University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Special Education and Communication Disorders Faculty Publications

Department of Special Education and Communication Disorders

2014

The Effect of Barium on Perceptions of Taste Intensity and Palatability

Angela M. Dietsch
Walter Reed National Military Medical Center, angela.dietsch@unl.edu

Nancy Pearl Solomon
Walter Reed National Military Medical Center

Catriona M. Steele
Toronto Rehabilitation Institute

Cathy A. Pelletier
University of Arkansas for Medical Sciences

Dysphagia (2014) 29:96–108
DOI 10.1007/s00455-013-9487-4

ORIGINAL ARTICLE

The Effect of Barium on Perceptions of Taste Intensity and Palatability

Angela M. Dietsch · Nancy Pearl Solomon · Catriona M. Steele · Cathy A. Pelletier

Received: 18 March 2013 / Accepted: 9 August 2013 / Published online: 14 September 2013

Abstract Barium may affect the perception of taste intensity and palatability. Such differences are important considerations in the selection of dysphagia assessment strategies and interpretation of results. Eighty healthy women grouped by age (younger, older) and genetic taste status (supertaster, nontaster) rated intensity and palatability for seven tastants prepared in deionized water with and without 40 % w/v barium: noncarbonated and carbonated water, diluted ethanol, and high concentrations of citric acid (sour), sodium chloride (salty), caffeine (bitter), and sucrose (sweet). Mixed-model analyses explored the effects of barium, taster status, and age on perceived taste intensity and acceptability of stimuli. Barium was associated with lower taste intensity ratings for sweet, salty, and bitter tastants, higher taste intensity in carbonated water, and lower palatability in water, sweet, sour, and carbonated water. Older subjects reported lower palatability (all barium samples, sour) and higher taste intensity scores (ethanol, sweet, sour) compared to younger subjects. Supertasters reported higher taste intensity (ethanol, sweet, sour, salty, bitter) and lower palatability (ethanol, salty, bitter) than nontasters. Refusal rates were highest for younger subjects and supertasters, and for barium (regardless of tastant), bitter, and ethanol. Barium suppressed the perceived intensity of some tastes and reduced palatability. These effects are more pronounced in older subjects and supertasters, but younger supertasters are least likely to tolerate trials of barium and strong tastant solutions.

Keywords Dysphagia · Taste · Mixture suppression · Barium · Palatability · Deglutition

The views expressed in this article are those of the authors and do not reflect the official policies of the Department of Defense or U.S. Government.

A. M. Dietsch (✉) · N. P. Solomon
Audiology & Speech Center, Walter Reed National Military Medical Center, Building 19, Floor 5, 8901 Wisconsin Avenue, Bethesda, MD 20889-5600, USA
e-mail: angela.m.dietsch@health.mil

A. M. Dietsch
Henry F. Jackson Foundation for the Advancement of Military Medicine, 6420-A Rockledge Dr., Suite 100, Bethesda, MD 20817, USA

C. M. Steele
Toronto Rehabilitation Institute, 550 University Avenue #12-101, Toronto, ON M5G 2A2, Canada

C. A. Pelletier
University of Arkansas for Medical Sciences, 4301 West Markham, Little Rock, AR 72205, USA

Present Address:
C. A. Pelletier
Charlestown Retirement Community, 709 Maiden Choice Lane, Catonsville, MD 21228, USA

Recommendations regarding appropriate dysphagia treatment techniques and the safety of oral intake often rely on the results of videofluoroscopic studies of swallowing (VFSS) in which patients ingest radiopaque barium sulfate while the speech-language pathologist and radiologist assess various components of swallowing physiology. In addition to a standard protocol of various viscosities and volumes, VFSS often include swallows with therapeutic manipulations to assess their effects on swallow function. One such tactic is the use of high-concentration taste stimuli, which could have therapeutic benefits despite being inappropriate as a dietary recommendation. It is important that the swallow physiology observed with the barium samples in a VFSS is comparable to that during intake of nonbarium foods and liquids that might be part of a typical meal. Factors including mixture suppression, age, and genetic taste status may influence the perception of taste stimuli and the associated motor response.

Ample evidence supports that swallow mechanics can be altered by manipulating sensory input. This input arises from many characteristics, including taste quality (sweet, sour, bitter, salty, umami), taste intensity, chemesthesis (a somatosensory perception triggered by chemical irritation of the mucosa as occurs with chili, menthol, carbonation, high acidity), bolus temperature, and viscosity. A highly sour taste has been associated with increased linguapalatal contact pressure [1], increased swallowing apnea duration (SAD) [2, 3], decreased oral transit time [4], decreased pharyngeal transit time [4, 5], quicker swallow onset time [4, 6], more efficient swallows [4, 7], and decreased frequency and severity of penetration-aspiration [3, 4, 8] in a variety of subject populations. Boluses with high-intensity taste qualities of sweet, sour, and salty elicited quicker [7] and stronger [6, 9–11] swallow responses compared to plain water boluses. Cola and colleagues [12] observed an interaction effect wherein a cold sour bolus yielded shorter pharyngeal transit duration compared to cold or sour alone. An ethanol–barium 50:50 mixture elicited longer SAD than plain barium solutions or those that included other chemesthetic agents [13]. Given these data, manipulation of sensory input has potential as a therapeutic technique in patients with dysphagia.

In VFSS, taste stimuli must be mixed with barium to be radiopaque, and this may alter the sensory perception of the solution through a phenomenon called mixture suppression. A number of studies have documented that combining two different taste stimuli diminishes the perceived intensity of either tastant alone [14–18]. According to Pelletier et al. [19], both older and younger subjects reported that a citric acid solution tasted less sour when sucrose or aspartame was added, and a sucrose solution tasted less sweet as citric acid was added. The addition of barium to a tastant solution could result in a similar pattern of mixture suppression. We are unaware of any previous reports comparing perceived taste intensity for barium versus nonbarium solutions, but one study found no significant difference in the palatability ratings for a citric acid solution in barium versus in deionized water using a 9-point hedonic scale [1]. These results could reflect strong dislike of high-concentration citric acid regardless of other components within a mixture, limitations of the measurement scale [20], or other considerations. If barium does influence the perception of a taste stimulus, it could have implications for the swallow response elicited and thus for the interpretation of sensory manipulation effects observed during VFSS and the development of therapeutic and dietary recommendations.

Genetic taste status may also affect the perception of taste and the biomechanics of swallowing for different taste stimuli. A person's genetic taste status is classified as supertaster, medium taster, and nontaster based on one's taste perceptions of a bitter compound [21], the size and abundance of fungiform papillae on the tongue [22, 23], and/or one's chromosomal patterns [24–26]. A number of studies have documented that supertasters have a heightened perception of taste [26–29] and other lingual sensations [23, 30] compared to nontasters and medium tasters. Supertasters also perceive the effects of mixture suppression differently [31], but this response varies according to the type and concentration of tastant [31]. Water- and barium-based boluses elicited different patterns of SADs in supertasters versus nontasters during swallows of some tastants but not others [2, 13, 32]. These results further confound our understanding of the relationship between genetic taste status and the perception of simple and complex tastes and of an individual's physiological response to a particular taste stimulus. Any interactions between genetic taste status and mixture suppression with barium versus nonbarium solutions could directly affect the interpretation of VFSS tests investigating taste stimuli as a potential treatment modality for a person with dysphagia.

