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Systematic Review

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Abstract

Consuming foods and liquids for nutrition requires the coordination of several muscles. Swallowing is triggered and modified by sensory inputs from the aerodigestive tract. Taste has recently received attention as a potential modulator of swallowing physiology, function, and neural activation; additionally, taste impairment is a sequela of COVID-19. This review presents factors impacting taste and swallowing, systematically summarizes the existing literature, and assesses the quality of included studies. A search was conducted for original research including taste stimulation, deglutition-related measure(s), and human participants. Study design, independent and

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Note: **Tables 2, 3, & 4** follow the **References**

dependent variables, and participant characteristics were coded; included studies were assessed for quality and risk of bias. Forty-eight articles were included after abstract and full-text review. Synthesis was complicated by variable sensory components of stimuli (taste category and intensity, pure taste vs. flavor, chemesthesis, volume/amount, consistency, temperature), participant characteristics, confounding variables such as genetic taster status, and methods of measurement. Most studies had a high risk of at least one type of bias and were of fair or poor quality. Interpretation is limited by wide variability in methods, taste stimulation, confounding factors, and lower-quality evidence. Existing studies suggest that taste can modulate swallowing, but more rigorous and standardized research is needed.

Keywords: Deglutition, flavor, genetic taster status, swallowing, taste

Introduction

Tasting and swallowing are closely related behaviors with complex underlying substrates and processes. The food science literature offers multidimensional understanding of the physical and chemical attributes of foods and liquids. Upon consumption, sensory and perceptual information about those foods or liquids in the oral cavity is integrated across multiple neural centers, and typically leads to the triggering of a swallow response. Swallowing is a sequence of movements involving the digestive and respiratory systems that transports the bolus from the oral cavity through the pharynx and esophagus and into the stomach while the airway is briefly closed. Our understanding of human swallowing has evolved over several decades, shifting from a strict go/ no-go brainstem-mediated reflex to a more complex and flexible pattern of component movements that is influenced by a host of sensory and perceptual factors.

In some regards, the sensory activity of tasting is a bottom-up process: chemical receptors on the tongue react to molecules within the food or liquid, cranial nerves relay the associated signals, and sensation information is delivered to relevant brainstem, subcortical, and cortical regions (Rajappa and Malandraki 2016; Simon et al. 2006). Key waystations within the medulla include the nucleus tractus solitarius (NTS), where taste signals are integrated with other sensory information (somatosensory, chemesthetic, thermal, proprioceptive, kinematic, etc.) until a threshold is reached (Steele and Miller 2010).

Then, the NTS signals the nucleus ambiguus within the central pattern generator to initiate a pharyngeal swallow response (Loret 2015). Simultaneously, top-down processing of taste within the cortex integrates cognitive and emotional factors such as attention, context, and past experiences. For example, the taster may recognize the constellation of sensory information as “orange juice,” and a positive or negative preference regarding the bolus in the oral cavity is made (de Araujo, Geha, and Small 2012). This perceptual information is relayed through relevant cortical and brainstem centers where it can serve to modulate cortical excitation as well as the timing and amplitude of the swallowing motor response (Abdul Wahab, Jones, and Huckabee 2010; Avivi-Arber et al. 2011; Dietsch, Westemeyer, et al. 2019; Mulheren, Kamarunas, and Ludlow 2016). Thus, the act of swallowing is one of sensorimotor integration across a multitude of factors.

Swallowing involves complex and precise coordination across the oral, pharyngeal, esophageal, and respiratory systems to perform a specific sequence of movements. A bolus is prepared in the oral cavity and then transported by the tongue to the pharynx. At the onset of a swallow, the hyoid bone and larynx elevate and move slightly anteriorly. This causes the leafy epiglottis to invert, covering the opening to the laryngeal vestibule. The velopharynx closes to prevent the bolus from entering the nasal cavity and to generate adequate pressures for swallowing. The vocal folds adduct to prevent any material from entering the trachea; this creates a brief period of apnea (≤1 second) during the swallow. The tongue base retracts and the pharyngeal walls constrict circumferentially and sequentially to propel the bolus through the pharynx toward the esophagus. The longitudinal muscles of the pharynx contract to shorten the distance from the oral cavity to the esophagus. The esophageal sphincters relax sequentially, and peristalsis guides the bolus toward the stomach. In a healthy swallow, airway invasion during swallowing is rare and minimal, and the bolus passes to the stomach efficiently without significant residue remaining in the oral, pharyngeal, or esophageal segments (Logemann 1998). A disruption to any component can result in dysphagia, or swallowing dysfunction (Matsuo and Palmer 2008). Neurological insults such as stroke or degenerative disease can interfere with sensory perception necessary to trigger a swallow response and can also cause weakness or incoordination in the motor sequence that comprises swallowing. Additionally, changes to the structures involved in swallowing due to injury, cancer, surgery, or other factors can cause dysphagia. To prevent complications of dysphagia such as aspiration pneumonia and death, rehabilitative efforts may incorporate motor-based exercises as well as sensory stimulation to reestablish safe and efficient swallowing (Logemann 1998).

The relationship between taste and swallowing has been explored in a growing body of literature with varying methods, selection criteria, and outcome measures. These studies have considered many factors that may modulate the relationship between taste and swallowing. To provide additional context for a systematic review of the relationship between taste manipulation and swallowing outcomes, a scoping review of secondary factors that may influence this primary taste-swallowing relationship was developed. This scoping review considers literature regarding properties associated with taste as well as influences of cognition, aging, saliva, genetics, and outcome measures on both taste and swallowing.

Taste and other bolus properties

The sensation of taste is a chemical reaction involving the excitation of chemoreceptors within the tastebuds. A stimulus that contains a sweet compound, for example, triggers chemoreceptors that are sensitive to that taste property, which release an action potential that is relayed to the central nervous system (Fjaeldstad, Petersen, and Ovesen 2017). Likewise, other chemoreceptors are sensitive to sour, salty, bitter, or umami compounds. These properties are considered “pure” tastes that are free from smell and other flavor components and are often the stimuli used in laboratory assessments of taste thresholds.

Real-life experiences of taste are typically not “pure” – most substances that we taste and consume have a combination of tastes as well as additional sensory properties that stimulate corresponding receptors and neural pathways. For example, orange juice contains a certain combination of sweet, sour, and occasional bitter; an orange color (visual stimulation); a liquid consistency with or without pulp (somatosensory stimulation); variable temperature (thermal stimulation); and an aroma (olfactory stimulation) that we perceive as “orange” based on our previous experiences. Further, a particularly sour batch of juice might have chemesthetic properties, which we often associate with a puckering-type response. Each of these sensory stimuli is processed via different receptor types, with specific neural pathways prior to sensory integration (Steele and Miller 2010). This combination of taste plus other sensory properties contribute to what is typically referred to as "flavor" and the overall perceptual experience of food/drink.

When our interpretation of these sensations matches our preexisting perceptions and expectations, we attribute the flavor to a certain stimulus identity. When there is a mismatch, such as a glass of semi-pulpy sweet-sour liquid that is green and lukewarm, the stimulus is often negatively perceived or not linked to our schema of the stimulus identity, even if the taste properties themselves are identical (DuBose, Cardello, and Maller 1980). In order to effectively evaluate the association between taste and swallowing as well as the effect of one process on the other, it is important to distinguish between "pure" taste stimulation and flavor (taste plus other stimuli) due to differing peripheral and central neural mechanisms between sensory properties.

Cognition and taste perception

Several cognitive factors can modulate the peripheral and central processing of taste. Detection thresholds for weak concentrations of taste stimuli are lower when the anticipated taste matches the actual stimulus, in comparison to a mismatch between anticipated and actual taste (Marks and Wheeler 1998a, 1998b). Attentional load can modify intensity ratings, with stronger stimuli being rated as less intense during more demanding attentional tasks despite no mediating effect of attention on weaker stimuli (van der Wal and van Dillen 2013). In addition to these changes in behavioral outcomes related to cognition, directing attention to different aspects of taste (e.g., palatability vs. intensity) results in different patterns of cortical activation (Grabenhorst and Rolls 2008).

In addition to experimental manipulation, taste perception may be altered by conditions that impact cognitive status. For example, taste identification scores are lower and moderately correlated with Mini Mental Status Examination (MMSE) scores in individuals with dementia and mild cognitive impairment in comparison to similarly aged controls (Lang et al. 2006; Steinbach et al. 2010). Although these results suggest that cognitive decline impacts taste perception, genetic risk for Alzheimer's disease in the absence of diagnosed dementia is associated with lower taste memory scores despite MMSE scores within normal limits (Schiffman et al. 2002).

Cognition and swallowing

Similar to taste, swallowing physiology can also change in response to shifts in cognitive processing. During evaluation, swallowing is often cued (e.g., "hold this in your mouth until I ask you to swallow"), in contrast to everyday, self-paced eating and drinking free from external or internal instruction. In a sample of younger adults, cued swallows resulted in longer pharyngeal transit and response times, more frequent initiation of swallowing with the bolus located deeper in the pharynx, less frequent upper esophageal sphincter (UES) opening prior to or simultaneous with the bolus entry, and more frequent maximum pharyngeal constriction occurring after maximum UES opening in comparison to uncued swallows (Molfenter, Leigh, and Steele 2014; Nagy et al. 2013). In contrast, cued swallows resulted in shorter swallowing durations and transit times than uncued swallows in a sample of older adults (Daniels et al. 2007), suggesting a differential effect of age (as detailed in the following section) on cognition and swallowing.

The notion that increased attention on swallowing can disrupt the automaticity of timing and coordination is also supported by dual task studies. Manipulating attention through distraction tasks has been shown to change swallowing, depending on cognitive status. A dual task yielded less severe airway invasion of swallowed material than single tasks in patients with Parkinson's disease who had more impaired cognition than other participants with Parkinson's disease (Troche et al. 2014). Shorter bolus transit times and total swallow duration were noted during the dual task, which could suggest that the distractor facilitated coordination for this group (Troche et al. 2014). In contrast, participants with milder cognitive impairment exhibited worse or static swallowing performance during dual vs. single task performance.

Disruptions in cognitive processes due to brain injury, degeneration, or other pathology may be associated with dysphagia. Reduced cognition has been associated with a longer time to initiate oral intake and to reach total oral intake after brain injury (Mackay, Morgan, and Bernstein 1999). Patients diagnosed with frontotemporal lobar dementia evidenced fast and compulsive eating, consumed large boluses, and had a higher risk for aspiration into the airway due to delayed swallowing and residue after the swallow (Langmore et al. 2007). Finally, disorientation and inability to follow simple verbal commands has been associated with aspiration of liquids (Leder, Suiter, and Lisitano Warner 2009). This evidence supports the association between cognition and swallowing, whether via experimental manipulation of cognitive tasks or by disruption of cognitive processes.

Aging and taste

Age-related changes in neural, psychological, and/or physiologic function and the increasing incidence of health complications with age can influence taste perception (Mojet, Christ-Hazelhof, and Heidema 2001). The self-reported prevalence of chemosensory deficits increases with age and has been associated with sensory impairments, functional limitations, and other negative health outcomes (Hoffman, Ishii, and Macturk 1998). Higher detection thresholds have been reported in older adults across taste quality categories (Methven et al. 2012), with similar results in detection of electrical and chemical taste stimulation across most regions of the tongue (Doty et al. 2016). Potential mechanisms of perceptual changes include fewer taste buds in older individuals in comparison to young adults (Arey, Tremaine, and Monzingo 1935; Kano et al. 2007; Shimizu 1997) and reduced activation of brain regions involved in taste processing starting in middle age (Green et al. 2013; Hoogeveen et al. 2015). Diminished taste identification in hospitalized older adults is associated with compromised oral care and hygiene (Solemdal et al. 2012) though taste detection may be improved by an oral hygiene regimen (Langan and Yearick 1976).

Aging and swallowing

Multiple physiologic swallowing features are noted to change with aging in the absence of other medical complications. The durations of swallowing events and bolus transit are noted to change in older adults in comparison to younger adults; additionally, reductions in pharyngeal constriction, tongue base retraction, hyoid anterosuperior movement, and UES opening may contribute to observations of increased pharyngeal residue with advancing age (Leonard, Kendall, and McKenzie 2004; Logemann et al. 2000; Mulheren et al. 2018; Rademaker et al. 1998). Although penetration of material into the laryngeal vestibule is more likely to be observed in adults over 50, aspiration into the trachea was found to be comparable between older and younger adults (Daggett et al. 2006; Daniels et al. 2004).

Several mechanisms may explain age-related changes in swallowing. Larger amounts of liquid are required to initiate laryngeal closure and UES relaxation in older adults, suggesting an overall decrease in oropharyngeal sensitivity with age (Kawamura et al. 2004; Ren et al. 2000; Shaker et al. 2003). Older persons exhibit increased quantity and stiffness of connective tissue in both the tongue and the UES (Schindler and Kelly 2002), with higher rates of hypopharyngeal wall protrusion noted (Xu et al. 2006). Mechano-, chemo-, and thermoreceptors of the oral and pharyngeal cavities are less responsive to stimulation in older adults, resulting in increased stimulation thresholds to detect sensory change (Schindler and Kelly 2002; Smith et al. 2006). Adults over age 65 exhibit alternative respiratory patterns (vs. typical expiration-swallow-expiration pattern) during swallowing, though without correlation between respiratory patterning and airway invasion (Martin-Harris et al. 2005). Finally, muscle atrophy that typically occurs with aging results in a larger pharyngeal lumen volume, with reduced pharyngeal constriction and more vallecular residue in older community-dwelling adults (Molfenter, Lenell, and Lazarus 2019).

