral cavity. Thus, whether the improvement of swallowing function with intense sour liquids is due to taste or chemesthesis is unclear.   As with carbonation, barium contrast agents also may decrease intensity of tastes (Dietsch et al., 2014). Again, whether concentration or perceived intensity is more important for potential effects of sour or salty on improved swallows is unknown.

5. Olfaction

5.1. Innervation and physiology

Olfactory neurons directly connect the brain (specifically the olfactory bulb) to the exterior environment (the mucosa inside the nasal cavity). While odor is often considered only the air entering the nasal passages through the nostrils, a large part of flavor comes from retronasal olfaction, which is air that passes through the back of the throat into the nasal passages. This retronasal olfaction is minimized when the air passages are blocked, such as with an upper respiratory infection. An individual may then claim he or she cannot “taste” anything while sick. Actually, taste (sweet, sour, salty, etc) is unaffected; retronasal olfaction is lost, leading to decreased perception of flavor.

Cilia of olfactory neurons cover the olfactory epithelium and are coated in mucus. In order for an odor to be detected, the odorant must dissolve into the mucus, sometimes with the aid of an odorant binding protein (Steinbrecht, 1998), and then access the receptor on the surface of the cilia. After activating the receptor, the signal is transduced along the axon of the neuron through the cribriform plate of the skull to glomeruli, which are clusters of nerves that all contain the same receptor types on their cilia (Benignus & Prah, 1982). These glomeruli, located in the olfactory bulb, relay the signal of odor to higher regions of the brain. The brain interprets the pattern of responses of the glomeruli to identify specific odors (Buck & Axel, 1991; Sullivan, Ressler, & Buck, 1994).

Complete loss of the ability to smell is termed “anosmia,” while a reduced ability to smell is termed “hyposmia.” The most common cause of reduced olfactory ability is upper respiratory infection, but more permanent loss of smell is also possible. Head trauma is a common cause of anosmia, as this type of injuries can lead to transection of the olfactory nerves where they pass through the cribriform plate. Fracture to this region of the skull can also lead to olfactory impairment. Hyposmia and reduced ability to identify odors have been proposed as early signs of Parkinson’s or Alzheimer’s diseases (Morley & Duda 2011; Wilson et al., 2009). Further, decreased smell acuity is generally associated with greater age even in healthy populations, though this might be a side effect of greater use of medications (Doty & Bromley 2004; Doty et al., 1984).

5.2. Sensations

Hundreds of odor receptors have been identified, which combined allow mammals to discriminate thousands of odors (Buck & Axel, 1991; Malnic, Gonzalez-Kristeller, & Gutiyama, 2010). Generally, odors are not limited to a discrete set of sensations, unlike taste. Further, odor is complex because compounds with similar chemical structures often have different odors and compounds with very different structures can have similar odors. The odor for a single compound can also change depending on concentration, and repeated exposure to compounds can increase human sensitivity to their odor (Doty, 1991).

5.3. Role in swallowing

Odor does not appear to play a direct role in swallowing, though the swallowing process contributes to retronasal olfaction by forcing small amounts of odor into the nasal cavity (Burdach & Doty, 1987; Hodgson, Langridge, Linforth, & Taylor, 2005). However, odor alone is unlikely to improve swallowing for individuals with dysphagia. Numerous studies have used odor in conjunction with taste, which likely makes the stimulus more palatable (Logemann et al., 1995; Wahab, Jones, & Huckabee, 2010, 2011). Notably, the palatability itself does not improve swallowing (Pelletier & Dhanaraj, 2006) but is important to improve compliance. Further, the only studies reporting improved swallows with just odor used black pepper oil, which would irritate the nasal passages as well as contribute to odor; use of a non-irritating oil, lavender, did not improve swallowing function (Ebihara et al., 2006; Munakata et al., 2008).