Another factor influencing the perception of taste and the response to taste stimuli is the age of the individual. Some investigations indicate that older subjects have higher thresholds for tastes than do younger subjects [33–36], but such differences were not detected in other cases [37–40]. Results for various concentrations of suprathreshold taste solutions are also mixed, with some documenting lower taste intensity ratings by older subjects [35, 36, 41] and others observing the opposite effect [42, 43] or similar ratings between younger and older groups [42, 43]. Differences could reflect actual decreases in taste sensitivity with age that may be nonlinear across tastant types and concentrations, differences in measurement techniques, effects of medications or nutritional deficiencies [44], or other factors. There is some evidence that age does not affect mixture suppression for sweet–sour solutions [19] and for sweetness in complex tastes associated with nutritional supplements [33], but this effect has not been explored in barium- versus water-based solutions. It is unclear how age might interact with mixture suppression, genetic taste status, and specific tastants to impact the sensory perception of taste stimuli and therefore the swallowing behaviors observed during taste manipulation trials in VFSS.

The present study aimed to expand understanding of the perception of high-concentration taste and chemesthetic stimuli in barium and nonbarium solutions as measured by palatability and taste intensity ratings. It was hypothesized that (H_1) the presence of barium will have no significant effect on intensity or palatability scores across age and taster status groups, (H_2) supertasters will report lower palatability and higher intensity ratings than nontasters for all samples, and (H_3) older subjects will perceive taste samples to be less intense than younger subjects.

Methods

Participants

Healthy volunteers, including 40 women aged 18–35 years and 40 women over 60 years of age stratified by genetic taste status, were recruited to achieve four study groups of 20 subjects each (Table 1). Using the general Labeled Magnitude Scale (gLMS) [45], participants rated the bitterness intensity of a filter paper soaked with 1.6 mg 6-*n*-propythiriyracil. Individuals who rated the bitterness <20/100 or >50/100 were classified as nontasters or supertasters, respectively [46]. The study was limited to women because they are more likely to be supertasters or nontasters compared to men [47]. The extreme taster and age categories were selected in order to maximize the potential for detecting group differences in a multitude of outcome variables within the larger study. Participants qualified for inclusion if they lived independently in the community, scored ≥25 on the Mini Mental State Examination [48], and demonstrated an ability to understand the gLMS by answering the following three questions with reasonably increasing intensity ratings: "What is the rating of a whisper? A conversation? The loudest sound you have ever heard?" Individuals were excluded if they had current taste or swallowing problems, open mouth sores, or a medical history or condition that would preclude participation, such as an allergy to any taste sample or significant cognitive deficits. Subjects provided informed consent to participate in this project as part of the Arkansas Taste and Swallowing Study, which was approved by the Institutional Review Board of the University of Arkansas for Medical Sciences. This study examined a variety of swallowing variables, some of which have been described elsewhere [2, 13, 32].

Table 1 Age of participants by genetic taste group

	Nontaster			Supertaster		
	Mean (years)	SD	*n*	Mean (years)	SD	*n*
Younger	25.8	4.7	20	26.5	3.4	20
Older	71.5	8.7	20	72.6	7.4	20

Stimuli

Fourteen of the stimuli presented within the larger study were relevant to the research questions addressed here. Seven taste stimuli profiles were mixed at identical concentrations in both nonbarium and barium solutions, and participants received 5-ml boluses of the samples in each of two rounds. Deionized water (60 L Progard™ Tank, Millipore, Billerica, MA) was the solvent for all barium (barium sulfate USP, 40 % w/v, Fisher Scientific, Fair Lawn, NJ) and nonbarium stimuli except carbonated water. Taste stimuli mixtures included noncarbonated deionized water, carbonated water (Polar® Seltzer water with no sodium [Polar Beverages, Worcester, MA] for the nonbarium solution, and sodium bicarbonate [2.22 % w/v, local grocer] plus citric acid USP [1.4 % w/v, Fisher Scientific, Fair Lawn, NJ] for the barium mixture), diluted ethanol (50 % v/v, 200 proof absolute, Pharmco Products, Brookfield, CT) and sucrose (34.2 % w/v, local grocer), citric acid USP (2.7 % w/v, Fisher Scientific), sodium chloride USP (5.84 % w/v, ScienceLab.com, Kingwood, TX), and caffeine anhydrous USP (0.621 % w/v, ScienceLab.com). Noncarbonated deionized water served as the control.

The larger study hypothesized that chemesthesis may play a role in evoking a more functional swallow in individuals with neurogenic dysphagia, so the carbonated seltzer water and high ethanol stimuli with and without barium were included. Given that a high citric acid mixture (intensely sour) is the only taste stimulus to date that has shown a positive effect on swallowing physiology in neurogenic dysphagia [4, 8], its inclusion was vital to study design. It is not known how other taste qualities at high concentrations may affect swallowing physiology; therefore, high concentrations of sucrose (intensely sweet), caffeine (intensely bitter), and sodium chloride (intensely salty) were included with and without barium. In this manner, basic questions about swallowing physiology may be answered in the future via videofluoroscopic swallow studies. None of the stimuli were intended to be therapeutic due to their extreme intensity. The tastant identities and concentration levels were similar to other published taste sensation studies and have subsequently been included in the NIH Toolbox for Gustation [49, 50].

In addition to these matched samples, the larger study included four low suprathreshold concentrations of sucrose, citric acid, salt, and caffeine. These were tested only in nonbarium solutions and thus are not included in this report. Since most beverages are consumed when chilled, samples were held in a refrigerator at <5 °C until immediately prior to presentation. The samples were placed in 30-ml clear plastic cups labeled with 3-digit random numbers, leaving participants blind to the identity of each trial with the exception of the nonbarium seltzer water and barium carbonated mixture. These two stimuli were opened or prepared in the presence of the participant to preserve the carbonation.

Procedures

In each round, the presentation order for samples was randomized within barium condition; all seven nonbarium solutions were presented in random order, followed by the seven barium mixtures (also randomized). Boluses were self-administered, and participants were asked to swallow the entire amount at once with no command to swallow while breathing through the nose. This allowed the respiratory pattern to be captured via a nasal cannula attached to the KayPentax Swallowing Workstation. In order to minimize context effects, participants performed three or more oral rinses with room-temperature tap water between all samples until there was no perception of taste or mouthfeel.

During the first round, participants rated the taste intensity of each sample using the gLMS [45, 51]. The gLMS is a vertical line labeled from 0 to 100, with descriptors ranging from barely detectible (1.4) to very strong (52.5). It has been shown to avoid ceiling effects in rating sensory perception by comparing a given stimulus to all sensations regardless of modality [26, 45]. Scores for taste identity, intensity, and, if applicable, chemesthetic properties of fizziness or burning/irritation were recorded immediately following the administration of each sample. After complete sets of the nonbarium and barium mixtures were administered, subjects had a break of at least 15 min before beginning the next round of taste samples for palatability.

In the second round, participants tasted each of the samples again, this time rating the intensity of liking/disliking using the hedonic gLMS (H-gLMS) [52, 53]. The H-gLMS resembles two mirrored and stacked gLMS scales such that the range is –100 to +100, reflecting a range from intense dislike to intense like. As in the first round, the taste stimuli were randomized for each individual within the nonbarium condition and then the barium condition. Subjects had the opportunity to specify and refuse samples based on their memory of the stimulus properties reported in the first round. In some cases (16 % of refusals), subjects rejected trials but offered palatability ratings based on those recollections. When subjects refused specific trials but did not provide a palatability rating at the time of refusal (28 % of refusals), a score of –100 was assigned to represent extreme dislike. If a subject discontinued the study prior to completing all of the round-two trials or declined to accept blocks of stimuli irrespective of their particular identities (56 % of refusals), no palatability scores were recorded for the untasted samples. Regardless of palatability rating status, each second-round trial that was declined was tracked as a refusal.

Statistical Methods

A fully factorial mixed-model analyses of variance (ANOVA) was calculated to account for repeated-measures effects on outcome variables of intensity and palatability, with Sidak tests for pairwise comparisons within significant interactions. Independent variables included tastant type, barium status, genetic taste group, and age. An α level of 0.05 was established as statistically significant. A logistic regression generalized estimating equation model was used to analyze refusal data.