Saliva and taste

Saliva is instrumental in taste transduction and thus perception. When taste stimuli enter the oral cavity, the flow, pH, and buffering capacity of saliva shift to aid in dissolving food and carrying taste to receptors within the taste buds (Gittings et al. 2015; Matsuo and Carpenter 2015). In the absence of food or other stimuli, the oral cavity is adapted to the taste of unstimulated saliva, and the introduction of taste is quickly detectable at low concentrations (McBurney and

Pfaffmann 1963). The degree of stimulated saliva flow is dependent on the concentration and perceptual ratings of intensity of the specific taste stimulus (Bonnans and Noble 1995; Dawes and Watanabe 1987; Watanabe and Dawes 1988), with maximum salivary flow peaking around 9.4 sec after the onset of taste stimulus delivery (Dawes and Watanabe 1987).

Individual differences in taste perception may also be reflected in salivary composition. 6-n-Propylthiouracil (PROP) sensitivity, often used as a measure of genetic taster status, is associated with a higher presence of certain chemical components of saliva (Cabras et al. 2012). Additionally, PROP sensitivity can be induced in nontasters by the introduction of salivary proteins and amino acids involved in PROP tasting (Cabras et al. 2012).

The interaction of saliva and taste perception is evident in conditions that disrupt typical saliva production. Patients reporting xerostomia, or dry mouth due to reduced saliva, may exhibit concomitant changes in taste perception, such as higher taste detection thresholds (Gomez et al. 2004; Henkin et al. 1972; Weiffenbach et al. 1995). This effect may be due to the reduced availability of saliva to transport stimuli to taste receptors (Hershkovich and Nagler 2004; Negoro et al. 2004). Taste strips with real-food flavors may serve as a treatment option for individuals with xerostomia by increasing saliva production (Dietsch, Pelletier, and Solomon 2018).

Saliva and swallowing

Although the presence of a foreign substance within the oral cavity is associated with increased saliva flow (Affoo et al. 2015), the association between saliva and swallowing is complicated by conflicting evidence. Salivary flow rate and weight were not associated with temporal measures of swallowing in persons without dysphagia (Sonies, Ship, and Baum 1989) and in persons who had undergone chemoradiation for head and neck cancer (Logemann et al. 2001; Logemann et al. 2003). Despite a higher frequency of oropharyngeal residue and penetration in patients with Sjogren’s syndrome than in healthy controls, these values were still judged to be within normal limits (Rogus-Pulia and Logemann 2011). Additionally, patients with Sjogren’s syndrome were found to have pharyngeal and esophageal pressures within normal limits despite abnormal peristalsis (Anselmino et al. 1997). These results suggest that changes in swallowing related to saliva production may be too subtle to induce dysphagia.

Other sources report more substantial effects on swallowing due to xerostomia and reduced salivary flow. In contrast to a general perception of dry mouth which was not associated with changes in salivary flow, xerostomia specific to meals and swallowing was associated with reductions in both stimulated and unstimulated salivary flow (Fox, Busch, and Baum 1987), suggesting that the association between xerostomia and salivary flow emerges during bolus processing. Dysphagia has been reported more frequently by patients with salivary dysfunction (confirmed by reduced stimulated and unstimulated salivary flow) than by healthy controls (Kaplan, Zuk-Paz, and Wolff 2008; Rhodus et al. 1995), with observed reductions in swallowing frequency and longer pharyngeal transit and swallowing durations (Caruso et al. 1989; Hughes et al. 1987; Rhodus et al. 1995). Differences in the available literature may be due to variability in selection and measurement of outcomes, severity of dysphagia and salivary dysfunction, and subclinical changes that still impact perceptions of function. Awareness and response to changes in the oral cavity may vary by individual, yielding contrasting impacts on swallowing. Finally, the interaction between saliva production and swallowing may be difficult to establish, as certain etiologies, such as chemoradiation, directly impact both functions (Jensen et al., 2010).

Genetics and taste

Genetic taster status (GTS) is an innate relative sensitivity to taste and is based on the genetic differences in the chromosomal expression of the TAS2R38 gene (Bartoshuk 2000; Kim et al. 2003; Reed et al. 1999). People can be classified as supertasters, midtasters, or nontasters based on their perceptual intensity to the bitter compound PROP (6-n-propylthiouracil; (Bartoshuk 1991; Smutzer et al. 2013). Sex differences have been documented among GTS groups, as women are more likely to be supertasters than men (Bartoshuk, Duffy, and Miller 1994). Anatomical differences across GTS are represented in the density of fungiform papillae and taste pores on the anterior tongue, as densities are highest in supertasters, followed by midtasters and nontasters, respectively (Bartoshuk 1993; Bartoshuk, Duffy, and Miller 1994; Essick et al. 2003). GTS manifests in perceptual differences to taste, as supertasters experience heightened responses to stimuli than mid- and nontasters (Dietsch, Westemeyer, et al. 2019; Ko et al. 2000; Nagy, Steele, and Pelletier 2014a, 2014b; Pelletier and Steele 2014). Genetic, anatomical, and perceptual differences could contribute to differences in the neural representation and networks involved in taste processing (Bembich et al. 2010; Dietsch, Westemeyer, et al. 2019; Eldeghaidy et al. 2011).

Genetics and swallowing

Emerging evidence suggests that GTS may be an important variable in swallowing physiology (Dietsch, Westemeyer, et al. 2019). In comparison to nontasters, supertasters have demonstrated higher submental activation (Pelletier and Steele 2014) and lingual-palatal pressures (Nagy, Steele, and Pelletier 2014a; Pelletier and Steele 2014) at higher concentrations of taste stimuli during swallow tasks. A greater extent of hyolaryngeal excursion and pharyngeal constriction and shortening has been documented in supertasters compared with nontasters (Dietsch, Westemeyer, et al. 2019). GTS has also been reported to affect kinematic measures of swallow physiology, as supertasters have exhibited longer swallow apnea duration than nontasters (Plonk et al. 2011). However, other swallowing parameters are reportedly not affected by GTS (Barry and Regan 2021; Nagy, Steele, and Pelletier 2014b; Todd et al. 2012a), and overall, few studies have investigated this effect.

Outcome measures

A broad range of outcome measures have been used to characterize the physiological effects and the impacts of taste on swallow function. Some studies measuring responses to taste stimulation have focused on specific physiologic components, such as tongue to palate pressures (Nagy, Steele, and Pelletier 2014a, 2014b; Pelletier and Dhanaraj 2006; Pelletier and Steele 2014), surface electromyography from submental muscles (Leow et al. 2006; Miura et al. 2009; Miyaoka et al. 2006; Nagy, Steele, and Pelletier 2014b; Palmer et al. 2005; Pelletier and

Steele 2014), or bolus transit times (Chee et al. 2005; Cola et al. 2010; Lee et al. 2012; Pauloski et al. 2013). Others have considered measures related to airway protection during swallows, including swallow apnea duration (Pelletier and Steele 2014; Plonk et al. 2011; Todd et al. 2012a, 2012b) and the Penetration-Aspiration Scale (Dietsch, Dorris, et al. 2019; Lee et al. 2012; Pelletier and Lawless 2003). Although these data elucidate important aspects of the swallows generated in response to taste stimuli, comparisons across studies with different outcomes is challenging.

The sensorimotor integration underlying taste stimulation and swallowing has also been examined through neuroimaging and other measures of neural networks. Motor evoked potentials have elucidated some aspects of the peripheral processing of taste inputs (Abdul Wahab, Jones, and Huckabee 2011; Mistry et al. 2006), and a few papers quantifying salivary flow in response to taste stimulation (Engelen et al. 2003; Imura et al. 2016; Karami-Nogourani, Kowsari-Isfahan, and Hosseini-Beheshti 2011) provide some indication of the secondary effects of taste stimulation that may contribute to swallowing. Central representation of taste stimulation within the brain has been explored using functional magnetic resonance imaging (fMRI; Babaei et al. 2010; Cerf-Ducastel, Haase, and Murphy 2012; Dalenberg et al. 2015; de Araujo, Geha, and Small 2012; Hoogeveen et al. 2015; Humbert and Joel 2012; Mascioli et al. 2015; van den Bosch et al. 2014; Veldhuizen, Gitelman, and Small 2012) and functional near-infrared spectroscopy (fNIRS; Mulheren, Kamarunas, and Ludlow 2016; Okamoto et al. 2009, 2011). These methodologies have helped outline a network of brain regions that may be involved in the integration of taste-specific sensory input and swallowing-related motor output, though the complications arising from the use of a range of stimulus types are also present in this literature. A third set of outcomes in the taste and swallowing literature consider the individual's perception of taste stimuli presented (Leow et al. 2006; Nagy, Steele, and Pelletier 2014a, 2014b). These outcomes are typically evaluated in correlation with measures of swallowing behavior, which enables some consideration of the relationship between an individual's experience of a particular taste stimulus. Given the range of features that can affect taste perception, this is likely an important factor to incorporate into future taste and swallowing studies.

Framework for systematic review

Whereas the broad range of secondary factors outlined above have the capacity to influence sensory perception and sensorimotor integration, examination of the association between taste stimulation and swallowing behaviors remains a primary opportunity to understand and influence how sensory inputs may be altered to facilitate specific motor outcomes. This relationship may have specific relevance for research in areas such as food science, swallowing physiology, and neuroscience, as well as clinical management of dysphagia. To highlight this dynamic, we designed a systematic review around one central research question: *What is the effect of taste stimulation on swallowing?* This question was further defined by the following PICO elements:

Population: healthy and dysphagic humans
Intervention: oral processing of taste properties (that can be isolated from other sensory inputs)
Comparison: unflavored or other taste properties
Outcome: swallowing-specific measure (physiology, quality of life, salivation, mastication, neural substrates)

Methods

The systematic review followed the guidelines outlined by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Group (Moher et al. 2009). These include a detailed checklist and recommendations to support the development, reporting, and replicability of systematic review methodology. Two large databases, PubMed and Web of Science, were searched from the earliest date available through November 2019. These databases were selected based on the rigor of their indexing criteria and their inclusion of the medical, allied health, and food science literatures in which relevant studies were anticipated to be published. The search terms, shown in **Table 1**, emphasized the intervention and outcome components of the research question.

After removing duplicates (**Figure 1**), papers were randomly divided across coauthors for screening within Rayyan (Ouzzani et al. 2013). Abstracts were screened and excluded if they (a) did not have human

Table 1. Database search terms.

Database	*Search descriptors*	*Results*
PubMed	(((((dysphagia[Title/Abstract]) OR swallow*[Title/Abstract]) OR deglutition[Title/ Abstract]) OR pharyn*[Title/Abstract])) AND ((((((tast*[Title/Abstract]) OR gustat*[Title/Abstract]) OR flavor[Title/Abstract]) OR sour[Title/Abstract]) OR citric acid[Title/Abstract])) AND “English”[Language]	1056 papers
Web of Science Core Collection	((TS =(dysphagia OR swallow* OR deglutition OR pharyn*) AND TS = (tast* OR gustat* OR flavor OR sour OR “citric acid”))) *AND* **LANGUAGE:** (English)	1310 papers

participants (regardless of health, age, gender, race, or other factors); (b) did not use a taste-related independent variable that stimulated taste receptors in the oral cavity; (c) did not have an outcome measure specific to swallowing physiology, quality of life, saliva flow, mastication, or neural substrates; (d) were not written in English; or (e) were a review paper, editorial, conference proceeding, thesis, or other non-peer-reviewed source. The reliability of screening decisions was assessed via blinded recategorization of a randomly selected 10% (for interrater agreement) and 5% (for intrarater agreement) of papers.