6. Clinical evaluation of human oral sensations

Standard evaluation of an individual's ability to discriminate texture of food samples orally has not been established. However, numerous methodologies could be adapted if an estimate of textural acuity was desired. Importantly, none of these methods have been correlated with any assessment of swallowing function or acceptability of texturally modified foods for dysphagia. Nonetheless, some recommendations for measuring oral textural acuity include measures of two-point discrimination, light touch detection, temperature discrimination, discrimination of rough verses smooth texture, and shape identification (Boliek et al., 2007; Dahan, Lelong, Celant, & Leysen, 2000). Again, while these techniques have been suggested for evaluating a person's ability to detect or discriminate textures, research linking the outcomes of these tests to swallowing efficiency has not been conducted. Clinical evaluations for general chemesthesis ability have not been developed.

Regarding gustation, the simplest method for clinical evaluation is to present a client with the four most familiar primary tastes (sweet, sour, salty, and bitter) and ask him/her to identify which taste sensation is experienced. Taste test kits are commercially available, typically as solutions or strips (filter paper impregnated with tastants). Taste stimuli for sweet, sour, and salty can also be easily prepared from grocery items such as table sugar, vinegar, and table salt. Bitter solutions present a greater challenge, as most food items that are bitter also have other taste qualities. There are also marked individual differences in sensitivity to some bitter compounds, mainly the synthetic compounds phenylthiocarbamide (PTC) and 6-n-propylthiouracil (PROP). Due to genetic variation in bitter taste receptors, some individuals experience no bitter sensation from these chemicals and other experience extreme bitterness (Bufe et al., 2005). If only a simple diagnostic of taste loss is desired, these two chemicals should not be used, as approximately 30% of people, depending on racial background, cannot taste these compounds (Guo & Reed, 2001). At taste and smell specialized clinical centers (such as the Monell Chemical Senses Center in Philadelphia, the University of Connecticut's Taste and Smell Center in Farmington, the University of Pennsylvania Smell and Taste Clinic in Philadelphia, etc.) more in depth evaluations may include threshold testing (determining the minimum concentration at which a taste is detected) and magnitude estimation (compares intensity ratings for various concentrations of tastants to intensity ratings for other stimuli). These tests give more in depth information on degree of taste acuity, rather than simple assessments of whether the taste is detectable at all.

Olfaction is typically evaluated using simple identification tests. Two of the most popular tests include the University of Pennsylvania Smell Identification Test (UPSIT), which are single use scratch and sniff booklets (Doty, Shaman, Kimmelman, & Dann, 1984), and Sniffin' Sticks, which are multi-use marker-like sticks with caps, filled with different odorants (Kobal et al., 1996). Notably, humans perform very poorly when asked to identify even very familiar odors without guidance (Lawless & Engen, 1977), so each of these tests asks the participant to select the correct odor from a list. Both of these products are commercially available.

7. Conclusions

Sensory properties show promise for managing dysphagia. The most common approach is texture modification, but research indicates strong potential for use of chemesthetic sensation, including irritation, chemical heat, and carbonation. Other sensations that show promise for managing dysphagia include taste and odor, and yet the sensations of sourness, intense saltiness, and black pepper odor may actually be improving swallows through their irritating properties rather than taste or smell. There are certainly numerous commercial products (seltzer water, hot sauce) that would contribute irritating or spicy sensations to foods and beverages. However, the scientific literature contains very few studies using commercially available products to stimulate chemesthesis, so clinicians and primary care providers have very little guidance on what foods or beverages could be actually be both safe and effective. Future research on such commonly available items would be extremely valuable.

Unfortunately, any alterations to expected flavor of a food may decrease consumer liking of a product. For individuals with dysphagia, this means that altering food or beverage properties to improve swallowing, whether by thickening liquids or adding spiciness or sourness, may result in low compliance with the prescribed diet. Research in other fields would indicate that food preference can be modified through frequent exposure (Mattes, 1990, 1993), so individuals could perhaps learn to enjoy modified foods over time. However, this has yet to be investigated specifically in dysphagia, and strong initial rejection of the food would make frequent exposure difficult. Nonetheless, the research indicates great promise for using oral sensation to improve swallowing. Hopefully, scientists, industry, and clinicians will be able to use this information to develop new foods or diets that maintain palatability, and also higher quality of life, for clients with dysphagia.