Results

Taste Intensity Ratings

Descriptive statistics and complete results of ANOVA for taste intensity are shown in Tables 2 and 3, respectively. For taste intensity ratings, there were no significant four- or three-way interactions. Three significant two-way interactions were noted. Pairwise comparisons within the barium × tastant interaction [$F(6, 309) = 8.43$, $p < 0.001$] indicated that the presence of barium was associated with lower taste intensity ratings for the sucrose, salt, and caffeine samples and higher intensity ratings for the carbonated trials collapsed across age and genetic status (Fig. 1). Analysis of the interaction between tastant and age [$F(6, 211) = 3.97$, $p = 0.001$] revealed higher intensity ratings by older subjects for ethanol, citric acid, and sucrose samples regardless of barium status (Fig. 2). The tastant × genetic taste group interaction [$F(6, 211) = 6.41$, $p < 0.001$] included significantly higher intensity ratings by supertasters for ethanol, citric acid, sucrose, salt, and caffeine samples regardless of barium status (Fig. 3). Significant main effects for barium status [$F(1, 731) = 3.96$, $p = 0.047$] and genetic taste group [$F(1, 78) = 18.67$, $p < 0.001$] were also noted, with lower intensity scores reported for barium samples and by the nontaster groups. Age did not result in statistically significant main effects in taste intensity scores.

Palatability Ratings

Tables 4 and 5 list descriptive statistics and complete ANOVA results for palatability ratings. A significant three-way interaction was noted between tastant, age, and genetic taste group [$F(6, 337) = 2.68$, $p = 0.015$] and is illustrated in Fig. 4. For the sucrose stimuli, pairwise differences revealed that older supertasters reported lower palatability

Table 2 General Labeled Magnitude Scale (range = 0 to 100) scores for taste intensity

	Nonbarium				Barium			
	Nontaster		Supertaster		Nontaster		Supertaster	
Stimulus	Younger	Older	Younger	Older	Younger	Older	Younger	Older
Deionized water	0.10	0.00	1.40	2.30	1.65	2.60	3.00	3.55
	(0.79)	(0.79)	(0.79)	(0.79)	(1.90)	(1.90)	(1.90)	(1.90)
Carbonated water	9.60	12.85	12.20	14.60	16.80	15.10	29.55	28.00
	(4.13)	(4.13)	(4.13)	(4.13)	(5.52)	(5.52)	(5.52)	(5.52)
Ethanol	30.15	42.45	45.30	53.00	37.15	45.48	43.70	60.85
	(6.50)	(6.50)	(6.50)	(6.50)	(6.87)	(7.00)	(6.87)	(6.87)
Sucrose	33.80	46.25	47.20	63.60	27.80	35.30	38.95	52.00
	(4.78)	(4.78)	(4.78)	(4.78)	(4.81)	(4.81)	(4.81)	(4.81)
Citric acid	42.20	55.20	62.15	67.75	38.30	57.05	57.25	64.75
	(4.84)	(4.84)	(4.84)	(4.84)	(5.29)	(5.29)	(5.29)	(5.29)
Sodium chloride	49.65	53.55	61.00	67.35	38.60	36.65	53.50	50.90
	(4.73)	(4.73)	(4.73)	(4.73)	(5.91)	(5.91)	(5.91)	(5.91)
Caffeine	39.35	39.40	64.05	62.74	33.70	31.35	57.50	57.45
	(5.87)	(5.87)	(5.87)	(5.99)	(5.79)	(5.79)	(5.79)	(5.79)

Values are mean (standard error)

Table 3 Fully factorial mixed-model ANOVA results for taste intensity ratings

Source	df	F	p
Barium × tastant × age × genetic	6,309	0.173	0.984
Barium × tastant × age	6,211	0.521	0.792
Barium × tastant × genetic	6,309	0.682	0.665
Barium × age × genetic	1,731	0.074	0.785
Tastant × age × genetic	6,211	0.565	0.758
Barium × tastant	6,309	8.429	<0.001‡
Barium × age	1,731	0.476	0.490
Barium × genetic	1,78	0.112	0.738
Tastant × age	6,211	3.967	0.001†
Tastant × genetic	6,211	6.410	<0.001‡
Age × genetic	1,78	0.000	0.996
Barium	1,731	3.962	0.047*
Tastant	6,211	219.684	<0.001‡
Age	1,78	3.273	0.074
Genetic taste group	1,78	18.670	<0.001‡

* $p < 0.05$; † $p < 0.01$; ‡ $p < 0.001$

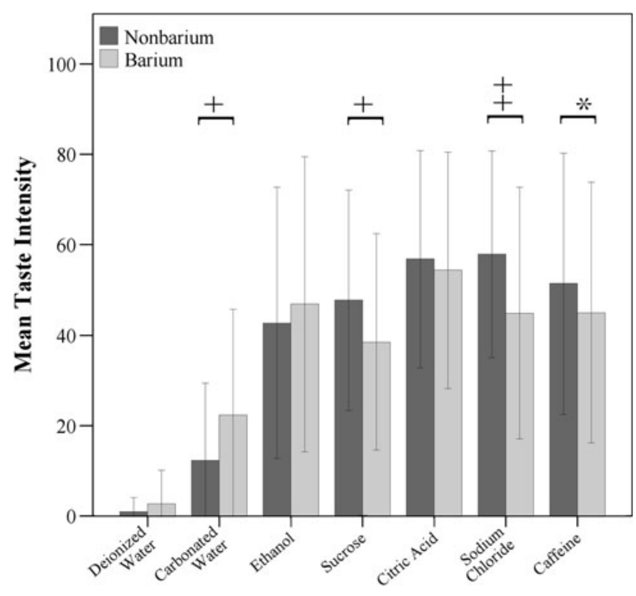

Fig. 1 Taste intensity ratings by barium status and tastant. Taste intensity scores are ratings on the general Labeled Magnitude Scale, for which 1.4 indicates barely detectible and 52.5 reflects very strong intensity. *Error bars* represent ±1 standard deviation. *$p < 0.05$; †$p < 0.01$; ‡$p < 0.001$

scores compared to older nontasters, whereas younger supertasters' palatability ratings were not different from younger nontasters. Conversely, younger supertasters disliked carbonated water and salt trials to a greater degree than did younger nontasters and older subjects of either genetic status. For noncarbonated water and citric acid boluses, palatability scores were similar across all age and supertaster groups at this level of analysis.

A number of two-way interactions within the palatability data were statistically significant. Examination of the interaction between barium and tastant [$F(6, 290) = 5.11$, $p < 0.001$] revealed that noncarbonated and carbonated water, sucrose, and citric acid stimuli were significantly less palatable in barium versus nonbarium regardless of age or

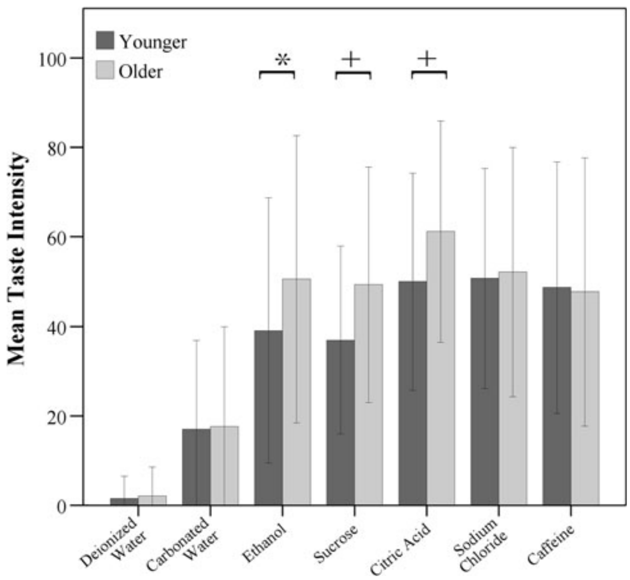

Fig. 2 Taste intensity ratings by tastant and age. Taste intensity scores are ratings on the general Labeled Magnitude Scale, for which 1.4 indicates barely detectible and 52.5 reflects very strong intensity. $n = 40$ per age group (collapsed across genetic taste status). *Error bars* represent ±1 standard deviation. $*p < 0.05$; $^{\dagger}p < 0.01$