Next, papers that passed the abstract screening process were randomly re-distributed across coauthors for full manuscript review. In addition to confirming the five exclusionary criteria used at abstract screening, full-text review thoroughly assessed experimental design, study population, taste-related independent variables, and swallowing-related dependent variables. For example, papers were evaluated for a control condition or a comparison across conditions; if neither was present, the paper was excluded from the final review set. Likewise, studies were excluded if the design did not enable taste-specific effects to be distinguished from other bolus features, or if correlations between taste and swallow measures rather than cause-effect relationships were described. A lack of adequate details for replication

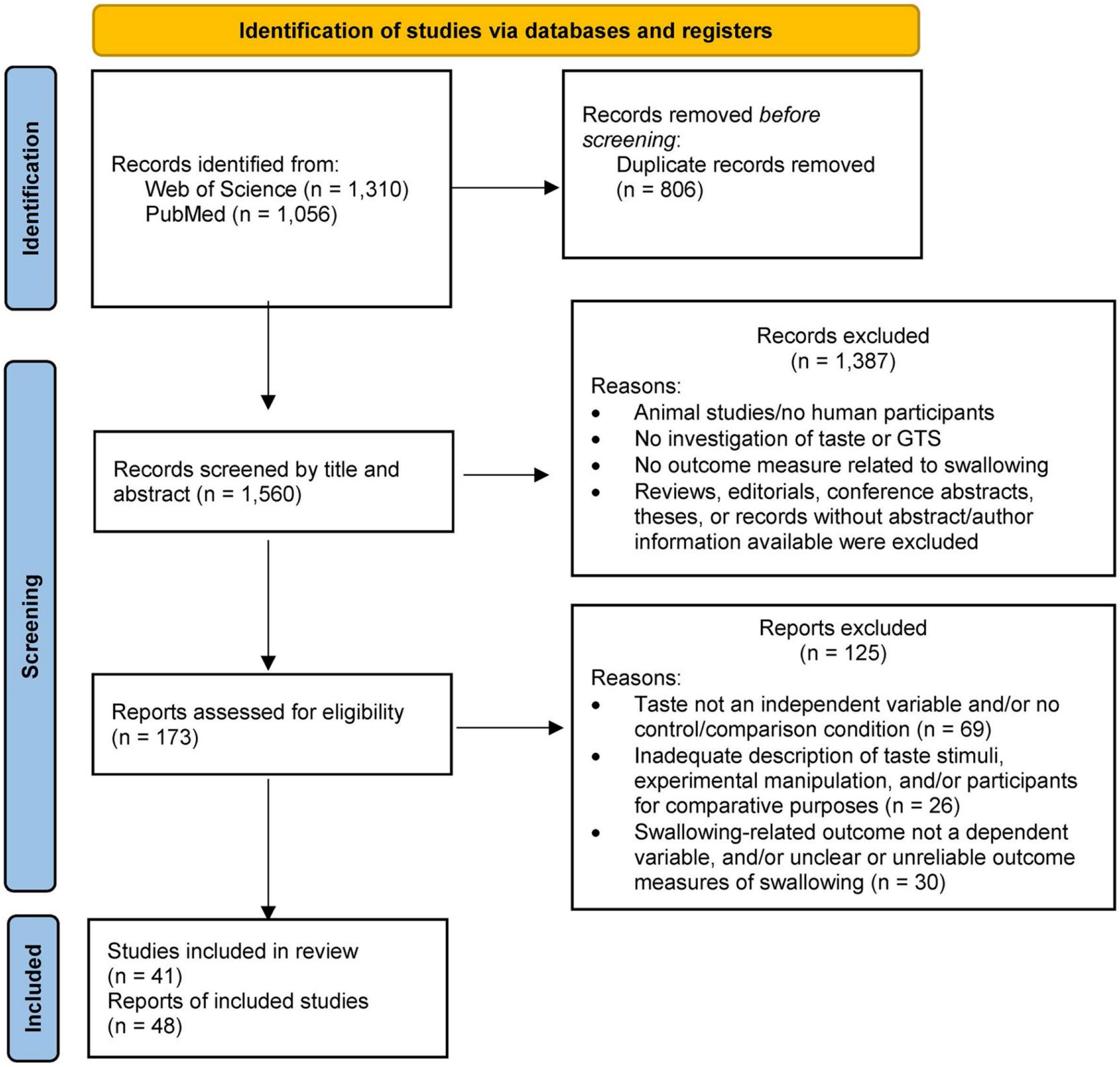

Figure 1. PRISMA flow diagram of systematic review (Page et al. 2021).

(e.g., no age parameters or health/diagnosis information about the study sample, vague description of stimuli such as “a sour liquid”, an unstandardized unpublished rating scale as the primary outcome) was also cause for exclusion from the review set.

Studies that were retained into the final systematic review were then evaluated using the Cochrane Risk of Bias tool (Sterne et al. 2019) and NIH Quality Assessment Tools (National Institutes of Health 2012). Reviewers chose the version of each tool that best fit the design of each study. Reviewers appraised, discussed, and summarized trends and characteristics of the final qualifying set of papers. This included consideration of the populations assessed, the stimuli tested, the outcome measures, and other parameters of the studies. These aspects were grouped and summarized for results reporting.

Results

The database searches yielded a total of 2366 papers. Identification and resolution of duplicates via Zotero and Rayyan platforms yielded 1560 unique papers that were screened for inclusion (see Figure 1). One hundred seventy-three papers survived the screening process and underwent full manuscript review. Of these, 48 were included in the final systematic review set.

Of the 156 papers designated for interrater checks during the screening stage, there were initial discrepancies on only 14 (91% interrater reliability). These tended to focus on factors such as the nature or reliability of outcome measures, and were resolved via brief discussion of each abstract among all three coauthors. Intrarater reliability was also high at 96%.

During data extraction from the 48 papers included in the final review, researchers noted that many papers listed multiple outcomes. Measures that were not described in adequate detail to be categorized or that did not have what was determined to be an adequate theoretical justification or evidence base were not included in the summary tables (**Tables 2 and 3**). Over 50 different outcome variables were found to have scientific merit and were included in these tables.

The results of the systematic review included a broad array of taste stimuli. Table 2 organized findings by stimulus categories. Taste stimuli spanned all five pure tastes as well as many complex flavors, and were delivered in textures ranging from thin liquid (with or without barium) to gelatin and dissolvable films. Bolus temperature added another layer to study stimuli, with some studies listing specific temperature ranges, others describing unspecified “cold” temperatures or “room” temperature, and still others not reporting data regarding stimulus temperature.

The wide variety of swallowing outcome measures could facilitate a comprehensive appreciation of the relationship between taste stimuli and swallowing behaviors, particularly if outcomes from the same stimuli and study population are compared to each other. Table 3 groups study findings by outcome categories of swallowing physiology, bolus transit efficiency, neuroimaging, neurostimulation, and salivary measures. A number of papers included responses to taste across multiple outcome categories (Abdul Wahab, Jones, and Huckabee 2010; Alves, Fabio, and Dantas 2013; Alves, Secaf, and Dantas 2013a; Ayala and Logemann 2010; Butler et al. 2011; Dietsch, Dorris, et al. 2019; Humbert et al. 2012; Logemann et al. 1995; Mulheren, Kamarunas, and Ludlow 2016; Nederkoorn, Smulders, and Jansen 1999; Pelletier and Lawless 2003). Many others included several outcome measures within a category. This was particularly common within swallowing physiology, which spanned a large number of kinematic, timing, pressure, and other physiological measures. However, most studies with multiple outcomes reported them in isolation, rather than correlating outcomes to help define clusters of coexisting swallowing characteristics in participants' responses to taste stimulation.

A few studies in the systematic review were conducted on what could be considered patient populations. Six of the 48 papers included persons with confirmed dysphagia as an inclusion criterion (Brady et al. 2016; Dietsch, Dorris, et al. 2019; Dietsch, Pelletier, and Solomon 2018; Lee et al. 2012; Logemann et al. 1995; Pelletier and Lawless 2003). Six other papers, two of which appeared to be related to the same study, had populations with medical diagnosis that put them at increased risk for dysphagia, including stroke (Alves, Fabio, and Dantas 2013; Cola et al. 2010, 2012; Gatto et al. 2013), preterm birth (Shubert, Sitaram, and Jadcherla 2016), and head/neck cancer (Pauloski et al. 2013).

The vast majority of papers in the systematic review were of taste-swallow relationships in healthy persons of varying ages. Although age effects on taste perception and swallowing outcomes is documented in other work, it was not consistently a point of consideration or comparison in the literature reviewed within this systematic review. Thirteen papers representing seven datasets had groups of younger and older healthy participants to allow comparisons across age categories, though the specific age cutoffs varied by paper (Ayala and Logemann 2010; Ding et al. 2003; Hiss et al. 2004; Humbert and Joel 2012; Nagy, Steele, and Pelletier 2014a, 2014b; Pelletier and Steele 2014; Plonk et al. 2011; Sciortino et al. 2003; Steele, van Lieshout, and Pelletier 2012; Todd et al. 2012a, 2012b). Two studies focused exclusively on older adults (Butler et al. 2011; Mulheren et al. 2018) and another had one participant group comprised of healthy older adults (Dietsch, Pelletier, and Solomon 2018). Half of the papers in the systematic review included either mixed age healthy participants (Alves, Fabio, and Dantas 2013; Alves, Secaf, and Dantas 2013a, 2013b; Chiu et al. 2016; Gurgor et al. 2017; Mulheren, Kamarunas, and Ludlow 2016; Pauloski et al. 2013) or younger adults (Abdul Wahab, Jones, and Huckabee 2010, 2011; Ayala and Logemann 2010; Babaei et al. 2010; Butler, Postma, and Fischer 2004; Chee et al. 2005; de Wijk, Wulfert, and Prinz 2006; Elshukri et al. 2016; Humbert et al. 2012; Kaatzke-McDonald, Post, and Davis 1996; Krival and Bates 2012; Leow et al. 2006; Miura et al. 2009; Miyaoka et al. 2006; Nederkoorn, Smulders, and Jansen 1999; Palmer et al. 2005; Pelletier and Dhanaraj 2006).

Despite emerging evidence of its relevance to taste perception and swallowing physiology, GTS was reported in only a handful of papers representing two studies (Mulheren, Kamarunas, and Ludlow 2016; Nagy, Steele, and Pelletier 2014a, 2014b; Pelletier and Steele 2014; Plonk et al. 2011; Todd et al. 2012a, 2012b).

The quality of studies included in the systematic review was variable, as shown in the results of the Risk of Bias and NIH Quality assessments (**Table 4**). Forty of the 48 papers in the systematic review had bias risk associated with detection per the Cochrane, most commonly due to lack of blinding by raters within the original studies. Only five papers were considered at low risk for bias across all five Cochrane categories. Notably, the NIH Quality Scales do not provide explicit cutoffs for the "overall assessment" categories of poor, fair, and good. Whereas two papers had scores far below the others and were labeled "poor", the vast majority fell into a broad range that we designated "fair". Quality ratings were adversely affected by limited use or reporting of study design factors such randomization, blinding of researchers and/or participants to study conditions, appropriate baseline measures and group comparisons, sample size justifications, and stability of outcome measures.

Discussion

This systematic review of the effect of taste on swallowing included 48 articles which evaluated over 65 taste stimuli using over 50 swallow outcome measures in healthy and clinical populations. The broad range of participant demographics, taste stimuli, methodological procedures, and swallow outcomes in this systematic review significantly complicates the determination of clear patterns of the effect of taste on swallow-related outcome measures.

The varying taste profiles, stimulus consistencies and volumes, delivery methods, and additional sensory properties across studies reflect the diversity of food science and also influenced interpretation of results. This review included a wide array of pure tastes (i.e., sweet, sour, salty, bitter, umami), complex flavors, and multimodal sensory stimuli. Tastant consistencies included dissolvable strips, filter paper, and a range of viscosities. Stimuli were also delivered in differing methods and volumes. These stimuli parameters can all modulate taste processing and/or swallow physiology. Viscosity can influence flavor intensity (Bult, de Wijk, and Hummel 2007), and the volume and location of stimulus delivery may affect the extent of taste receptor cells stimulated (Heckmann et al. 2003). Larger, more viscous boluses provide greater mechano-sensory input via trigeminal pathways and can elicit increased duration and magnitude of swallow movements (Lazarus 2017). Several investigations incorporated additional sensory experiences with tastants like experimental retronasal olfaction stimulation (Abdul Wahab, Jones, and Huckabee 2010, 2011), oropharyngeal tactile stimulation (Sciortino et al. 2003), varying volumes of stimuli (Gurgor et al. 2017; Hiss et al. 2004), and cold temperature (Ayala and Logemann 2010; Cola et al. 2010, 2012; Gatto et al. 2013; Sciortino et al. 2003). Although taste is inherently related and integrated with olfaction and somatosensation, each sensation has differences in their underlying neurophysiology (Duffy 2007; Simon et al. 2006; Steele and Miller 2010). Consequently, any effect on swallowing that multimodal sensation elicited makes it challenging to delineate which outcomes were attributed to taste or other sensory experiences.

Despite these limitations, some trends in the effects of specific taste properties did emerge from the systematic review. Intense sour and intense sweet showed the most favorable results. When compared to unflavored trials, intense sour was associated with pervasive and advantageous changes in swallowing kinematics including quicker muscle activation (Chee et al. 2005; Ding et al. 2003), longer apnea duration for airway protection (Plonk et al. 2011), increased amplitude and/or duration of muscle activation (Dietsch, Dorris, et al. 2019; Leow et al. 2006; Miura et al. 2009; Nagy, Steele, and Pelletier 2014b; Pelletier and Dhanaraj 2006; Pelletier and Steele 2014), and less airway invasion of the bolus (Dietsch, Dorris, et al. 2019; Pelletier and Lawless 2003). This was in contrast to a small minority of studies identifying no sour vs. plain differences in measures of hyolaryngeal excursion (Humbert and Joel 2012), apnea duration (Leow et al. 2006; Todd et al. 2012a), and submental activation (Ding et al. 2003). High-concentration sweet trials may also enhance swallowing physiology but the effects appear less widespread. There were some indications of faster muscle response (Chee et al. 2005; Ding et al. 2003), shorter oral preparation times (Leow et al. 2006), and increased lingual pressures (Nagy, Steele, and Pelletier 2014b; Pelletier and Dhanaraj 2006) with intense sweet compared to plain trials. But for other measures such as swallow apnea duration (Leow et al. 2006; Todd et al. 2012b), pharyngeal and esophageal transit times (Alves, Fabio, and Dantas 2013; Pauloski et al. 2013), and submental muscle activation (Ding et al. 2003; Leow et al. 2006; Miura et al. 2009; Miyaoka et al. 2006; Nagy, Steele, and Pelletier 2014b), studies found no differences between sweet and unflavored stimuli. Further, studies that directly compared sour to sweet trials revealed a greater advantageous capacity for sour on an array of swallowing measures (Leow et al. 2006; Mulheren, Kamarunas, and Ludlow 2016; Nagy, Steele, and Pelletier 2014b) perhaps because of the dual taste/ chemesthetic sensory pathways triggered by intense sour.