8. References

Baron, R. F., & Penfield, M. P. (1996). Capsaicin heat intensity - Concentration, carrier, fat level, and serving temperature effects. *J Sens Stud, 11*(4), 295-316. doi:10.1111/j.1745-459X.1996.tb00046.x

Benignus, V. A., & Prah, J. D. (1982). Olfaction: Anatomy, physiology, and behavior. *Environ Health Perspect, 44*, 15-21.

Bennett, S. M., Zhou, L., & Hayes, J. E. (2012). Using milk fat to reduce the irritation and bitter taste of ibuprofen. *Chemosens Percept, 5*(3-4), 231-236. doi:10.1007/s12078-012-9128-6

Boliek, C. A., Rieger, J. M., Li, S. Y., Mohamed, Z., Kickham, J., & Amundsen, K. (2007). Establishing a reliable protocol to measure tongue sensation. *J Oral Rehabil, 34*(6), 433-441. doi:10.1111/j.1365-2842.2007.01735.x

Bradley, R. M. (1991). Salivary Secretion. In T. V. Getchell, R. L. Doty, L. M. Bartoshuk, & J. B. Snow (Eds.), Smell and Taste in Health and Disease (pp. 127-144). New York: Raven Press.

Buck, L., & Axel, R. (1991). A novel multigene family may encode odorant receptors: a molecular basis for odor recognition. *Cell, 65*(1), 175-187.

Bufe, B., Breslin, P. A. S., Kuhn, C., Reed, D. R., Tharp, C. D., Slack, J. P., . . . Meyerhof, W. (2005). The molecular basis of individual differences in phenylthiocarbamide and propylthiouracil bitterness perception. *Curr Biol, 15*(4), 322-327. doi:10.1016/j.cub.2005.01.047

Bull, T. R. (1965). Taste and the Chorda Tympani. *J Laryngol Otol, 79*, 479-493.

Burdach, K. J., & Doty, R. L. (1987). The effects of mouth movements, swallowing, and spitting on retronasal odor perception. *Physiol Behav, 41*(4), 353-356.

Bülow, M., Olsson, R., & Ekberg, O. (2003). Videoradiographic analysis of how carbonated thin liquids and thickened liquids affect the physiology of swallowing in subjects with aspiration on thin liquids. *Acta Radiol, 44*(4), 366-372.

Chandrashekar, J., Yarmolinsky, D., von Buchholtz, L., Oka, Y., Sly, W., Ryba, N. J., & Zuker, C. S. (2009). The taste of carbonation. *Science, 326*(5951), 443-445. doi:10.1126/science.1174601

Dahan, J. S., Lelong, O., Celant, S., & Leysen, V. (2000). Oral perception in tongue thrust and other oral habits. *Am J Orthod Dentofacial Orthop, 118*(4), 385-391. doi:10.1067/mod.2000.109101

Dawes, C., & Jenkins, G. N. (1964). The effects of different stimuli on the composition of saliva in man. *J Physiol, 170*, 86-100.

Deems, D. A., Doty, R. L., Settle, G., Mooregillon, V., Shaman, P., Mester, A. F., . . . Snow, J. B. (1991). Smell and taste disorders, a study of 750 patients from the

University of Pennsylvania Smell and Taste Center. *Arch Otolaryngol, 117*(5), 519-528.

Dietsch, A. M., Solomon, N. P., Steele, C. M., & Pelletier, C. A. (2014). The effect of barium on perceptions of taste intensity and palatability. *Dysphagia, 29*(1), 96-108. doi:10.1007/s00455-013-9487-4

Doty, R. L. (1991). Olfactory system. In T. V. Getchell, R. L. Doty, L. M. Bartoshuk, & J. B. Snow (Eds.), Smell and Taste in Health and Disease (pp. 175-203). New York: Raven Press.

Doty, R. L., & Bromley, S. M. (2004). Effects of drugs on olfaction and taste. *Otolaryng Clin N Am, 37*(6), 1229-1254. doi: 10.1016/j.otc.2004.05.002

Doty, R. L., Shaman, P., Kimmelman, C. P., & Dann, M. S. (1984). University of Pennsylvania Smell Identification Test: a rapid quantitative olfactory function test for the clinic. *Laryngoscope, 94*(2 Pt 1), 176-178.