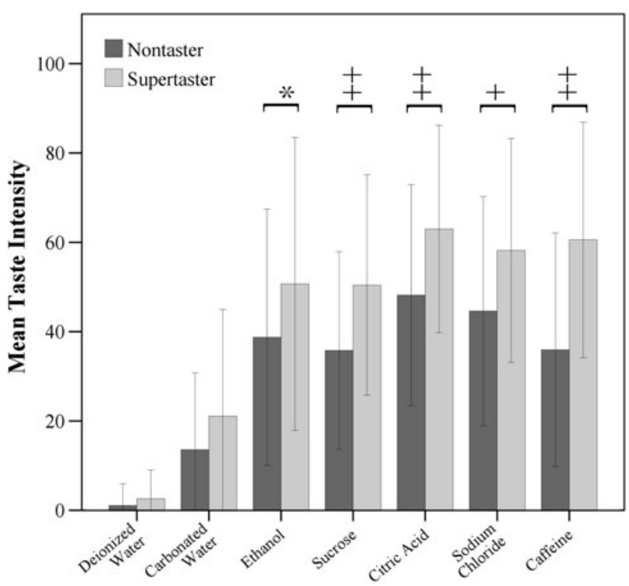

Fig. 3 Taste intensity ratings by tastant and genetic taste status. Taste intensity scores are ratings on the general Labeled Magnitude Scale, for which 1.4 indicates barely detectible and 52.5 reflects very strong intensity. $n = 40$ per genetic taste group (collapsed across age). *Error bars* represent ±1 standard deviation. $*p < 0.05$; $^{\dagger}p < 0.01$; $^{\ddagger}p < 0.001$

genetic taste status, whereas ethanol, salt, and caffeine ratings were similar across barium status (Fig. 5). Although both younger and older participants preferred nonbarium samples to barium samples, this trend was stronger in the younger group, as reflected by a significant barium × age interaction [$F(1, 860) = 9.19$, $p = 0.003$]. The interaction effect for tastant × age [$F(6, 338) = 4.70$, $p < 0.001$] was specific to a strong dislike for citric acid samples (regardless of barium condition) by older participants, with no significant age differences for any other tastant (Fig. 6). Analysis of the tastant × genetic taste status interaction [$F(6, 338) = 8.74$, $p < 0.001$] showed that supertasters found ethanol, salt, and caffeine mixtures to be significantly less palatable than did nontasters (Fig. 7). Main effects analysis indicated lower palatability scores for barium samples [$F(1, 860) = 51.17$, $p < 0.001$] and by supertasters [$F(1, 78) = 17.63$, $p < 0.001$]. As with intensity scores, palatability scores were not significantly different across age group as a main effect.

Refusal Rates

Analysis of refusal rates revealed statistically significant interaction effects for tastant × barium. The presence of barium made a statistically significant difference in refusal rates for sucrose, citric acid, sodium chloride, deionized water, and carbonated water (Table 6). Main effects for barium were significant ($p = 0.002$), with barium samples almost twice as likely to be rejected as nonbarium samples. Tastant main effects were also significant ($p < 0.001$); ethanol and caffeine trials were refused most frequently regardless of barium status and also had the lowest palatability scores of any tastants. Although refusal rates varied by genetic taste status (supertasters 11.6 % vs. nontasters 5.1 %, $p = 0.417$) and age (younger 10.7 % vs. older 6.0 %, $p = 0.280$), these differences did not achieve statistical significance for any main or interaction effects. This could be due to the relatively small number of refusals overall combined with the limited degrees of freedom for these two-level variables.

Discussion

Eighty healthy women reported taste intensity and palatability ratings for a variety of taste samples in a barium solution compared to nonbarium mixtures. Barium is the standard contrast medium used in VFSS, and patient performance on such studies is assumed to be representative of swallow function in clinical and functional situations. If barium affects the sensory aspects of swallowing, however, it could also impact swallow physiology and thus the clinical relevance of VFSS results. Barium was not predicted to influence taste intensity or palatability scores, but data from this cohort suggests both main and interaction effects for barium status across tastant, age group, and genetic taste status.

Table 4 Hedonic general Labeled Magnitude Scale (range = −100 to 100) scores for palatability

	Nonbarium				Barium			
	Nontaster		Supertaster		Nontaster		Supertaster	
Stimulus	Younger	Older	Younger	Older	Younger	Older	Younger	Older
Deionized water	−0.35	2.85	3.61	4.75	−13.91	−12.71	−20.01	−15.56
	(3.18)	(3.18)	(3.26)	(3.18)	(3.89)	(3.89)	(4.21)	(3.98)
Carbonated water	−4.10	−11.15	−14.57	−6.20	−27.99	−29.95	−46.70	−31.15
	(5.33)	(5.33)	(5.47)	(5.33)	(6.42)	(6.42)	(6.96)	(6.42)
Ethanol	−46.05	−48.50	−75.03	−75.47	−50.80	−48.13	−82.13	−68.43
	(6.67)	(6.67)	(7.39)	(6.82)	(7.10)	(7.10)	(7.91)	(7.27)
Sucrose	29.95	41.65	38.85	21.10	12.35	34.39	12.40	11.23
	(7.70)	(7.70)	(8.09)	(7.70)	(7.31)	(7.31)	(7.70)	(7.31)
Citric acid	−12.70	−55.65	−22.57	−48.20	−35.53	−57.87	−41.56	−51.09
	(8.32)	(8.32)	(8.52)	(8.73)	(7.01)	(7.01)	(7.82)	(7.18)
Sodium chloride	−22.05	−31.15	−41.28	−30.05	−27.13	−22.78	−53.68	−36.04
	(7.41)	(7.41)	(8.00)	(7.58)	(7.51)	(7.51)	(8.14)	(7.70)
Caffeine	−30.25	−40.40	−60.52	−61.44	−38.56	−44.16	−79.49	−59.39
	(6.03)	(6.03)	(6.89)	(6.49)	(6.16)	(6.16)	(7.08)	(6.47)

Table 5 Fully factorial mixed-model ANOVA for palatability ratings

Source	df	*F*	*p*
Barium × tastant × age × genetic	6,290	0.107	0.996
Barium × tastant × age	6,290	0.668	0.676
Barium × tastant × genetic	6,290	0.468	0.832
Barium × age × genetic	1,860	0.311	0.577
Tastant × age × genetic	6,338	2.680	0.015*
Barium × tastant	6,290	5.107	<0.001‡
Barium × age	1,860	9.190	0.003†
Barium × genetic	1,870	1.712	0.191
Tastant × age	6,338	4.704	<0.001‡
Tastant × genetic	6,338	8.736	<0.001‡
Age × genetic	1,78	0.833	0.364
Barium	1,860	51.165	<0.001‡
Tastant	6,338	190.910	<0.001‡
Age	1,78	0.121	0.729
Genetic taste group	1,78	17.630	<0.001‡