Efforts to ameliorate the unpleasant hedonic aspects of high-intensity sour stimuli using a strong sweet-sour stimulus have yielded promising results including quicker muscle activation (Steele, van Lieshout, and Pelletier 2012) and greater amplitude of swallowing movements (Dietsch, Dorris, et al. 2019) compared to plain trials. The sweet-sour kinematics were reported by Dietsch, Dorris, et al. (2019) as being more functional than those observed with sour, whereas others found the opposite (Leow et al. 2006; Pelletier and Lawless 2003). The disparities in results may be at least partially related to the masking effect associated with combining tastants in varying concentrations. Further investigation of taste combinations to target palatable stimuli is warranted given the limited research to date.

Other pure taste stimuli have yielded fewer differences from plain trials. High-concentration salty trials were linked to quicker muscle activation (Chee et al. 2005; Ding et al. 2003) and greater amplitude of submental (Ding et al. 2003; Leow et al. 2006; Miura et al. 2009) or lingual (Nagy, Steele, and Pelletier 2014b; Pelletier and Dhanaraj 2006) contraction in some studies, but others identified no differences in apnea duration (Leow et al. 2006; Todd et al. 2012b) nor submental contraction (Nagy, Steele, and Pelletier 2014b). Like sour, intense salty stimuli can trigger chemesthetic receptors so results may at least partially reflect differences in salt concentrations across studies. In contrast to these other tastants, trials of bitter (Chee et al. 2005; Leow et al. 2006; Miura et al. 2009; Nagy, Steele, and Pelletier 2014b; Pelletier and Dhanaraj 2006; Todd et al. 2012b) and umami (Miura et al. 2009; Miyaoka et al. 2006) tended not to elicit differences in timing nor amplitude of movements compared to plain. The lack of favorable results with salty, bitter, umami, and even sweet trials likely accounts for the greater number of studies incorporating intense sour or sweet-sour as taste stimuli. Even so, interpretation and application of these trends requires consideration of the specific concentrations, mediums, and populations utilized in the associated studies.

This systematic review highlights the wide variability in the types of stimuli that can be selected for research purposes. Controlling for other sensory properties by the use of “pure taste” stimuli allows researchers to establish the specific mechanism of the effect on swallowing. However, as intake for nutrition and pleasure typically involves several sensory components, studies that include taste-only stimuli have limited application to the real-world experiences of eating and drinking. While the results indicate a need for further research to understand the association between taste, swallowing, and mediating factors, a balance is needed between controls to establish cause and effect for ample internal validity and the assessment of stimuli that more closely approximate real foods for external validity. Consideration of the sensory components of a bolus or stimulus is also necessary when using taste as a treatment technique for dysphagia, as the receptors and neural pathways differ by type of sensory stimulation and may yield differential effects between using taste alone vs. taste plus additional sensory components.

Individual variability in perception presents a challenge to synthesizing the available evidence on taste and swallowing. As previously discussed, genetic taster status modulates the perception of taste intensity, and few studies have directly assessed or accounted for this effect in relation to swallowing outcomes. In addition to ratings of taste intensity, genetic taster status has also been found to impact the perceived intensity of chemesthesis (Karrer and Bartoshuk 1991; Snyder, Prescott, and Bartoshuk 2006), taste quality confusion (Doty, Chen, and Overend 2017), and salivary flow (Cabras et al. 2012). Studies that have unbalanced designs regarding the sex of participants may also be susceptible to limited validity due to the known effect of sex on genetic taster status (Bartoshuk, Duffy, and Miller 1994). The few studies that included genetic status taster status in the analysis of taste stimulation and swallowing outcomes have yielded mixed results, and future research should consider the mediating effect of perceptual variability due to genetics.

Individual differences in the wide range of modulating factors for oral sensation (Duffy 2007) highlight the importance of assessing and documenting sensation, especially in clinical settings. Assessment of sensation in swallowing evaluation is not standardized, though its value is receiving increasing attention in the field of speech-language pathology (Madhavan and Etter 2021). Swallowing is a sensorimotor response, and comprehensive evaluation of the integrity and physiology of swallowing should include assessing both sensory and motor aspects of the swallow (Groher and Crary 2020). This thorough evaluation should lead to identification of physiologic deficits, which will then inform decision-making about management strategies. Clinical populations with a potentially increased risk for sensory deficits affecting the aerodigestive tract include Parkinson's disease (Hammer and Barlow 2010), Alzheimer's disease (Affoo et al. 2013), stroke (Cabib et al. 2017), and COVID-19 (Vergara et al. 2021).

Although research that includes participants with different etiologies of dysphagia is necessary to establish the treatment efficacy and effectiveness of taste stimulation, it is difficult to know whether taste perception has been reduced by the same mechanisms disrupting swallowing without testing sensory function and comparison to norms or baseline. Given similarities in cranial nerve innervation, brainstem coordination, and central processing of taste and swallowing (Matsuo and Palmer 2008; Rajappa and Malandraki 2016; Steele and Miller 2010), both processes may be simultaneously disrupted by neurogenic, structural, or iatrogenic causes. If taste transduction and/or perception is diminished or absent, the use of taste stimulation may be less effective in treatment of dysphagia as the sensory input may not be detected by relevant receptors or transmitted to processing regions. Conversely, as heightened cortical activation of gustatory regions was noted to be present in patients with ageusia (Hummel et al. 2007), taste stimulation may be a means of retraining the sensory system and enhancing the motor programming of swallowing. Medical diagnoses and interventions associated with changes in taste and swallowing may also alter the related processes previously discussed, such as cognition and salivation, as well as other sensory processes such as smell and somatosensation.

The majority of included studies focused on the adult population, limiting conclusions concerning the effect of taste on swallowing in children. While some studies accounted for the effect of aging on both taste and swallowing through stratification (e.g., older vs. younger groups) and inclusion of age as a variable in statistical analyses, many did not, leaving the potential for age as a confounding variable (Logemann et al. 2000; Mojet, Christ-Hazelhof, and Heidema 2001). Even in the absence of xerostomia, individual differences in salivary flow rates may have impacted taste perception (Christensen, Brand, and Malamud 1987) and thus swallowing. These sources of individual variability are further compounded in the presence of pathology; even among a cohort with a similar etiology of dysphagia (e.g., stroke), the region and extent of damage and the resulting impact on function vary between individuals.

The topic of taste and swallowing is particularly relevant given the recent impact of COVID-19 on the chemosensory and aerodigestive systems (Vergara et al. 2021). A recent meta-analysis reported a prevalence of taste disorders in 48% of patients with COVID-19, with a higher prevalence based on objective rather than subjective measures of taste (Saniasiaya, Islam, and Abdullah 2021). Disruptions in taste have been reported to resolve in a short period of time (Paderno et al. 2020), particularly in patients with mild symptoms (Boscolo-Rizzo et al. 2020). However, if dysgeusia persists beyond the acute phase, taste stimulation may have a dampened effect on swallowing in research or clinical application. Dysphagia has been documented in patients hospitalized due to COVID-19 infection, with potential mechanisms including respiratory compromise impacting airway protection, deconditioning, intubation, mechanical ventilation, and neurologic complications (Archer, Iezzi, and Gilpin 2021; Lagier et al., 2021). While the long-term effects of COVID-19 on taste and swallowing remain unclear, future research may consider whether the effects of taste stimulation on swallowing differs between individuals with a recent history of acute infection, a chronic infection, or no known infection.

Given the complexities involved in the relationship between taste stimulation and swallowing outcomes, a more systematic approach to such research may allow for direct comparisons and more rapid advancement of the science. The recently developed STARTED framework could be an important tool in these endeavors (STARTED Collaborative 2021). This protocol was developed by a group of dysphagia experts after a comprehensive review of existing research in swallowing and swallowing disorders. It involves an interactive online tool with a series of questions to guide the design and reporting of swallowing-related research, and may facilitate higher quality research and reporting standards going forward.

The relationship between taste and swallowing has opportunities and implications for researchers and clinicians in areas of food science and swallowing function. Thoughtful study design can help to inform the complexities involved in utilizing sensory properties of food to enhance swallow function. For example, when developing and testing taste and flavor stimuli, food science researchers may want to consider the downstream effect of taste and other sensory properties on how foods are processed and swallowed. Likewise, swallowing researchers should be mindful of the various sensory features of the stimuli. It should be noted that these reviews focused on the oral processing and sensory perception of taste stimulation, and excluded research on testing the cough reflex via nebulized tastants such as citric acid and capsaicin. Due to the relevance of cough response to airway protection during swallowing, the impact of taste on cough function merits consideration in future reviews. These scoping and systematic reviews provide a comprehensive foundation to understand existing literature and to inform future work.

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Table 2. Results of studies examining the effect of taste on swallowing-related outcomes by stimuli and contrasts.

Pure taste contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
Sour	liquid	vs. plain	Chee et al. 2005	Swallowing speed measures: shorter for sour < water in younger **healthy participants**
			Ding et al. 2003	Submental and infrahyoid sEMG activation: earlier for sour > water with stronger effect in younger > older **healthy participants**; sEMG amplitude: no difference between sour and water in younger and older **healthy participants**
			Humbert and Joel 2012	BOLD signal in M1: lower for sour < water; BOLD signal in SMA: higher for sour > water in younger and older **healthy participants**
			Humbert et al. 2012	Hyolaryngeal timing and kinematics: no difference between sour and water in younger **healthy participants**
			Miura et al. 2009	sEMG total power spectral density, amplitude, and duration: higher for sour > water in younger **healthy participants**
			Mulheren, Kamarunas, and Ludlow 2016	Number of swallows: higher for sour > water; hemodynamic response 17-22 sec after bolus with addition of slow water infusion: higher for sour > water in **healthy participants** of mixed ages
			Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: higher for sour > water and in older > younger **healthy participants**; anterior tongue pressure: higher for sour > water in younger and older **healthy participants**
			Pelletier and Dhanaraj 2006	Peak lingual pressure: higher for high sour (2.7%) > water, no difference between moderate sour (0.15%) and water; duration to peak pressure: no difference between sour and water in younger **healthy participants**
			Pelletier and Steele 2014	Anterior lingual-palatal pressures and sEMG amplitudes: higher for intense sour (2.7%) > water in younger and older **healthy participants**, enhanced but non-significant effect in supertasters
			Plonk et al. 2011	Swallowing apnea duration: higher for sour > water in younger and older **healthy participants**, enhanced effect in supertasters
			Pelletier and Lawless 2003	Occurrences of penetration and aspiration: lower for sour < water; number of spontaneous swallows after initial swallow: higher for sour > water in older **patients with neurogenic dysphagia**
		high vs. low	Nagy, Steele, and Pelletier 2014a	Linguapalatal pressures: higher for high sour (0.128 M) > low sour (0.002 M) in younger and older **healthy participants**, enhanced effect in supertasters
		vs. sweet	Mulheren, Kamarunas, and Ludlow 2016	Number of swallows: higher for sour > sweet; hemodynamic response: no difference between sour and sweet in **healthy participants** of mixed ages
			Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: higher for sour > sweet and in older > younger **healthy participants**; tongue pressure: no difference between sour and sweet in younger and older **healthy participants**

Pure taste contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
		vs. bitter	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: higher for sour > bitter and in older > younger **healthy participants**; anterior tongue pressure higher for sour > bitter in younger and older **healthy participants**
		vs. salty	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: higher for sour > salty and in older > younger **healthy participants**; tongue pressures: no difference between sour and salty in younger and older **healthy participants**
		vs. sweet-sour mixture	Pelletier and Lawless 2003	Number of spontaneous swallows after initial swallow: higher for sour > sweet-sour mixture in older **patients with neurogenic dysphagia**
		vs. ethanol	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: no difference between sour and ethanol, higher in older > younger **healthy participants**; anterior tongue pressure: higher for sour > ethanol in younger and older **healthy participants**
		vs. mineral water	Elshukri et al. 2016	Pharyngeal MEPs at least 15 min post-stimulation: higher for weak sour (0.5%) > mineral water in younger **healthy participants**
		vs. sodium-free seltzer	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: higher for sour > seltzer and in older > younger **healthy participants**; tongue pressures: no difference between sour and seltzer in younger and older **healthy participants**
	liquid plus barium	vs. plain	Pelletier and Dhanaraj 2006	Peak lingual pressure: higher for sour barium > water; duration to peak pressure: no difference between sour and water in younger **healthy participants**
		vs. plain plus barium	Dietsch, Dorris, et al. 2019	Penetration Aspiration Scale and pharyngoesophageal opening MBSImP scores: lower (less impaired) for sour < plain barium; hyolaryngeal displacement, pharyngeal shortening, and tongue base retraction on CASM: higher for sour > plain barium in younger **patients with sensory-based dysphagia**
			Todd et al. 2012a	Swallowing apnea duration: no difference between sour and plain barium, longer in older > younger **healthy participants**
		vs. sweet-sour mixture plus barium	Dietsch, Dorris, et al. 2019	Hyolaryngeal displacement and tongue base retraction on CASM: higher for sweet-sour mixture > sour barium in younger **patients with sensory-based dysphagia**
	gelatin	vs. plain	Leow et al. 2006	Mean amplitude submental sEMG: higher for sour > neutral gelatin; swallowing apnea phase, apnea duration, and oral prep time: no difference between sour and neutral gelatin in younger **healthy participants**
		vs. sweet	Leow et al., 2006	Mean amplitude submental sEMG: higher for sour > sweet gelatin; swallowing apnea phase, apnea duration, and oral prep time: no difference between sour and sweet gelatin in younger **healthy participants**
		vs. bitter	Leow et al. 2006	Mean amplitude submental sEMG: higher for sour > bitter gelatin; oral prep time: lower for sour < bitter gelatin; duration submental sEMG: higher for bitter > sour gelatin; swallowing apnea phase and duration: no difference between sour and bitter gelatin in younger **healthy participants**