Ebihara, T., Ebihara, S., Maruyama, M., Kobayashi, M., Itou, A., Arai, H., & Sasaki, H. (2006). A randomized trial of olfactory stimulation using black pepper oil in older people with swallowing dysfunction. *J Am Geriatr Soc, 54*(9), 1401-1406. doi:10.1111/j.1532-5415.2006.00840.x

Ebihara, T., Takahashi, H., Ebihara, S., Okazaki, T., Sasaki, T., Watando, A., . . . Sasaki, H. (2005). Capsaicin troche for swallowing dysfunction in older people. *J Am Geriatr Soc, 53*, 824-828.

Green, B. G. (1986). Sensory interactions between capsaicin and temperature in the oral cavity. *Chem Senses, 11*(3), 371-382. doi:10.1093/chemse/11.3.371

Green, B. G. (2000). Measurement of sensory irritation of the skin. *Am J Contact Dermat, 11*(3), 170-180. doi:10.1053/ajcd.2000.7185

Green, B. G. (2012). Chemesthesis and the Chemical Senses as Components of a "Chemofensor Complex". *Chem Senses, 37*(3), 201-206. doi:DOI 10.1093/chemse/bjr119

Green, B. G., Alvarez-Reeves, M., George, P., & Akirav, C. (2005). Chemesthesis and taste: evidence of independent processing of sensation intensity. *Physiol Behav, 86*(4), 526-537. doi:10.1016/j.physbeh.2005.08.038

Green, B. G., & Lawless, H. T. (1991). The psychophysics of somatosensory chemoreception in the nose and mouth. In T. V. Getchell, R. L. Doty, L. M. Bartoshuk, & J. B. Snow (Eds.), Smell and Taste in Health and Disease. New York: Raven Press.

Guinard, J. X., & Mazzucchelli, R. (1996). The sensory perception of texture and mouthfeel. *Trends Food Sci Tech, 7*(7), 213-219. doi:http://dx.doi.org/10.1016/0924-2244(96)10025-X

Guo, S. W., & Reed, D. R. (2001). The genetics of phenylthiocarbamide perception. *Ann Hum Biol, 28*(2), 111-142.

Heft, M. W., & Robinson, M. E. (2014). Age differences in suprathreshold sensory function. *Age (Dordr), 36*(1), 1-8. doi: 10.1007/s11357-013-9536-9

Hodgson, M. D., Langridge, J. P., Linforth, R. S., & Taylor, A. J. (2005). Aroma release and delivery following the consumption of beverages. *J Agric Food Chem, 53*(5), 1700-1706. doi:10.1021/jf040316g

Kobal, G., Hummel, T., Sekinger, B., Barz, S., Roscher, S., & Wolf, S. (1996). "Sniffin' sticks": screening of olfactory performance. *Rhinology, 34*(4), 222-226.

Koç, H., Vinyard, C. J., Essick, G. K., & Foegeding, E. A. (2013). Food oral processing: conversion of food structure to textural perception. *Annu Rev Food Sci Technol, 4*, 237-266. doi:10.1146/annurev-food-030212-182637

Krival, C. (2007). Effect of carbonated vs. thin and thickened liquids on swallowing in adults with neurogenic oropharyngeal dysphagia. Doctoral thesis, University of Cincinnati, Cincinnati, OH.

Krival, K., & Bates, C. (2012). Effects of club soda and ginger brew on linguapalatal pressures in healthy swallowing. *Dysphagia, 27*(2), 228-239. doi:10.1007/s00455-011-9358-9

Kveton, J. F., & Bartoshuk, L. M. (1994). The effect of unilateral chorda tympani damage on taste. *Laryngoscope, 104*(1 Pt 1), 25-29. doi:10.1288/00005537-199401000-00006

Lawless, H. T., & Engen, T. (1977). Associations to odors: interference, mnemonics, and verbal labeling. *J Exp Psychol Hum Learn, 3*(1), 52-59.