* $p < 0.05$; † $p < 0.01$; ‡ $p < 0.001$

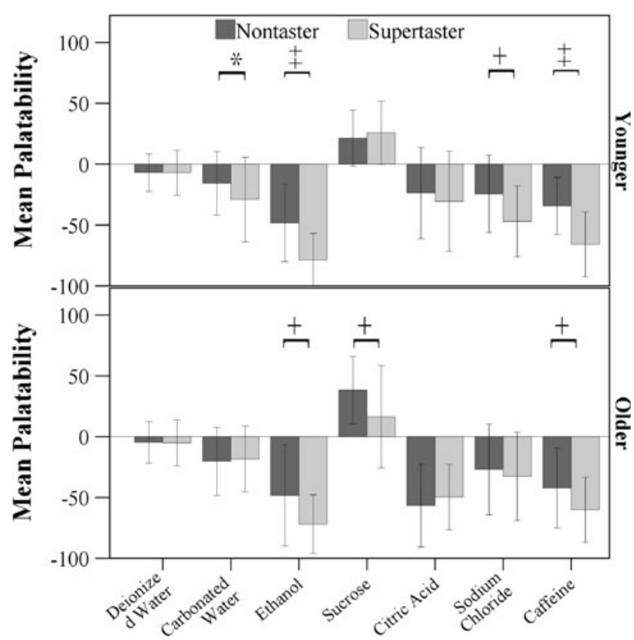

Fig. 4 Palatability ratings by tastant, genetic taste status, and age. Palatability scores are ratings on the hedonic general Labeled Magnitude Scale, for which *zero* indicates neither like nor dislike, positive numbers reflect intensity of liking, and negative numbers reflect intensity of disliking. $n = 20$ per genetic taste status and age combination. *Error bars* represent ±1 standard deviation. *$p < 0.05$; †$p < 0.01$; ‡$p < 0.001$

Barium Effects

Overall, the presence of barium was associated with reduced taste intensity. The effect occurred primarily in the high-concentration sucrose, salt, and caffeine solutions as opposed to other mixtures, suggesting that mixture suppression may have influenced taste perception of these tastants to a greater degree than anticipated in the study hypotheses. Contrary to the overall trend, taste intensity ratings were higher in the barium-based ethanol, noncarbonated water, and carbonated water mixtures than in the nonbarium versions of these tastants, although the difference was statistically significant only for carbonated water.

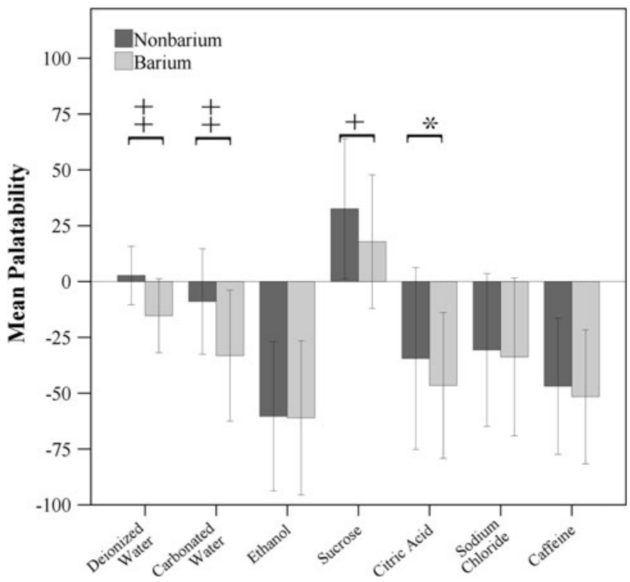

Fig. 5 Palatability ratings by barium status and tastant. Palatability scores are ratings on the hedonic general Labeled Magnitude Scale, for which *zero* indicates neither like nor dislike, positive numbers reflect intensity of liking, and negative numbers reflect intensity of disliking. *Error bars* represent ±1 standard deviation. $*p < 0.05$; $^{\dagger}p < 0.01$; $^{\ddagger}p < 0.001$

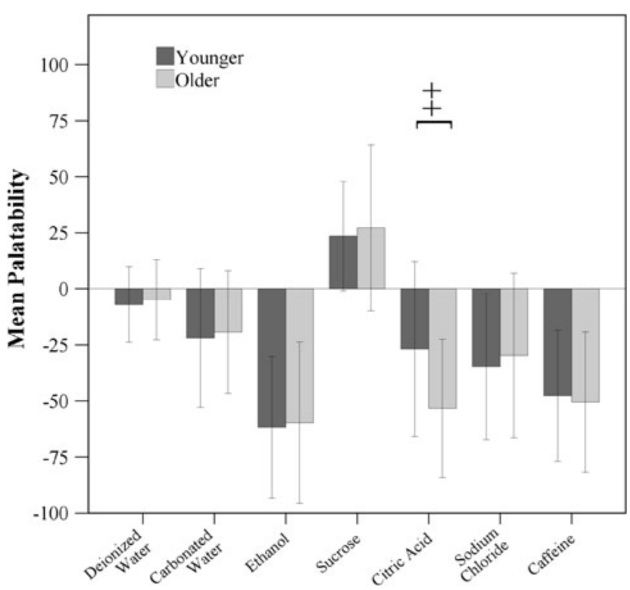

Fig. 6 Palatability ratings by tastant and age. Palatability scores are ratings on the hedonic general Labeled Magnitude Scale, for which *zero* indicates neither like nor dislike, positive numbers reflect intensity of liking, and negative numbers reflect intensity of disliking. $n = 40$ per age group (collapsed across genetic taste status). *Error bars* represent ±1 standard deviation. $^{\ddagger}p < 0.001$

Ethanol and carbonated water are characterized mostly by their chemesthetic properties rather than taste per se. These stimuli theoretically should not have a taste. However, the study protocol inquired whether a taste quality was

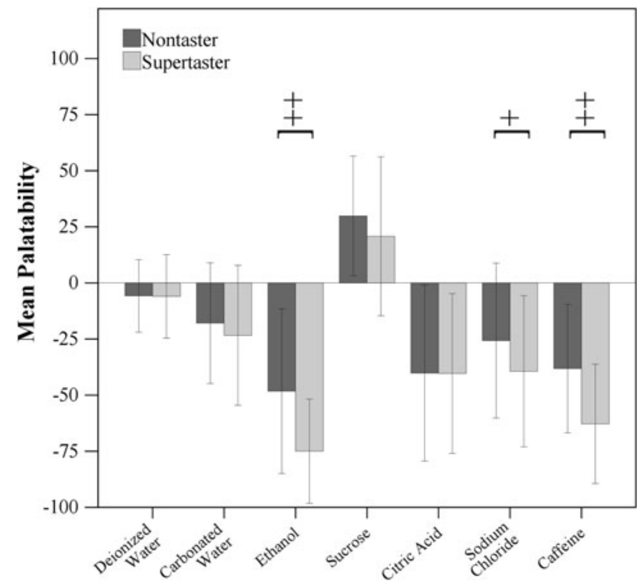

Fig. 7 Palatability ratings by tastant and genetic taste status. Palatability scores are ratings on the hedonic general Labeled Magnitude Scale, for which *zero* indicates neither like nor dislike, positive numbers reflect intensity of liking, and negative numbers reflect intensity of disliking. $n = 40$ per genetic taste group (collapsed across age). *Error bars* represent ±1 standard deviation. $^{\dagger}p < 0.01$; $^{\ddagger}p < 0.001$

perceived for all samples. It is possible that participants may have confused these two different perceptions, i.e., taste intensity versus chemesthesis. Furthermore, although the perceived intensity of carbonation is enhanced when samples are chilled [54–56], the interactive effect of temperature and barium is unknown and was not addressed in this study. Noncarbonated water does not have chemesthetic properties on its own, but the taste and/or mouthfeel properties of barium may have been more pronounced in the absence of other taste stimuli [57]. Other studies have shown that swallowing mechanics are different across high- versus low-density barium solutions [58, 59] and across barium versus viscosity-matched nonbarium [60], suggesting that the density of barium may alter bolus perception, even when controlling for other factors. Thus, the presence of barium may have added to the overall perception of somatosensory input, leading to reports of increased intensity for some samples. The nonbarium- and barium-based carbonated water solutions required different compositions (seltzer water and sodium bicarbonate plus citric acid, respectively) in order to achieve similar carbonation effects at the time of sampling. Therefore, it is unclear whether the difference in carbonated water's intensity ratings across barium status was due to true barium effects, different carbonation methods, confusion of the property being rated, or a combination of these factors. Studies examining divergent results between stimuli that have both taste and chemesthetic qualities indicate that