Table 2. Continued

Pure taste contrasts	*Medium/consistency*	*Contrast*	*Associated papers*	*General findings*
		vs. salty	Leow et al. 2006	Mean amplitude submental sEMG: higher for sour > salty gelatin; oral prep time: lower for sour < salty, swallowing apnea phase and duration: no difference between sour and salty gelatin in younger **healthy participants**
Sweet	liquid	vs. plain	Chee et al. 2005	Swallowing speed measures: shorter for sweet < water in younger **healthy participants**
			Ding et al. 2003	Submental and infrahyoid sEMG activation: earlier for sweet > water with stronger effect in younger > older **healthy participants**; sEMG amplitude: no difference between sweet and water in younger and older **healthy participants**
			Miura et al. 2009	Submental sEMG total power spectral density, duration, and amplitude: no difference between sweet and water in younger **healthy participants**
			Mulheren, Kamarunas, and Ludlow 2016	Number of swallows and hemodynamic response: no difference between sweet and water in **healthy participants** of mixed ages
			Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: no difference between sweet and water, higher in older > younger **healthy participants**; midpalate tongue pressure: higher for sweet > water in younger and older **healthy participants**
			Pelletier and Dhanaraj 2006	Peak lingual pressure: higher for moderate sweet (10%) > water, no difference between high sweet (30%) and water; duration to peak pressure: no difference between sweet and water in younger **healthy participants**
			Todd et al. 2012b	Swallowing apnea duration: no difference between sweet and water, longer for older > younger **healthy participants**; respiratory pattern: no difference between sweet and water in younger and older **healthy participants**
			Alves, Secaf, and Dantas 2013b	Esophageal transit durations, clearance durations, and residue: no difference between sweet and water in **healthy participants and patients post-stroke** of mixed ages
			Shubert, Sitaram, and Jadcherla 2016	Response latency to first pharyngeal swallow: lower for sweet < no taste via pacifier; esophageal motility, respiratory rhythm, and impedance transit: no difference between sweet and no taste in **preterm infants**
		vs. baseline	Mistry et al. 2006	Pharyngeal MEPs 30 min after swallowing oral infusion: lower for sweet < baseline in younger **healthy participants**
			Shubert, Sitaram, and Jadcherla 2016	Basal tone in proximal and distal esophagus: lower for sweet via pacifier < baseline in **preterm infants**
		–	Mulheren et al. 2018	Water swallow screen: failure associated with lower perceived intensity of sweet in older **healthy participants**
		high vs. low	Nagy, Steele, and Pelletier 2014a	Linguapalatal pressures: higher for high sweet (1 M) > low sweet (0.15 M) in younger and older **healthy participants**
		vs. bitter	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: no difference between sweet and bitter, higher in older > younger **healthy participants**; midpalate tongue pressure: higher for sweet > bitter in younger and older **healthy participants**

Pure taste contrasts	*Medium/consistency*	*Contrast*	*Associated papers*	*General findings*
		vs. salty	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude and tongue pressures: no difference between sweet and salty, higher in older > younger **healthy participants**; tongue pressures: no difference between sweet and salty in older and younger **healthy participants**
		vs. ethanol	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: lower for sweet < ethanol, higher in older > younger **healthy participants**; midpalate tongue pressure: higher for sweet > ethanol in younger and older **healthy participants**
		vs. lemon juice	Alves, Fabio, and Dantas 2013	Transit and clearance durations in distal esophagus: lower for sweet < lemon juice, transit and clearance durations in proximal and middle esophagus: no difference between sweet and lemon juice in **healthy participants and patients post-stroke** of mixed ages; residue in middle & distal esophagus: lower for sweet < lemon juice, residue in proximal esophagus: no difference between sweet and lemon juice in **healthy participants** of mixed ages
		vs. Peumas bolus (herbal tea)	Alves, Secaf, and Dantas 2013b	Oral, pharyngeal, and esophageal transit times, clearance times, and residue: no difference between sweet and Peumas boldus in **healthy participants** of mixed ages
			Alves, Fabio, and Dantas 2013	Esophageal transit durations, clearance durations, and residue: no difference between sweet and Peumas boldus in **healthy participants and patients post-stroke** of mixed ages
		vs. sodium-free seltzer	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude and tongue pressures: no difference between sweet and seltzer, higher in older > younger **healthy participants;** tongue pressures: no difference between sweet and seltzer in younger and older **healthy participants**
	liquid delivered to faucial pillar	vs. plain	Kaatzke-McDonald, Post, and Davis 1996	Swallow latency and swallow frequency: no difference between sweet and water in younger **healthy participants**
		vs. saline	Kaatzke-McDonald, Post, and Davis 1996	Swallow latency: no difference between sweet and saline; swallow frequency: lower for sweet < saline in younger **healthy participants**
	liquid plus barium	vs. plain plus barium	Pauloski et al. 2013	Pharyngeal transit time: no difference between sweet and plain barium in mixed-age **healthy participants** and **patients with head and neck cancer**
		vs. lemon juice plus barium	Ayala and Logemann 2010	Oropharyngeal swallow efficiency scores and duration of laryngeal elevation: lower for sweet < lemon juice barium liquid; pharyngeal delay time: longer for sweet > lemon juice barium liquid; base of tongue to posterior pharyngeal wall contact duration, duration of laryngeal closure, and cricopharyngeal opening duration: no difference between sweet and lemon juice barium liquid in younger and older **healthy participants**
	thickened liquid	vs. plain	Miyaoka et al. 2006	Suprahyoid sEMG amplitudes: no difference between sweet and plain thickened liquids in younger **healthy participants**
		vs. salty	Miyaoka et al. 2006	Suprahyoid sEMG amplitudes: no difference between sweet and salty thickened liquids in younger **healthy participants**

Table 2. Continued

Pure taste contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
		vs. umami	Miyaoka et al. 2006	Suprahyoid sEMG amplitudes: no difference between sweet and umami thickened liquids in younger **healthy participants**
	gelatin	vs. plain	Leow et al. 2006	Oral prep time: lower for sweet < plain gelatin; swallowing apnea phase, apnea duration, and mean submental sEMG amplitude: no difference between sweet and plain gelatin in younger **healthy participants**
		vs. bitter	Leow et al. 2006	Oral prep time and duration submental sEMG: lower for sweet < bitter gelatin; swallowing apnea phase, apnea duration, and mean submental sEMG amplitude: no difference between sweet and bitter gelatin in younger **healthy participants**
		vs. salty	Leow et al., 2006	Oral prep time: lower for sweet < salty gelatin; swallowing apnea phase, apnea duration, and mean submental sEMG amplitude: no difference between sweet and salty gelatin in younger **healthy participants**
Bitter	liquid	vs. plain	Chee et al. 2005	Swallowing speed measures: no difference between bitter and water in younger **healthy participants**
			Miura et al. 2009	Submental sEMG total power spectral density, duration, and amplitude: no difference between bitter and water in younger **healthy participants**
			Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude and tongue pressures: no difference between bitter and water, higher in older > younger **healthy participants**; tongue pressures: no difference between bitter and water in younger and older **healthy participants**
			Pelletier and Dhanaraj 2006	Peak lingual pressure and duration to peak pressure: no difference between bitter (0.15 and 30%) and water in younger **healthy participants**
			Todd et al. 2012b	Swallowing apnea duration: no difference between bitter and water, longer for older > younger **healthy participants**; respiratory pattern: no difference between bitter and water in younger and older **healthy participants**
		vs. baseline	Mistry et al. 2006	Pharyngeal MEPs 30 min after swallowing: lower for bitter < baseline in younger **healthy participants**
		–	Mulheren et al. 2018	Water swallow screen: failure associated with higher perceived intensity of bitter in older **healthy participants**
		high vs. low	Nagy, Steele, and Pelletier 2014a	Linguapalatal pressures: higher for high bitter (0.032 M) > low bitter (0.003 M) in younger and older **healthy participants**
		vs. salty	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: no difference between bitter and salty, higher in older > younger **healthy participants**; anterior tongue pressure: lower for bitter < salty in younger and older **healthy participants**
		vs. ethanol	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: lower for bitter < ethanol, higher in older > younger **healthy participants**; tongue pressures: no difference between bitter and ethanol in younger and older **healthy participants**

Pure taste contrasts	*Medium/consistency*	*Contrast*	*Associated papers*	*General findings*
		vs. sodium-free seltzer	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude and tongue pressures: no difference between bitter and seltzer, higher in older > younger **healthy participants**; tongue pressures: no difference between bitter and seltzer in younger and older **healthy participants**
	gelatin	vs. plain	Leow et al. 2006	Submental sEMG duration higher for bitter > plain gelatin; swallowing apnea phase, apnea duration, and mean submental sEMG amplitude: no difference between bitter and plain gelatin in younger **healthy participants**
		vs. salty	Leow et al. 2006	Swallowing apnea phase and duration, oral prep time, and submental sEMG duration and amplitude: no difference between bitter and salty gelatin in younger **healthy participants**
Salty	liquid	vs. plain	Chee et al. 2005	Swallowing speed measures: shorter for salty < water in younger **healthy participants**
			Ding et al. 2003	Submental sEMG amplitude: higher for salty > water; submental sEMG activation: earlier for salty > water with stronger effect in younger > older **healthy participants**; infrahyoid sEMG activation: no difference between salty and water in younger and older **healthy participants,**
			Miura et al. 2009	Submental sEMG total power spectral density, amplitude, and duration: higher for salty > water in younger **healthy participants**
			Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: no difference between salty and water, higher in older > younger **healthy participants**; anterior tongue pressure: higher for salty > water in younger and older **healthy participant**s
			Pelletier and Dhanaraj 2006	Peak lingual pressure: higher for high salty (2.7%) > water, no difference between moderate salty (0.5%) and water; duration to peak pressure: no difference between salty and water in younger **healthy participant**s
			Todd et al. 2012b	Swallowing apnea duration: no difference between salty and water, longer for older > younger **healthy participants**; respiratory pattern: no difference between salty and water in younger and older **healthy participants**
		high vs. low	Nagy, Steele, and Pelletier 2014a	Linguapalatal pressures: higher for high salty (1 M)> low salty (0.034 M) in younger and older **healthy participants**, enhanced effect in supertasters
		vs. ethanol	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: lower for salty < ethanol, higher in older > younger **healthy participants**; anterior tongue pressure: higher for salty > ethanol in younger and older **healthy participants**
		vs. sodium-free seltzer	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: no difference between salty and seltzer, higher in older > younger **healthy participants**; tongue pressures: no difference between salty and seltzer in younger and older **healthy participants**
	liquid plus barium	vs. plain plus barium	Pauloski et al. 2013	Pharyngeal transit time: higher for salty > plain barium in mixed-age **patients with head and neck cancer**

Table 2. Continued

Pure taste contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
	thickened liquid	vs. plain	Miyaoka et al. 2006	Suprahyoid sEMG amplitudes: no difference between salty and plain thickened liquids in younger **healthy participants**
		vs. umami	Miyaoka et al. 2006	Suprahyoid sEMG amplitudes: no difference between salty and umami thickened liquids in younger **healthy participants**
	gelatin	vs. plain	Leow et al. 2006	Submental sEMG duration: higher for salty > plain gelatin; swallowing apnea phase, apnea duration, and mean submental sEMG amplitude: no difference between salty and plain gelatin in younger **healthy participants**
Umami	liquid	vs. plain	Miura et al. 2009	Submental sEMG total power spectral density, duration, and amplitude: no difference between umami and water in younger **healthy participants**
	thickened liquid	vs. plain	Miyaoka et al. 2006	Suprahyoid sEMG amplitudes: no difference between umami and plain thickened liquids in younger **healthy participants**
		high vs. low	Miyaoka et al. 2006	Suprahyoid sEMG amplitudes: higher for high umami (0.05 M)> low umami (0.01 M) in younger **healthy participants**
Sweet-sour mixture	liquid	vs. plain	Steele, van Lieshout, and Pelletier 2012	Tongue movement onset: earlier for sweet-sour mixture > water; tongue movement envelope duration: shorter for sweet-sour mixture < water in younger and older **healthy participants**
			Pelletier & Lawless., 2003	Number of spontaneous swallows after initial swallow: higher for sweet-sour mixture > water; occurrence of penetration or aspiration: no difference between sweet-sour mixture and water in older **patients with neurogenic dysphagia**
	liquid plus barium	vs. plain plus barium	Dietsch, Dorris, et al. 2019	Hyolaryngeal displacement, pharyngeal shortening, and tongue base retraction on CASM: higher for sweet-sour mixture > plain barium in younger **patients with sensory-based dysphagia**
Complex flavor contrasts				
Lemon juice	liquid	vs. plain	Alves, Fabio, and Dantas 2013	Transit and clearance durations in distal esophagus: higher for lemon juice > water in **healthy participants** and **patients post-stroke** of mixed ages
			Alves, Secaf, and Dantas 2013a	Transit and clearance durations in distal esophagus: higher for lemon juice > water; transit and clearance in proximal esophagus: lower for lemon juice < water; residue in middle and distal esophagus: higher for lemon juice > water; transit and clearance durations in oropharynx: no difference between lemon juice and water in **healthy participants** of mixed ages
			Butler, Postma, and Fischer 2004	Swallowing apnea duration: no difference between lemon juice and apple juice (collapsed across trials) and water in younger **healthy participants**
			Nederkoorn, Smulders, and Jansen 1999	Saliva amount and number of swallows: higher for lemon juice > water in younger **healthy participants**
			Palmer et al. 2005	Intramuscular EMG discharge onset time for mylohyoid, anterior digastric, and geniohyoid: lower for lemon juice < water; contraction strength for mylohyoid, anterior digastric, and geniohyoid: higher for lemon juice > water; muscle activity duration, pattern of activation, and swallow onset time: no difference between lemon juice and water in younger **healthy participants**