Logemann, J. A., Pauloski, B. R., Colangelo, L., Lazarus, C., Fujiu, M., & Kahrilas, P. J. (1995). Effects of a sour bolus on oropharyngeal swallowing measures in patients with neurogenic dysphagia. *J Speech Hear Res, 38*(3), 556-563.

Loret, C. (2015). Using sensory properties of food to trigger swallowing: a review. *Crit Rev Food Sci Nutr, 55*(1), 140-145. doi:10.1080/10408398.2011.649810

Malnic, B., Gonzalez-Kristeller, D. C., & Gutiyama, L. M. (2010). Odorant Receptors. In A. Menini (Ed.), The Neurobiology of Olfaction. Boca Raton, FL: CRC Press.

Mattes, R. D. (1990). Discretionary Salt and Compliance with Reduced Sodium Diet. *Nutr Res, 10*(12), 1337-1352.

Mattes, R. D. (1993). Fat preference and adherence to a reduced-fat diet. *Am J Clin Nutr, 57*(3), 373-381.

Mattes, R. D. (2011). Accumulating evidence supports a taste component for free fatty acids in humans. *Physiol Behav, 104*(4), 624-631. doi:10.1016/j.physbeh.2011.05.002

Miller, I. J., & Bartoshuk, L. (1991). Taste Perception, Taste Bud Distribution, and Spatial Relationships. In T. V. Getchell, R. L. Doty, L. M. Bartoshuk, & J. B. Snow (Eds.), Smell and Taste in Health and Disease (pp. 205-234). New York: Raven Press.

Morley, J. F., & Duda, J. E. (2011). Neuropsychological correlates of olfactory dysfunction in Parkinson's disease. *J Neurol Sci, 310*(1-2), 228-230. doi: 10.1016/j.jns.2011.05.030

Munakata, M., Kobayashi, K., Niisato-Nezu, J., Tanaka, S., Kakisaka, Y., Ebihara, T., . . . Onuma, A. (2008). Olfactory stimulation using black pepper oil facilitates oral feeding in pediatric patients receiving long-term enteral nutrition. *Tohoku J Exp Med, 214*(4), 327-332.

Pelletier, C. A., & Dhanaraj, G. E. (2006). The effect of taste and palatability on lingual swallowing pressure. *Dysphagia, 21*(2), 121-128. doi:10.1007/s00455-006-9020-0

Pelletier, C. A., & Lawless, H. T. (2003). Effect of citric acid and citric acid-sucrose mixtures on swallowing in neurogenic oropharyngeal dysphagia. *Dysphagia, 18*(4), 231-241. doi:10.1007/s00455-003-0013-y

Prescott, J., Allen, S., & Stephens, L. (1993). Interactions between oral chemical irritation, taste and temperature. *Chem Senses, 18*(4), 389-404. doi:10.1093/chemse/18.4.389

Prescott, J., & Stevenson, R. J. (1995). Effects of oral chemical irritation on tastes and flavors in frequent and infrequent users of chili. *Physiol Behav, 58*(6), 1117-1127.

Pritchard, T. C. (1991). The Primate Gustatory System. In T. V. Getchell, R. L. Doty, L. M. Bartoshuk, & J. B. Snow (Eds.), Smell and Taste in Health and Disease (pp. 109-125). New York: Raven Press.

Rofes, L., Arreola, V., Martin, A., & Clavé, P. (2013). Natural capsaicinoids improve swallow response in older patients with oropharyngeal dysphagia. *Gut, 62*(9), 1280-1287. doi:10.1136/gutjnl-2011-300753

Rofes, L., Arreola, V., Martin, A., & Clavé, P. (2014). Effect of oral piperine on the swallow response of patients with oropharyngeal dysphagia. *J Gastroenterol, 49*(12), 1517-1523. doi:10.1007/s00535-013-0920-0

Running, C. A., Craig, B. A., & Mattes, R. D. (2015). Oleogustus: The unique taste of fat. *Chem Senses, 40*(7): 507-516.

Sakagami, M. (2009). Taste Disorder After Middle Ear Surgery. *Int. Adv. Otol., 5*(3), 382-390.