Table 6 Refusal rates by barium status and tastant

Stimulus	Nonbarium (%)	Barium (%)	*p*
Deionized water	1.5	7.1	0.026*
Carbonated water	1.6	7.1	0.027*
Ethanol	16.0	19.3	0.108
Sucrose	1.6	5.9	0.045*
Citric acid	4.7	10.7	0.027*
Sodium chloride	4.2	8.3	0.050*
Caffeine	12.0	15.7	0.075
Total	5.9	10.6	0.002*

* $p < 0.05$

these qualities differentially affect oral sensory perception [3–5, 8] and consequently, perhaps, the centrally mediated control of swallowing. Barium appears to influence taste intensity scores differently across tastants [13, 32], with the net effect of masking the perceived intensity of barium-based solutions tested here.

The results failed to support the hypothesis that barium would not affect palatability. Although most samples were disliked regardless of barium status, palatability ratings were lower for every barium mixture compared to its non-barium counterpart. This effect was statistically significant in noncarbonated and carbonated water, sucrose, and citric acid solutions. Pelletier and Dhanaraj [1] reported no significant difference in palatability for citric acid in barium versus nonbarium, but the H-gLMS used here was likely to have been more sensitive than the 9-point hedonic scale used in the 2006 study and only one of the tested acid concentrations was as high as that included here [1, 20]. Caffeine and ethanol were the least palatable stimuli overall; perhaps they were so disliked in general that the presence or absence of barium was inconsequential. Palatability for the salt solution was similar across barium conditions. Overall, only three samples (nonbarium water, nonbarium sucrose, and barium sucrose) were liked by subjects, as indicated by positive mean palatability scores. These data are consistent with previous evidence that sweet taste tends to elicit a greater pleasure response than other taste qualities across the human life span [61–64], apparently even in the presence of barium. Higher refusal rates for barium samples reinforced the palatability score results in that the samples with the lowest palatability scores tended to be most frequently refused. Furthermore, all of the stimuli with statistically significant differences in palatability ratings across barium status also had barium-related significant differences in refusal rates. An order effect must be considered when evaluating the barium versus nonbarium refusals, however, since nonbarium samples were always administered first to minimize any carryover effects from barium coating the oral cavity. Abundant documentation supports the alteration of swallowing physiology in response to boluses with differently perceived taste intensities and qualities [1–11], raising concerns about whether swallows observed during VFSS with barium-based high-concentration tastants are representative of swallow function with similarly flavored nonbarium solutions.

Genetic Taste Status Effects

Genetic taste status influenced taste intensity and palatability scores as predicted. Supertasters found taste intensity to be higher overall, and the effect was statistically significant for all tastants except noncarbonated and carbonated water. This is consistent with previous literature indicating that supertasters are more sensitive to a variety of orolingual stimuli [23, 26–30]. Supertasters also reported significantly lower palatability scores across samples, with a particular dislike for ethanol, caffeine, and salt stimuli. This suggests that supertasters' heightened sensitivity to taste stimuli magnified an inverse relationship between intensity and palatability ratings for unpleasant tastants (i.e., those that received negative palatability scores). A contrasting effect was noted with sucrose, the most palatable of the tested stimuli regardless of barium status. All supertasters rated sucrose as more intense than did nontasters. For younger supertasters, the higher intensity of sweetness was also associated with a higher palatability rating as compared to younger nontasters. The opposite was true for older subjects: older supertasters found sucrose to be more intense than their nontaster peers, but they liked it less than the older nontasters and both younger cohorts. Several older supertasters were noted to comment that the stimulus was "too sweet," consistent with the lower palatability scores and previous evidence that sweet taste preference decreases with age [65]. Despite the lack of a two-way interaction between genetic taste status and age, the statistically significant three-way interaction suggests that such a relationship exists for certain tastants and thus may warrant further investigation.

Age Effects

Although main effects for age did not reach statistically significant levels as predicted, age did influence intensity and palatability ratings for some tastants and for barium status. For sucrose, citric acid, and ethanol stimuli, older participants reported higher intensity scores than younger subjects, contradicting the expected effect. Older subjects have reported higher taste intensity scores than younger counterparts for weak suprathreshold sucrose, citric acid, salt, and quinine hydrochloride (bitter) solutions [43], but more concentrated solutions typically have yielded lower intensity perception among older subjects [35, 37, 40]. The only significant age × tastant interaction for palatability was a strong dislike for citric acid by older participants. For this tastant, the inverse relationship between intensity and palatability among older participants was similar to that observed in supertasters for extremely unpleasant tastants. Other stimuli elicited a different effect across age groups in that older subjects appeared more tolerant of adverse taste experiences. For example, despite experiencing higher taste intensity for sucrose, citric acid, and ethanol tastants, older subjects disliked them no more or less than their younger peers. Also, the presence of barium did not affect intensity ratings across the age groups, suggesting that any masking effect was not age-related. Barium did yield significantly lower palatability ratings by both groups, but the barium effect was more pronounced for younger participants. Refusal rates offer further evidence of this age-related taste intolerance; younger subjects were more likely to refuse trials even though their palatability ratings for the most rejected tastants were equivalent to (ethanol and caffeine) or higher than (citric acid) those of the older group.

Implications for Dysphagia Management

Except the water samples and perhaps sucrose, none of these stimuli would be appropriate for dietary recommendations in the concentrations tested here because of their poor palatability and potential for gastrointestinal tract irritation. They were selected as part of a larger study to elucidate how high concentrations of tastants may influence swallowing physiology given the positive effects previously reported with high-concentration citric acid. Oropharyngeal dysphagia is often characterized by delayed or prolonged timing and/or reduced magnitude of movements during swallows, so typical rehabilitation goals include facilitating a more timely response or more efficient bolus propulsion. High concentrations of sucrose and quinine hydrochloride, i.e., highly sweet/pleasant versus bitter/unpleasant stimuli, respectively, have been shown to directly influence the excitability of the swallowing motor pathway by reducing the thresholds for triggering a pharyngeal motor response compared to water [66]. Additionally, higher-concentration taste stimulants elicit greater intensity of activation in key areas for swallowing, including the pons, cerebellum, and insula [67, 68], compared to lower concentrations of the same tastants. Priming the corticobulbar pathways for swallowing through the use of high-concentration tastants could, therefore, facilitate more timely and efficient swallows in individuals with dysphagia [3–7], particularly considering the tongue's roles as both the primary sensor for taste and the primary driver for bolus propulsion. Beyond this immediate effect on swallowing biomechanics, the use of high-concentration tastants appears to satisfy key criteria for enhancing experience-dependent neuroplasticity [69]. For these reasons, the use of high-concentration taste stimulants may have important implications for understanding swallowing neurophysiology and eventual dysphagia rehabilitation even though they would not be suited for dietary intake.

A common etiology of neurogenic dysphagia is unilateral stroke. Although these patients can experience unilateral taste loss, they do not perceive a decrease in taste intensity during food/liquid intake. This is due to disinhibition of the glossopharyngeal nerve [42, 43] and whole-mouth taste stimulation when consuming foods and liquids. Therefore, taste manipulation could still be a viable strategy for these patients. Since healthy individuals' perception of sensory input varies by age and genetic taste status, these factors may also influence how a particular person with dysphagia responds to strong tastants meant to improve swallowing behaviors.