Complex flavor contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
		vs. baseline	Chiu et al. 2016	Parotid salivary flow: higher for lemon juice > baseline in mixed-age **healthy participants**
		vs. Peumas boldus (herbal tea)	Alves, Fabio, and Dantas 2013	Transit and clearance durations in distal esophagus: higher for lemon juice > Peumas boldus in **healthy participants** and **patients post-stroke** of mixed ages
		vs. apple juice	Butler, Postma, and Fischer 2004	Swallowing apnea duration: no difference between lemon juice and apple juice in younger **healthy participants**
	liquid plus barium	vs. plain plus barium	Pauloski et al. 2013	Pharyngeal transit time: lower for lemon juice < plain barium in mixed-age **patients with head and neck cancer** and **healthy participants**
			Lee et al. 2012	Oral transit time: lower for lemon juice < plain barium; PAS score: lower (less impaired) for lemon juice < plain barium; pharyngeal transit, pharyngeal delay time, and presence of reflex cough: no difference between lemon juice and plain barium in older **patients with dysphagia due to brain injury**
			Logemann et al. 1995	Oral and pharyngeal transit times, pharyngeal delay time: lower for lemon juice < plain barium; oropharyngeal swallow efficiency: higher for lemon juice > plain barium; pharyngeal response, onset of tongue base motion toward the PPW, duration of contact of tongue base to PPW, hyoid movement, laryngeal elevation, laryngeal closure, and cricopharyngeal opening, percent of oral and pharyngeal residue, and percent of aspiration before, during, and after the swallow: no difference between lemon juice and plain liquid barium in older **patients with dysphagia post-stroke** Duration of tongue base to PPW contact: shorter for lemon juice < plain barium; onset of tongue base movement to PPW: later for lemon juice < plain barium; oral and pharyngeal transit times, pharyngeal delay time, pharyngeal response time, duration of hyoid movement, laryngeal elevation, laryngeal closure, and cricopharyngeal opening, percent of oral and pharyngeal residue, percent of aspiration before, during, and after the swallow, and oropharyngeal swallow efficiency: no difference between lemon juice and plain liquid barium in younger **patients with other neurologic etiologies of dysphagia besides stroke**
	liquid plus barium paste	vs. plain barium paste	Cola et al. 2010	Pharyngeal transit times: no difference between lemon juice and plain barium paste in older **patients post-stroke**
			Cola et al. 2012	Pharyngeal transit times: no difference between lemon juice and plain barium paste in older **patients post-stroke**
			Gatto et al. 2013	Oral transit time: no difference between lemon juice and plain barium paste in older **patients post-stroke**
		vs. cold plain barium paste	Cola et al. 2010	Pharyngeal transit times: no difference between lemon juice and cold plain barium paste in older **patients post-stroke**
			Cola et al. 2012	Pharyngeal transit times: no difference between lemon juice and cold plain barium paste in older **patients post-stroke**

Table 2. Continued

Complex flavor contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
			Gatto et al. 2013	Oral transit time: no difference between lemon juice and cold plain barium paste in older **patients post-stroke**
	filter paper	vs. baseline	Abdul Wahab, Jones, and Huckabee 2010	MEP submental amplitudes: no difference between lemon juice filter paper and baseline in younger **healthy participants**
	filter paper	vs. filter paper with no taste	Abdul Wahab, Jones, and Huckabee 2010	MEP submental latency immediate effect: lower for lemon juice filter paper < control condition, late effect: no difference between lemon juice filter paper and control in younger **healthy participants**
Lemonade	liquid	vs. dry swallow	Babaei et al. 2010	BOLD activated voxels in prefrontal, sensory/motor, and total cortical swallowing network regions: higher for lemonade > dry swallow; average % signal increase in cingulate, prefrontal, sensory/motor, and total cortical swallowing network regions: higher for lemonade > dry swallow in younger **healthy participants**
		vs. plain	Babaei et al. 2010	BOLD average % signal increase in cingulate, prefrontal, sensory/motor, and total cortical swallowing network regions: higher for lemonade > water in younger **healthy participants**
Lemon-lime	dissolvable strip	vs. unflavored dissolvable strip	Dietsch, Pelletier, and Solomon 2018	Salivary amount: higher for lemon-lime > unflavored dissolvable strip in older **healthy participants and persons with xerostomia and/or dysphagia**
Ginger ale	liquid	vs. plain	Krival and Bates 2012	Peak linguapalatal pressures and rising and release phase durations at anterior, middle, and posterior bulbs: higher for ginger ale > water in younger **healthy participants**
		vs. club soda	Krival and Bates 2012	Peak linguapalatal pressure at middle and posterior bulbs and rising and release phase durations at middle bulb: higher for ginger ale > club soda in younger **healthy participants**
Apple juice	liquid	vs. plain	Hiss et al. 2004	Swallowing apnea onset: no difference between apple juice and water in younger and older **healthy participants**
Glazed donut	dissolvable strip	vs. unflavored dissolvable strip	Dietsch, Pelletier, and Solomon 2018	Salivary amount: higher for glazed donut vs. unflavored dissolvable strip in older **healthy participants and persons with xerostomia and/or dysphagia**
Peumas boldus (herbal tea)	liquid	vs. plain	Alves, Fabio, and Dantas 2013	Esophageal transit and clearance durations and residue: no difference between Peumas boldus and water in **healthy participants and patients post-stroke** of mixed ages
Chocolate	liquid	vs. dry swallow	Babaei et al. 2010	BOLD activated voxels in prefrontal, sensory/motor, and total cortical swallowing network regions: higher for chocolate > dry swallow; average % signal increase in cingulate, prefrontal, sensory/motor, and total cortical swallowing network regions: higher for chocolate > dry swallow in younger **healthy participants**
		vs. plain	Babaei et al. 2010	BOLD average % signal increase in cingulate, prefrontal, sensory/motor, and total cortical swallowing network regions: higher for chocolate > water in younger **healthy participants**

Complex flavor contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
Popcorn	liquid	vs. dry swallow	Babaei et al. 2010	BOLD activated voxels in prefrontal, sensory/motor, and total cortical swallowing network regions: higher for popcorn > dry swallow; average % signal increase in cingulate, prefrontal, sensory/motor, and total cortical swallowing network regions: higher for popcorn > dry swallow in younger **healthy participants**
		vs. plain	Babaei et al. 2010	BOLD average % signal increase in cingulate, prefrontal, sensory/motor, and total cortical swallowing network regions: higher for popcorn > water in younger **healthy participants**
	dissolvable strip	vs. unflavored dissolvable strip	Dietsch, Pelletier, and Solomon 2018	Salivary amount: higher for buttered popcorn > unflavored dissolvable strip in older **healthy participants and persons with xerostomia**
Milk	liquid	vs. plain	Butler et al. 2011	PAS score: higher (more impaired) for whole milk > skim milk and water, no difference between whole and 2% milk in older **healthy participants**
		vs. milk + aspartame stock	de Wijk, Wulfert, and Prinz 2006	Oral transit time and tongue movement: no difference between unsweetened and sweetened 3% milk in younger **healthy participants**
Cottage cheese + taste/flavor		vs. plain cottage cheese	Ding et al. 2003	Submental and infrahyoid sEMG activation: earlier for cottage cheese + taste/flavor (sweet, salty, lemon juice) > plain cottage cheese, stronger effect in younger > older **healthy participants**
Mint	dissolvable strip	vs. unflavored dissolvable strip	Dietsch, Pelletier, and Solomon 2018	Salivary amount: higher for icy mint > unflavored dissolvable strip in older **healthy participants** and **persons with xerostomia**
		vs. rest	Brady et al. 2016	Number of swallows: higher for spearmint dissolvable strip > rest in mixed age group of **patients with known or suspected dysphagia**
Ethanol	liquid	vs. plain	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: higher for ethanol > water, higher in older > younger **healthy participants**; tongue pressures: no difference between ethanol and water in younger and older **healthy participants**
		vs. sodium-free seltzer	Nagy, Steele, and Pelletier 2014b	Submental sEMG amplitude: higher for ethanol > seltzer, higher in older > younger **healthy participants**; tongue pressures: no difference between ethanol and seltzer in younger and older **healthy participants**
	liquid plus barium	vs. plain plus barium	Todd et al. 2012a	Swallowing apnea duration: higher for ethanol > plain barium, longer for older > younger **healthy participants**
Complex flavors + additional sensory components				
Flavor + olfaction	Lemon juice on filter paper + retronasal lemon odor	vs. baseline	Abdul Wahab, Jones, and Huckabee 2010	MEP submental amplitudes immediate effect: no difference between lemon juice + lemon odor and baseline, late effect at 30-, 60-, and 90-min post-stimulation: higher for lemon juice + lemon odor > baseline in younger **healthy participants**
	Lemon juice on filter paper + retronasal lemon odor	vs. water filter paper + retronasal nebulized water	Abdul Wahab, Jones, and Huckabee 2010	MEP submental latency: no difference between lemon juice + lemon odor and control in younger **healthy participants**

Table 2. Continued

Complex flavor contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
		vs. baseline	Abdul Wahab, Jones, and Huckabee 2011	Submental sEMG amplitude and duration: no difference between lemon juice + lemon odor and baseline, higher amplitude for lemon juice + lemon odor > baseline 60 min post-stimulation; glossopalatal pressure and duration: higher anterior-glossopalatal pressure after lemon juice + lemon odor stimulation > baseline, lower mid-glossopalatal pressure after lemon juice + lemon odor stimulation < baseline 30 min post-stimulation; anterior and midglossopalatal duration lower for lemon juice + lemon odor < baseline 60 min post-stimulation; pharyngeal pressure: lower for lemon juice + lemon odor < baseline in hypopharynx, no difference in pressure recording of the upper esophageal sphincter, no delayed effects on pharyngeal pressures in younger **healthy participants**
Flavor + tactile + temperature	Cold lemon juice probe	vs. sham	Sciortino et al. 2003	Swallow latency times: quicker for cold probe dipped in lemon juice rubbed on faucial pillars < sham; subemental EMG duration: no difference between cold probe dipped in lemon juice rubbed on faucial pillars and sham condition in younger and older **healthy participants**
		vs. lemon juice probe	Sciortino et al. 2003	Swallow latency times and submental EMG duration: no difference between cold probe dipped in lemon juice rubbed on faucial pillars and body temperature probe dipped in lemon juice rubbed on faucial pillars in younger and older **healthy participants**
Flavor + tactile	Lemon juice probe	vs. sham	Sciortino et al. 2003	Swallow latency times and submental EMG duration: no difference between body temperature probe dipped in lemon juice rubbed on faucial pillars and sham condition in younger and older **healthy participants**
Flavor + volume	Lemon juice at different volumes	vs. plain	Gurgor et al. 2017	Number of swallows: higher for lemon juice > water; apnea duration lemon juice (15 and 20 ml) < water; submandibular EMG amplitude higher for lemon juice (10 ml) > water; EMG duration: higher for lemon juice) (15 and 20 ml) > water: orbicularis oculi EMG duration: higher for lemon juice (10 and 15 ml) > water in **healthy participants** of mixed ages
	Apple juice at different volumes	vs. plain at matched volumes	Hiss et al. 2004	Swallowing apnea onset: no difference between apple juice (5 and 20 ml) and water (5 and 20 ml) in younger and older **healthy participants**
Flavor + temperature	Cold lemon juice barium paste	vs. room temp plain barium paste	Cola et al. 2010	Pharyngeal transit times: lower for cold lemon juice < room temp plain barium paste in older **patients post-stroke**
			Cola et al. 2012	Pharyngeal transit times: lower for cold lemon juice < room temp plain barium paste in nonrandomized sequence, no difference in randomized sequence in older **patients post-stroke**
			Gatto et al. 2013	Oral transit time: shorter for cold lemon juice < plain barium paste in older **patients post-stroke**
		vs. room temp lemon juice barium paste	Cola et al. 2010	Pharyngeal transit times: lower for cold lemon juice < room temp lemon juice barium paste in older **patients post-stroke**

Complex flavor contrasts	***Medium/consistency***	***Contrast***	***Associated papers***	***General findings***
			Cola et al. 2012	Pharyngeal transit times: lower for cold lemon juice < room temp lemon juice barium paste in nonrandomized sequence, no difference in randomized sequence in older **patients post-stroke**
			Gatto et al. 2013	Oral transit time: no difference between cold lemon juice and. plain barium paste in older **patients post-stroke**
		vs. cold plain barium paste	Cola et al. 2010	Pharyngeal transit times: lower for cold lemon juice < cold plain barium paste in older **patients post-stroke**
			Cola et al. 2012	Pharyngeal transit times: lower for cold lemon juice < cold plain barium paste in nonrandomized sequence, no difference in randomized sequence in older **patients post-stroke**
			Gatto et al. 2013	Oral transit time: no difference between cold lemon juice vs. cold plain barium paste in older **patients post-stroke**
	Cold lemon juice barium liquid	vs. lemon juice barium liquid	Ayala and Logemann 2010	Oropharyngeal swallow efficiency scores, pharyngeal delay time, base of tongue to posterior pharyngeal wall contact duration, duration of laryngeal elevation, duration of laryngeal closure, and cricopharyngeal opening duration: no difference between cold lemon juice barium liquid vs. lemon juice barium liquid in younger and older **healthy participants**
		vs. sweet barium liquid	Ayala and Logemann 2010	Oropharyngeal swallow efficiency scores: higher for cold lemon juice barium liquid > sweet barium liquid; pharyngeal delay time: shorter for cold lemon juice barium liquid < sweet barium liquid; base of tongue to posterior pharyngeal wall contact duration, duration of laryngeal elevation, duration of laryngeal closure, and cricopharyngeal opening duration: no difference between cold lemon juice barium liquid and sweet barium liquid in younger and older **healthy participants**

Note. BOLD = blood-oxygen-level dependent; CASM = Computational Analysis of Swallowing Mechanics; EMG = electromyography; MSBImP = Modified Barium Swallow Impairment ProfileTM; MEP = motor evoked potential; PAS = Penetration Aspiration Scale; sEMG = surface electromyography.