Scott, C. L., & Downey, R. G. (2007). Types of food aversions: animal, vegetable, and texture. *J Psychol, 141*(2), 127-134. doi:10.3200/jrlp.141.2.127-134

Sdravou, K., Walshe, M., & Dagdilelis, L. (2012). Effects of carbonated liquids on oropharyngeal swallowing measures in people with neurogenic dysphagia. *Dysphagia, 27*(2), 240-250. doi:10.1007/s00455-011-9359-8

Steele, C. M., Alsanei, W. A., Ayanikalath, S., Barbon, C. E., Chen, J., Cichero, J. A., . . . Wang, H. (2015). The influence of food texture and liquid consistency modification on swallowing physiology and function: a systematic review. *Dysphagia, 30*(1), 2-26. doi:10.1007/s00455-014-9578-x

Steinbrecht, R. A. (1998). Odorant-binding proteins: expression and function. *Ann N Y Acad Sci, 855*, 323-332.

Stokes, J. R. (2012a). 'Oral' Rheology. In J. Chen & L. Engelen (Eds.), Food Oral Processing: Fundamentals of Eating and Sensory Perception (pp. 227-263). Chicester, West Sussex: John Wiley & Sons.

Stokes, J. R. (2012b). 'Oral' Tribology. In J. Chen & L. Engelen (Eds.), Food Oral Processing: Fundamentals of Eating and Sensory Perception (pp. 265-287). Chicester, West Sussex: John Wiley & Sons.

Stokes, J. R., Boehm, M. W., & Baier, S. K. (2013). Oral processing, texture and mouthfeel: From rheology to tribology and beyond. *Curr Opin Colloid In, 18*(4), 349-359. doi:http://dx.doi.org/10.1016/j.cocis.2013.04.010

Sullivan, S. L., Ressler, K. J., & Buck, L. B. (1994). Odorant receptor diversity and patterned gene expression in the mammalian olfactory epithelium. *Prog Clin Biol Res, 390*, 75-84.

Tordoff, M. G., Alarcon, L. K., Valmeki, S., & Jiang, P. (2012). T1R3: a human calcium taste receptor. *Sci Rep, 2*, 496. doi:10.1038/srep00496

Wahab, N. A., Jones, R. D., & Huckabee, M. L. (2010). Effects of olfactory and gustatory stimuli on neural excitability for swallowing. *Physiol Behav, 101*(5), 568-575. doi:10.1016/j.physbeh.2010.09.008

Wahab, N. A., Jones, R. D., & Huckabee, M. L. (2011). Effects of olfactory and gustatory stimuli on the biomechanics of swallowing. *Physiol Behav, 102*(5), 485-490. doi:10.1016/j.physbeh.2010.11.030

Wilson, R. S., Arnold, S. E., Schneider, J. A., Boyle, P. A., Buchman, A. S., & Bennett, D. A. (2009). Olfactory impairment in presymptomatic Alzheimer's disease. *Ann N Y Acad Sci, 1170*, 730-735. doi: 10.1111/j.1749-6632.2009.04013.x

9. Continuing Education

Learning outcome: After reading this article, students should be able to describe the oral sensations of texture, chemesthesis, odor, and taste and how these sensations may be of use (or not) in managing clinical dysphagia.

Which two sensations are detected by the trigeminal nerve (cranial nerve V)?
a) Texture and Chemesthesis
b) Texture and Taste
c) Chemesthesis and Odor
d) Taste and Odor

Frequent ear infections or middle ear surgery can lead to:
a) Complete lack of chemesthetic sensation.
b) Diminished odor perception.
c) Localized loss of taste function.
d) Transection of the glossopharyngeal nerve.

Spiciness of chili peppers is an example of:
a) Olfaction
b) Gustation
c) Rheology
d) Chemesthesis

Odors can be detected while food is inside the mouth, due to the passage of air through the rear of the mouth into the nasal cavity. This is called:

a) Odor memory.
b) Oral olfaction.
c) Orthonasal olfaction.
d) Retronasal olfaction.

When experiencing a cold or other upper respiratory infection, a person is likely to experience loss of food:

a) Taste
b) Odor
c) Irritancy
d) Texture