A main objective of this study was to examine how barium influences taste intensity and palatability, as this sensory input may affect swallowing physiology during VFSS. Barium-related statistically significant differences in perceived taste intensity and/or palatability were observed for every tastant included in this study, but effects varied by tastant. Some tastants, such as high-concentration citric acid (strong sour), yielded similar taste intensity ratings in barium and nonbarium solutions. Although the relationship between taste perception and swallowing mechanics is still being defined, these results support that taste intensity perception during taste manipulation trials using citric acid is similar during VFSS with barium and during nonbarium trials. This finding is of particular interest because strong sour is the only taste quality that has demonstrated a positive effect on swallowing physiology in individuals with dysphagia [1, 4, 8] and is the taste quality most frequently used in taste manipulation trials clinically and in research.

Further investigation is necessary to determine whether other taste qualities might improve swallowing safety and whether differences in taste perception ratings across barium conditions correlate to differences in measures of swallowing physiology. If so, tastant concentrations during VFSS can be adjusted to account for any masking effects of barium. Similar adjustments could be made for older versus younger subjects if palatability ratings and swallowing mechanics are found to be related since age interacted with barium to alter palatability scores. Clinicians would then have some assurance that any physiological benefits observed during VFSS correspond to swallowing physiology during intake of the nonbarium tastants.

A key limitation of this study is that only participants with normal swallow function were included. It is not known whether sensory and motor impairments related to dysphagia may be affected differently by barium in a patient population. Further, the stimuli used in this study were chilled since that is how beverages are typically served. It is not known whether taste perception ratings across barium conditions would be affected by the temperature of the bolus. Since cold boluses have been shown to elicit shorter swallow latencies compared to otherwise equivalent unchilled boluses [12, 70], further studies of the relationship between taste perception and swallowing physiology should consider bolus temperature. Nonetheless, these data indicate that ratings of intensity and palatability differ across barium condition, tastant, age, and genetic status, so clinicians must consider all of these variables during the implementation of VFSS as they attempt to generalize their results to therapeutic and dietary recommendations. Future research will address whether variations in taste and chemesthetic stimuli affect swallow physiology in addition to their perceptual characteristics. Per previously published results from the larger study involving these stimuli and participants, it appears that at least some chemesthetic stimuli elicited longer SADs even when participants did not recognize any difference in the stimuli's perceptual characteristics [32]. If a taste or chemesthetic stimulus itself can generate positive swallowing behaviors regardless of perceived sensation, the stimulus could be useful as a treatment strategy.

Summary

Seven high-concentration taste and chemesthetic stimuli in barium and nonbarium solutions were administered to cohorts of older and younger supertasters and nontasters. Participants' ratings of taste intensity and palatability revealed multiple interactions between type of taste stimuli, barium status, age, and genetic taster status. Other than one investigation of palatability for citric acid across barium contexts [1], no data regarding the perception of taste for qualities such as high bitter, salt, and sweet with and without barium have been reported previously. The findings here offer partial support for the hypothesized effects of barium, genetic taste status, and age group on taste intensity and palatability ratings. For some but not all tastants, barium masked the intensity and reduced the palatability of the mixture. As expected, supertasters provided higher intensity and lower palatability ratings than nontasters, but the effect was unequal across tastants. Older participants were more tolerant of unpleasant taste stimuli as evidenced by refusal data, despite finding some taste qualities to be more intense than the younger group. Any impact of these factors and their interactions on motor aspects of swallow function could have significant implications for the ecological validity of VFSS. These data indicate that taste quality, mixture suppression effects of barium, genetic taste status, and age may be relevant to the accurate evaluation of swallowing biomechanics in response to high-concentration taste stimuli for clinical populations and in future studies.

Acknowledgments This work was supported by awards from the American Speech-Language-Hearing Foundation New Investigators Grant (Pelletier) and US Army Medical Research Acquisition Activity No. W811XWH (Solomon).

Conflict of interest The authors certify that they have no conflicts of interest to declare; there are no significant financial interests with a research sponsor or other organization that may otherwise reasonably appear to affect or be affected by the research.

References

1. Pelletier CA, Dhanaraj GE. The effect of taste and palatability on lingual swallowing pressure. Dysphagia. 2006;21(2):121–8. doi:10.1007/s00455-006-9020-0.
2. Plonk DP, Butler SG, Grace-Martin K, Pelletier CA. Effects of chemesthetic stimuli, age, and genetic taste groups on swallowing apnea duration. Otolaryngol Head Neck Surg. 2011;145(4):618–22. doi:10.1177/0194599811407280.
3. Lee KL, Kim DY, Kim WH, Kim EJ, Lee WS, Hahn SJ, Kang MS, Ahn SY. The influence of sour taste on dysphagia in brain injury: blind study. Ann Rehabil Med. 2012;36(3):365–70. doi:10.5535/arm.2012.36.3.365.
4. Logemann JA, Pauloski BR, Colangelo L, Lazarus C, Fujiu M, Kahrilas PJ. Effects of a sour bolus on oropharyngeal swallowing measures in patients with neurogenic dysphagia. J Speech Hear Res. 1995;38(3):556–63.
5. Roa Pauloski B, Logemann JA, Rademaker AW, Lundy D, Sullivan PA, Newman LA, Lazarus C, Bacon M. Effects of enhanced bolus flavors on oropharyngeal swallow in patients treated for head and neck cancer. Head Neck. 2013;35(8):1124–31. doi:10.1002/hed.23086.
6. Palmer PM, McCulloch TM, Jaffe D, Neel AT. Effects of a sour bolus on the intramuscular electromyographic (EMG) activity of muscles in the submental region. Dysphagia. 2005;20(3):210–7. doi:10.1007/s00455-005-0017-x.
7. Chee C, Arshad S, Singh S, Mistry S, Hamdy S. The influence of chemical gustatory stimuli and oral anaesthesia on healthy human pharyngeal swallowing. Chem Senses. 2005;30(5):393–400. doi:10.1093/chemse/bji034.
8. Pelletier CA, Lawless HT. Effect of citric acid and citric acid-sucrose mixtures on swallowing in neurogenic oropharyngeal dysphagia. Dysphagia. 2003;18(4):231–41. doi:10.1007/s00455-003-0013-y.
9. Ding R, Logemann JA, Larson CR, Rademaker AW. The effects of taste and consistency on swallow physiology in younger and older healthy individuals: a surface electromyographic study. J Speech Lang Hear Res. 2003;46(4):977–89. doi:10.1044/1092-4388.
10. Miura Y, Morita Y, Koizumi H, Shingai T. Effects of taste solutions, carbonation, and cold stimulus on the power frequency content of swallowing submental surface electromyography. Chem Senses. 2009;34(4):325–31. doi:10.1093/chemse/bjp005.
11. Leow LP, Huckabee ML, Sharma S, Tooley TP. The influence of taste on swallowing apnea, oral preparation time, and duration