Table 3. Results of studies examining the effect of taste on swallowing-related outcomes by outcome measure.

Outcome	***Specific Measure***	***Associated papers***	***General findings***
Swallowing physiology			
Morphometry/ kinematics	CASM (May et al. 2017)	Dietsch, Dorris, et al. 2019	Hyolaryngeal displacement, pharyngeal shortening, and tongue base retraction on CASM: higher for sour > plain and higher for sweet-sour > plain; hyolaryngeal displacement and tongue base retraction: higher for sweet-sour > sour in younger **patients with sensory-based dysphagia**
	Change in tongue movements at different times of swallow	de Wijk, Wulfert, and Prinz 2006	No difference between unsweetened, low, and high sweetness concentrations of milk in younger **healthy participants**
	Hyoid range of motion (horizontal and vertical)	Humbert et al. 2012	No difference between sour and water in younger **healthy participants**
	Laryngeal vertical movement	Humbert et al. 2012	No difference between sour and water in younger **healthy participants**
Timing measures	Tongue movement onset and duration	Steele, van Lieshout, and Pelletier 2012	Tongue movement onset: earlier for sweet-sour mixture > water; tongue movement envelope duration: shorter for sweet-sour mixture < water in younger and older **healthy participants**
	Oral transit time	Alves, Secaf, and Dantas 2013b	No difference between Peumas bolus (herbal tea) and sweet in **healthy participants** of mixed ages
		Alves, Secaf, and Dantas 2013a	No difference between lemon juice and water in **healthy participants** of mixed ages
		de Wijk, Wulfert, and Prinz 2006	No difference between unsweetened, low, and high sweetness concentrations of milk in younger **healthy participants**
		Gatto et al. 2013	Shorter for cold lemon juice barium paste < plain barium paste in older **patients post-stroke**
		Lee et al. 2012	Shorter for lemon juice < plain barium in older **patients with dysphagia due to brain injury**
		Logemann et al. 1995	Shorter for lemon juice liquid barium < plain barium in older **patients with dysphagia post-stroke;** no difference between lemon juice liquid barium and plain barium in younger **patients with neurogenic dysphagia besides stroke**
	Swallowing velocity subdomain of the water swallow test	Chee et al. 2005	Shorter for sour, sweet, and salty < plain, no difference between salty and plain in younger **healthy participants**
	Oral clearance time	Alves, Secaf, and Dantas 2013b	No difference between Peumas bolus (herbal tea) and sweet in **healthy participants** of mixed ages
		Alves, Secaf, and Dantas 2013a	No difference between lemon juice and water in **healthy participants** of mixed ages
	Duration of velopharyngeal closure	Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	Swallow latency	Kaatzke-McDonald, Post, and Davis 1996	No difference between saline, glucose, or water delivered to the faucial pillar in younger **healthy participants**
		Sciortino et al. 2003	Shorter for cold probe dipped in lemon juice rubbed on faucial pillars < sham condition; no difference between cold probe dipped in lemon juice rubbed on faucial pillars and body temperature probe dipped in lemon juice rubbed on faucial pillars or body temperature probe dipped in lemon juice rubbed on faucial pillars and sham condition in younger and older **healthy participants**

Outcome	***Specific Measure***	***Associated papers***	***General findings***
	Pharyngeal response time	Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	Pharyngeal transit time	Alves, Secaf, and Dantas 2013b	No difference between Peumas bolus (herbal tea) and sweet in **healthy participants** of mixed ages
		Alves, Secaf, and Dantas 2013a	No difference between lemon juice and water in **healthy participants** of mixed ages
		Cola et al. 2010	Shorter for cold lemon juice barium paste < plain barium paste, cold lemon juice barium paste < lemon juice barium paste, and cold lemon juice barium paste < cold plain barium paste in older **patients post-stroke**
		Cola et al. 2012	Shorter for cold lemon juice barium paste < plain barium paste, cold lemon juice barium paste < lemon juice barium paste, and cold lemon juice barium paste < cold plain barium paste in nonrandomized sequence, no difference in randomized sequence in older **patients post-stroke**
		Lee et al. 2012	No difference for lemon juice < plain barium in older **patients with dysphagia due to brain injury**
		Logemann et al. 1995	Shorter for lemon juice liquid barium < plain barium in older **patients with dysphagia post-stroke;** no difference between lemon juice liquid barium and plain barium in younger **patients with neurogenic dysphagia besides stroke**
		Pauloski et al. 2013	Shorter for lemon juice < plain barium, no difference between sweet and plain barium in mixed-age **patients with head-neck cancer and healthy participants**; higher for salty > plain barium in **patients with head and neck cancer**
	Pharyngeal delay time	Ayala and Logemann 2010	No difference between cold lemon juice barium liquid and lemon juice barium liquid; shorter for cold lemon juice barium liquid < sweet barium liquid and lemon juice barium liquid < sweet barium liquid in **y**ounger and older **healthy participants**
		Lee et al. 2012	No difference between lemon juice and plain barium in older **patients with dysphagia due to brain injury**
		Logemann et al. 1995	Shorter for lemon juice liquid barium < plain barium in older **patients with dysphagia post-stroke;** no difference between lemon juice liquid barium and plain barium in younger **patients with neurogenic dysphagia besides stroke**
	Hyoid reaction time	Humbert et al. 2012	No difference between sour and water in younger **healthy participants**
	Hyoid ramp time	Humbert et al. 2012	No difference between sour and water in younger **healthy participants**
	Hyoid duration at peak elevation	Humbert et al. 2012	No difference between sour and water in younger **healthy participants**
	Hyoid duration at anterior position	Humbert et al. 2012	No difference between sour and water in younger **healthy participants**
	Duration of hyoid movement	Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	Laryngeal elevation duration	Ayala and Logemann 2010	No difference between cold lemon juice barium liquid and lemon juice barium liquid or cold lemon juice barium liquid and sweet barium liquid; longer duration for lemon juice barium liquid > sweet barium liquid in younger and older **healthy participants**
		Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**

Table 3. Continued

Outcome	***Specific Measure***	***Associated papers***	***General findings***
	Onset of base of tongue motion toward the PPW	Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke**; later for lemon juice liquid barium > plain barium in younger **patients with neurogenic dysphagia besides stroke**
	Base of tongue to posterior pharyngeal wall contact duration	Ayala and Logemann 2010	No difference between cold lemon juice barium liquid and lemon juice barium liquid, cold lemon juice barium liquid and sweet barium liquid, or lemon juice barium liquid and sweet barium liquid in younger and older **healthy participants**
		Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke;** shorter for lemon juice liquid barium < plain barium in younger **patients with neurogenic dysphagia besides stroke**
	Pharyngeal clearance time	Alves, Secaf, and Dantas 2013b	No difference between Peumas bolus (herbal tea) and sweet in **healthy participants** of mixed ages
		Alves, Secaf, and Dantas 2013a	No difference between lemon juice and water in **healthy participants** of mixed ages
	Laryngeal vestibule closure duration	Humbert et al. 2012	No difference between sour and water in younger **healthy participants**
		Ayala and Logemann 2010	No difference between cold lemon juice barium liquid and. lemon juice barium liquid, cold lemon juice barium liquid and sweet barium liquid, or lemon juice barium liquid and sweet barium liquid in younger and older **healthy participants**
		Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	Swallowing apnea duration	Butler, Postma, and Fischer 2004	No difference between apple juice and lemon juice collapsed across trials and water in younger **healthy participants**
		Gurgor et al. 2017	Shorter for lemon juice (15 and 20 ml) < water in **healthy participants** of mixed ages
		Leow et al. 2006	No difference between sour, sweet, bitter, salty, and plain gelatin in younger **healthy participants**
		Plonk et al. 2011	Longer for sour > water in older and younger **healthy participants**, enhanced effect in supertasters
		Todd et al. 2012b	No difference between sweet, salty, bitter, and water, longer in older > younger **healthy participants**
		Todd et al. 2012a	Longer for ethanol > plain barium, no difference between sour and plain barium, longer in older > younger **healthy participants**
	Swallowing apnea phase	Leow et al. 2006	No difference between sour, sweet, bitter, salty, and plain gelatin in younger **healthy participants**
	Swallow apnea onset	Hiss et al. 2004	No difference between different volumes of apple juice and water in younger and older **healthy participants**
	Cricopharyngeal opening duration	Ayala and Logemann 2010	No difference between cold lemon juice barium liquid and lemon juice barium liquid, cold lemon juice barium liquid and sweet barium liquid, or lemon juice barium liquid and sweet barium liquid in younger and older **healthy participants**
		Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	Esophageal transit time	Alves, Secaf, and Dantas 2013b	No difference between Peumas bolsus (herbal tea) and sweet in **healthy participants** of mixed ages

Outcome	***Specific Measure***	***Associated papers***	***General findings***
	Esophageal clearance time	Alves, Fabio, and Dantas 2013	Longer for lemon juice > Peumas boldus (herbal tea), lemon juice > water, and lemon juice > sweet in distal esophagus, no difference in proximal or middle esophagus in **healthy participants and patients post-stroke** of mixed ages
		Alves, Secaf, and Dantas 2013a	Longer for water > lemon juice in proximal esophagus; longer for lemon juice > water in distal esophagus in **healthy participants** of mixed ages
		Alves, Secaf, and Dantas 2013b	No difference between Peumas boldus (herbal tea) and sweet in **healthy participants** of mixed ages
		Alves, Fabio, and Dantas 2013	Longer for lemon juice > Peumas boldus (herbal tea), lemon juice > water, and lemon juice > sweet in distal esophagus, no difference in proximal or middle esophagus in **healthy participants and patients post-stroke** of mixed ages
		Alves, Secaf, and Dantas 2013a	Longer for water > lemon juice in proximal esophagus; Longer for lemon juice > water in distal esophagus in **healthy participants** of mixed ages
Pressure measures	Linguapalatal bulbs	Abdul Wahab, Jones, and Huckabee 2011	Anterior glossopalatal pressure and duration: higher for lemon juice + lemon odor > baseline; midglossopalatal pressure: lower for lemon juice + lemon odor < baseline 30 min post-stimulation; anterior and midglossopalatal duration lower for lemon juice + lemon odor < baseline 60 min post-stimulation in younger **healthy participants**
		Krival and Bates 2012	Higher for ginger ale > water at anterior, middle, and posterior bulbs; higher for ginger ale > club soda at middle & posterior bulbs; higher for club soda > water at posterior bulb only in younger **healthy participants**
		Nagy, Steele, and Pelletier 2014a	Higher for high concentrations > low concentration of sweet, sour, salty, and bitter liquid stimuli in younger and older **healthy participants**
		Nagy, Steele, and Pelletier 2014b	Higher for sour > water, sour > bitter, sour > ethanol, salty > water, salty > bitter, salty > ethanol at anterior bulb; higher for sweet > water, sweet > ethanol, sweet > bitter at midpalate bulb in younger and older **healthy participants**
		Pelletier and Dhanaraj 2006	Peak pressure: higher for high sour (2.7%) > water, moderate sweet (10%) > water, high salty (2.7%) > water, sour + barium > water, no difference between moderate sour (0.15%), high sweet (30%), moderate salty (0.5%) vs. water; duration to peak pressure: no difference between tastes in younger **healthy participants**
		Pelletier and Steele 2014	Higher for high sour (2.7%)> water at anterior bulb in older and younger **healthy participants**
	High resolution impedance manometry	Shubert, Sitaram, and Jadcherla 2016	Response latency to first pharyngeal swallow: lower for sweet < no taste via pacifier; esophageal motility, respiratory rhythm, and impedance transit: no difference between sweet and no taste; basal tone in proximal and distal esophagus: lower with sweet via pacifier < baseline in **preterm infants**
	Transnasal manometry	Abdul Wahab, Jones, and Huckabee 2011	Pharyngeal pressure: lower for lemon juice + lemon odor < baseline in hypopharynx, no difference in pressure recording of the upper esophageal sphincter, no delayed effects on pharyngeal pressures in younger **healthy participants**
Surface electromyographic measures	Submental	Abdul Wahab, Jones, and Huckabee 2011	Amplitude and duration: no difference between lemon juice + lemon odor stimulation vs.baseline, higher amplitude for lemon juice + lemon odor > baseline 60 min post-stimulation in younger **healthy participants**

Table 3. Continued

Outcome	***Specific Measure***	***Associated papers***	***General findings***
		Ding et al. 2003	Activation: earlier for sour > water, sweet > water, and salty > water; amplitude higher for salty > water with stronger effect in younger > older **healthy participants**, no difference between sweet and water and sour and water in younger and older **healthy participants**,
		Leow et al. 2006	Oral prep time: shorter for sour < bitter gelatin, sour < salty, sweet < plain, sweet < salty, higher for bitter > sweet, no difference between remaining contrasts; duration of activation: shorter for sour < bitter gelatin and sweet < bitter, longer for bitter > plain and salty > plain, no difference between remaining contrasts; peak amplitude higher for sour > all boluses (bitter, sweet, salty, plain) in younger **healthy participants**
		Miura et al. 2009	Total power spectral density, duration, and amplitude: higher and longer for sour > water and salty > water, no difference between water and sweet, bitter, and umami in younger **healthy participants**
		Nagy, Steele, and Pelletier 2014b	Amplitudes: higher for sour > water, sour > seltzer, sour > sweet, sour > bitter, sour > salty, ethanol > water, ethanol > seltzer, ethanol > sweet, ethanol > bitter, ethanol > salty, no difference between sour and ethanol, and higher in older > younger **healthy participants**
		Pelletier and Steele 2014	Amplitudes: higher for intense sour > water in younger and older **healthy participants**
		Sciortino et al. 2003	Duration: no difference between cold probe dipped in lemon juice rubbed on faucial pillars, body temperature probe dipped in lemon juice rubbed on faucial pillars, or sham in younger and older **healthy participants**
	Submandibular	Gurgor et al. 2017	Number of swallows: higher for lemon juice > water; submandibular EMG amplitude: higher for lemon juice (10 ml) > water; EMG duration: longer for lemon juice) (15 and 20 ml) > water: orbicularis oculi EMG duration: higher for lemon juice (10 and 15 ml) > water in **healthy participants** of mixed ages
	Suprahyoid	Miyaoka et al. 2006	Amplitudes: higher for high concentrations > high concentrations of thickened sweet, salty, and umami, higher for all tastes > thickened water, no difference between tastes in younger **healthy participants**
	Infrahyoid	Ding et al. 2003	Activation: earlier for sweet > water and sour > water with stronger effect in younger > older **healthy participants**, no difference between salty and water in younger and older **healthy participants**
	Digastric	Nederkoorn, Smulders, and Jansen 1999	Number of swallows: higher for lemon juice > water in younger **healthy participants**
Intramuscular electromyographic measures	Mylohyoid, anterior digastric, geniohyoid	Palmer et al. 2005	Discharge onset time: shorter for lemon juice < water; muscle contraction strength: longer for lemon juice > water; muscle activity duration, pattern of activation, and swallow onset time: no difference between lemon juice and water in younger **healthy participants**
Perceptual ratings	MBSImP (Martin-Harris et al. 2008)	Dietsch, Dorris, et al. 2019	Pharyngoesophageal opening: lower (less impaired) for sour < plain barium in younger **patients with sensory-based dysphagia**
Swallowing frequency	Number of spontaneous swallows	Kaatzke-McDonald, Post, and Davis 1996	Higher for saline > water to the faucial pillar, no difference between saline and glucose or glucose and water in younger **healthy participants**
		Mulheren, Kamarunas, and Ludlow 2016	Higher for sour > water and sour > sweet, no difference between sweet and water in **healthy participants** of mixed ages

Outcome	***Specific Measure***	***Associated papers***	***General findings***
		Brady et al. 2016	Higher for spearmint dissolvable strip > rest in mixed age group of **patients with known or suspected dysphagia**
	Number of spontaneous swallows after initial swallow	Pelletier and Lawless 2003	Higher for sour > water, sour > sweet-sour, sweet-sour > water in older **patients with neurogenic dysphagia**
Respiratory measures	Respiratory phase patterns	Todd et al. 2012b	No difference between sweet, salty, bitter, and water in younger and older **healthy participants**
Bolus transit efficiency	Penetration-Aspiration Scale (Rosenbek et al. 1996)	Butler et al. 2011	Higher (more impaired) for whole milk > skim milk and water, no difference between whole and 2% milk in older **healthy participants**
		Dietsch, Dorris, et al. 2019	Lower (less impaired) for sour < plain barium in younger **patients with sensory-based dysphagia**
	Occurrence of penetration/ aspiration	Pelletier and Lawless 2003	Lower for sour < water; no difference between sweet-sour and water in older **patients with neurogenic dysphagia**
	% of aspiration before, during, and after the swallow	Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	% of total bolus remaining	Alves, Secaf, and Dantas 2013b	Oral, pharyngeal, and esophageal: no difference between Peumas boldus (herbal tea) and sweet in **healthy participants** of mixed ages
		Alves, Fabio, and Dantas 2013	Middle & distal esophagus: higher for lemon juice > Peumas boldus (herbal tea), lemon juice > water, and lemon juice > sweet in **healthy participants**; no difference between stimuli in proximal esophagus or in **patients post-stroke** of mixed ages
		Alves, Secaf, and Dantas 2013a	Oropharyngeal: no difference between lemon juice and water; middle and distal esophagus: higher for lemon juice > water; proximal esophagus: no difference between lemon juice and water in **healthy participants** of mixed ages
	% of oral residue	Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	% of pharyngeal residue	Logemann et al. 1995	No difference between lemon juice liquid barium and plain barium in older **patients with dysphagia post-stroke** or younger **patients with neurogenic dysphagia besides stroke**
	3 oz water challenge	Mulheren et al. 2018	Water swallow screen: failure associated with lower perceived intensity of sweet and higher perceived intensity of bitter in older **healthy participants**
	Oropharyngeal swallow efficiency (% bolus swallowed/total oropharyngeal transit time)	Ayala and Logemann 2010	No difference between cold lemon juice barium liquid and lemon juice barium liquid; higher for cold lemon juice barium liquid > sweet barium liquid and lemon juice barium liquid > sweet barium liquid in younger and older **healthy participants**
		Logemann et al. 1995	Higher for lemon juice liquid barium > plain barium in older **patients with dysphagia post-stroke;** no difference between lemon juice liquid barium and plain barium in younger **patients with neurogenic dysphagia besides stroke**

Table 3. Continued

Outcome	***Specific Measure***	***Associated papers***	***General findings***
Neuroimaging	fMRI	Babaei et al. 2010	BOLD activated voxels in prefrontal, sensory/motor, and total cortical swallowing network regions: higher for flavors (chocolate, popcorn, lemonade)> dry swallow; average % signal increase: higher for flavors > dry swallow and flavors > water in younger **healthy participants**
		Humbert and Joel 2012	BOLD signal in M1: lower for sour < water; BOLD signal in SMA: higher for sour > water in younger and older **healthy participants**
	fNIRS	Mulheren, Kamarunas, and Ludlow 2016	Hemodynamic response 2-7 sec after bolus delivery: no difference between sour, sweet, water; hemodynamic response 17-22 sec after bolus delivery with addition of slow water infusion: higher for sour > water in **healthy participants** of mixed ages
Neurostimulation	Motor-evoked potentials	Elshukri et al. 2016	Pharyngeal: Higher for weak sour (.5% w/v citric acid)> mineral water at least 15 min after trials in younger **healthy participants**
		Mistry et al. 2006	Pharyngeal: lower for bitter < baseline and sweet < baseline 30 min after swallowing oral infusions in younger **healthy participants**
		Abdul Wahab, Jones, and Huckabee 2010	Submental amplitude: no difference between lemon juice filter paper and baseline, no immediate effect difference between lemon juice filter paper + lemon odor and baseline, higher for lemon juice filter paper + lemon odor > baseline 30-, 60-, and 90-min post-stimulation; latency: immediate effect lower for lemon juice filter paper < control, no difference in late effect in younger **healthy participants**
Salivary measures	Whole mouth flow	Dietsch, Pelletier, and Solomon 2018	Higher for flavored dissolvable strips (buttered popcorn, glazed donut, lemon-line, icy mint) > unflavored dissolvable strip in older **healthy participants and persons with xerostomia and/or dysphagia**
		Nederkoorn, Smulders, and Jansen 1999	Higher for lemon juice > water in younger **healthy participants**
	Parotid flow	Chiu et al. 2016	Higher for lemon juice > baseline in mixed-age **healthy participants**

Table 4.

Table 4. Ratings of quality and bias.

	Potential sources of bias per Cochrane criteria								
Study	*Selection*	*Reporting*	*Performance*	*Detection*	*Attrition*	*NIH quality scale form*	*NIH scores (yes/no/NR)*	*NIH quality ratio*	*Overall assessment*
Abdul Wahab, Jones, and Huckabee 2010	–	–	–	+	–	Cross-sectional	12/1/0	12	fair
Abdul Wahab, Jones, and Huckabee 2011	–	–	–	+	+	Cross-sectional	11/2/1	5.5	fair
Alves, Fabio, and Dantas 2013	+	–	–	+	–	Cross-sectional	10/4/0	2.5	fair
Alves, Secaf, and Dantas 2013a	–	–	–	+	–	Cross-sectional	10/4/0	2.5	fair
Alves, Secaf, and Dantas 2013b	–	–	–	+	–	Cross-sectional	10/4/0	2.5	fair
Ayala and Logemann 2010	–	–	–	–	–	Cross-sectional	13/1/0	13	fair
Babaei et al. 2010	–	–	+	–	–	Cross-sectional	12/2/0	6	fair
Brady et al. 2016	+	–	–	+	+	Cross-sectional	7/6/1	1.2	fair
Butler, Postma, and Fischer 2004	–	–	–	+	+	Cross-sectional	12/1/1	12	fair
Butler et al. 2011	–	–	+	+	–	Controlled intervention	4/3/7	1.3	fair
Chee et al. 2005	–	–	–	–	+	Cross-sectional	11/3/0	3.7	fair
Chiu et al. 2016	–	–	–	–	–	Controlled intervention	4/4/6	1	fair
Cola et al. 2010	–	–	–	+	+	Cross-sectional	9/4/1	2.3	fair
Cola et al. 2012	–	–	–	+	+	Cross-sectional	10/3/1	3.3	fair
de Wijk, Wulfert, and Prinz 2006	–	–	+	+	+	Cross-sectional	10/3/1	3.3	fair
Dietsch, Pelletier, and Solomon 2018	–	–	–	+	+	Cross-sectional	12/1/1	12	fair
Dietsch, Dorris, et al. 2019	–	–	–	–	–	Cross-sectional	12/2/0	6	fair
Ding et al. 2003	–	–	–	–	–	Controlled intervention	8/1/5	8	fair
Elshukri et al. 2016	–	–	+	+	–	Controlled intervention	5/4/5	1.3	fair
Gatto et al. 2013	–	–	–	+	+	Cross-sectional	10/3/1	3.3	fair
Gurgor et al. 2017	–	–	+	+	–	Cross-sectional	10/4/0	2.5	fair
Hiss et al. 2004	–	–	–	+	+	Cross-sectional	12/1/1	12	fair
Humbert and Joel 2012	–	–	–	+	–	Cross-sectional	11/3/0	3.7	fair
Humbert et al. 2012	–	–	–	–	–	Cross-sectional	12/2/0	6	fair
Kaatzke-McDonald, Post, and Davis 1996	+	–	–	+	–	Cross-sectional	10/3/1	3.3	fair
Krival and Bates 2012	–	–	–	+	–	Cross-sectional	7/4/3	1.8	fair

Table 4. Continued.

Study	*Potential sources of bias per Cochrane criteria*					*NIH quality scale form*	*NIH scores (yes/no/NR)*	*NIH quality ratio*	*Overall assessment*
	Selection	*Reporting*	*Performance*	*Detection*	*Attrition*				
Lee et al. 2012	+	–	–	–	–	Cross-sectional	5/6/3	8.3	fair
Leow et al. 2006	–	–	–	+	–	Cross-sectional	11/3/0	3.7	fair
Logemann et al. 1995	–	–	–	+	+	Cross-sectional	12/1/1	12	fair
Mistry et al. 2006	–	–	–	+	–	Cross-sectional	11/2/1	5.5	fair
Miura et al. 2009	–	–	–	+	–	Cross-sectional	11/3/0	3.7	fair
Miyaoka et al. 2006	+	–	–	+	–	Cross-sectional	5/6/3	8.3	fair
Mulheren, Kamarunas, and Ludlow 2016	–	–	–	+	–	Cross-sectional	12/2/0	6	fair
Mulheren et al. 2018	–	–	–	+	–	Cross-sectional	8/3/3	2.7	fair
Nagy, Steele, and Pelletier 2014a	–	–	–	+	–	Cross-sectional	8/3/3	2.7	fair
Nagy, Steele, and Pelletier 2014b	–	–	–	+	–	Cross-sectional	11/3/0	3.7	fair
Nederkoorn, Smulders, and Jansen 1999	–	–	+	+	–	Cross-sectional	4/8/2	0.5	poor
Palmer et al. 2005	–	–	–	+	–	Cross-sectional	12/2/0	6	fair
Pauloski et al. 2013	+	–	+	+	–	Cross-sectional	4/8/2	0.5	poor
Pelletier and Lawless 2003	–	–	–	+	–	Cross-sectional	12/2/0	6	fair
Pelletier and Dhanaraj 2006	–	–	–	+	–	Cross-sectional	12/2/0	6	fair
Pelletier and Steele 2014	–	–	–	+	+	Cross-sectional	12/1/1	12	fair
Plonk et al. 2011	–	–	–	+	–	Cross-sectional	8/3/3	2.7	fair
Sciortino et al. 2003	–	–	–	+	–	Cross-sectional	12/1/1	12	fair
Shubert, Sitaram, and Jadcherla 2016	–	–	+	+	–	Cross-sectional	9/4/1	2.3	fair
Steele, van Lieshout, and Pelletier 2012	–	–	+	+	–	Cross-sectional	7/4/3	1.8	fair
Todd et al. 2012a	–	–	–	+	–	Cross-sectional	11/3/0	3.7	fair
Todd et al. 2012b	–	–	–	+	–	Cross-sectional	11/3/0	3.7	fair

Note. + high risk of bias; - low risk of bias.