and amplitude of submental muscle contraction. Chem Senses. 2007;32(2):119–28. doi:10.1093/chemse/bjl037.
12. Cola PC, Gatto AR, Silva RG, Spadotto AA, Schelp AO, Henry MA. The influence of sour taste and cold temperature in pharyngeal transit duration in patients with stroke. Arq Gastroenterol. 2010;47(1):18–21. doi:10.1590/S0004-28032010000100004.
13. Todd JT, Butler SG, Plonk DP, Grace-Martin K, Pelletier CA. Main taste effects on swallowing apnea duration in healthy adults. Otolaryngol Head Neck Surg. 2012;147(4):678–83. doi:10.1177/0194599812450839.
14. Lawless HT. The pleasantness of mixtures in taste and olfaction. Sens Processes. 1977;1(3):227–37.
15. Lawless HT, Heymann H. Sensory evaluation of food. New York: Chapman and Hall; 1998.
16. Frank RA, van der Klaauw NJ, Schifferstein HN. Both perceptual and conceptual factors influence taste-odor and taste–taste interactions. Percept Psychophys. 1993;54(3):343–54. doi:10/3758/BF03205269.
17. Green BG, Lim J, Osterhoff F, Blacher K, Nachtigal D. Taste mixture interactions: suppression, additivity, and the predominance of sweetness. Physiol Behav. 2010;101(5):731–7. doi:10.1016/j.physbeh.2010.08.013.
18. Keast RS, Russell SJ, Breslin PA, Paul AS. An overview of binary taste–taste interactions. Food Qual Pref. 2003;14(2):111–24. doi:10.1016/S0950-3293(02)00110-6.
19. Pelletier CA, Lawless HT, Horne J. Sweet-sour mixture suppression in older and younger adults. Food Qual Pref. 2004;15:105–16. doi:10.1016/S0950-3293(03)00037-5.
20. Kalva JJ, Sims SK, Bartoshuk L, Puentes L. Comparison of the hedonic general Labeled Magnitude Scale to the hedonic 9-point scale. Chicago: Paper presented at the annual meeting of the Institute of Food Technology; 2009.
21. Bartoshuk L. Sweetness: history, preference, and genetic variability. Food Technol. 1991;45(11):108–13.
22. Bartoshuk L. The biological basis of food perception and acceptance. Food Qual Pref. 1993;4:21–32. doi:10.1016/0950-3293(93)90310-3.
23. Essick GK, Chopra A, Guest S, McGlone F. Lingual tactile acuity, taste perception, and the density and diameter of fungiform papillae in female subjects. Physiol Behav. 2003;80((2-3):289–302. doi:10.1016/j.physbeh.2003.08.007.
24. Reed DR, Nanthakumar E, North M, Bell C, Bartoshuk LM, Price RA. Localization of a gene for bitter-taste perception to human chromosome 5p15. Am J Hum Genet. 1999;64(5):1478–80. doi:10.1086/302367.
25. Kim UK, Jorgenson E, Coon H, Leppert M, Risch N, Drayna D. Positional cloning of the human quantitative trait locus underlying taste sensitivity to phenylthiocarbamide. Science. 2003;299(5610):1221–5. doi:10.1126/science.1080190.
26. Bartoshuk LM. Comparing sensory experiences across individuals: recent psychophysical advances illuminate genetic variation in taste perception. Chem Senses. 2000;25(4):447–60. doi:10.1093/chemse/25.4.447.
27. Ko CW, Hoffman HJ, Lucchina LA, Snyder DJ, Weiffenbach JM, Bartoshuk LM. Differential perceptions of intensity for the four basic taste qualities in PROP supertasters versus nontasters. Chem Senses. 2000;25:639–40.
28. Mennella JA, Pepino MY, Reed DR. Genetic and environmental determinants of bitter perception and sweet preferences. Pediatrics. 2005;115(2):e216–22. doi:10.1542/peds.2004-1582.
29. Bartoshuk LM, Duffy VB, Lucchina LA, Prutkin J, Fast K. PROP (6-*n*-propylthiouracil) supertasters and the saltiness of NaCl. Ann NY Acad Sci. 1998;855:793–6. doi:10.1111/j.1749-6632.1998.tb10660.x.
30. Karrer T, Bartoshuk LM, Conner E, Fehrenbaker S, Grubin D, Snow D. PROP status and its relationship to the perceived burn intensity of capsaicin at different tongue loci. Chem Senses. 1992;17:649.
31. Prescott J, Ripandelli N, Wakeling I. Binary taste mixture interactions in prop non-tasters, medium-tasters and super-tasters. Chem Senses. 2001;26(8):993–1003. doi:10.1093/chemse/26.8.993.
32. Todd JT, Butler SG, Plonk DP, Grace-Martin K, Pelletier CA. Effects of chemesthetic stimuli mixtures with barium on swallowing apnea duration. Laryngoscope. 2012;122(10):2248–51. doi:10.1002/lary.23511.
33. Kennedy O, Law C, Methven L, Mottram D, Gosney M. Investigating age-related changes in taste and affects on sensory perceptions of oral nutritional supplements. Age Ageing. 2010;39(6):733–8. doi:10.1093/ageing/afq104.
34. Heft MW, Robinson ME. Age differences in orofacial sensory thresholds. J Dent Res. 2010;89(10):1102–5. doi:10.1177/0022034510375287.
35. Fukunaga A, Uematsu H, Sugimoto K. Influences of aging on taste perception and oral somatic sensation. J Gerontol A. 2005;60(1):109–13.
36. Stevens JC, Cain WS, Demarque A, Ruthruff AM. On the discrimination of missing ingredients: aging and salt flavor. Appetite. 1991;16(2):129–40. doi:10.1016/0195-6663(91)90038-T.
37. Cowart BJ. Relationships between taste and smell across the adult life span. Ann NY Acad Sci. 1989;561:39–55. doi:10.1111/j.1749-6632.1989.tb20968.x.
38. Mojet J, Christ-Hazelhof E, Heidema J. Taste perception with age: generic or specific losses in threshold sensitivity to the five basic tastes? Chem Senses. 2001;26(7):845–60. doi:10.1093/chemse/28.5.397.
39. Schiffman SS. The role of taste and smell in appetite and satiety: impact of chemosensory changes due to aging and drug interactions. Paper presented at the Nutrition in a Sustainable Environment (Proceedings of the XVth International Congress of Nutrition, IUNS Adelaide), London, 1994.
40. Stevens JC, Cruz LA, Hoffman JM, Patterson MQ. Taste sensitivity and aging: high incidence of decline revealed by repeated threshold measures. Chem Senses. 1995;20(4):451–9. doi:10.1093/chemse/20.4.451.
41. Whissell-Buechy D. Effects of age and sex on taste sensitivity to phenylthiocarbamide (PTC) in the Berkeley guidance sample. Chem Senses. 1990;15:39–57. doi:10.1093/chemse/15.1.39.
42. Bartoshuk LM, Rifkin B, Marks LE, Bars P. Taste and aging. J Gerontol. 1986;41(1):51–7. doi:10.1093/geronj/41.1.51.
43. Bartoshuk LM. Taste. Robust across the age span? Ann NY Acad Sci. 1989;561:65–75. doi:10.1111/j.1749-6632.1989.tb20970.x.
44. Imoscopi A, Inelmen EM, Sergi G, Miotto F, Manzato E. Taste loss in the elderly: epidemiology, causes and consequences. Aging Clin Exp Res. 2012;24(6):570–9. doi:10.3275/8520.
45. Bartoshuk LM, Duffy VB, Green BG, Hoffman HJ, Ko CW, Lucchina LA, Marks LE, Snyder DJ, Weiffenbach JM. Valid across-group comparisons with labeled scales: the gLMS versus magnitude matching. Physiol Behav. 2004;82(1):109–14. doi:10.1016/j.physbeh.2004.02.033.
46. Hayes JE, Bartoshuk LM, Kidd JR, Duffy VB. Supertasting and PROP bitterness depends on more than the TAS2R38 gene. Chem Senses. 2008;33(3):255–65. doi:10.1093/chemse/bjm084.
47. Bartoshuk LM, Duffy VB, Miller IJ. PTC/PROP tasting: anatomy, psychophysics, and sex effects. Physiol Behav. 1994;56(6):1165–71. doi:10.1016/0031-9384(94)90361-1.
48. Folstein MF, Folstein SE, McHugh PR. “Mini-mental state” a practical method for grading the cognitive state of patients for the clinician. J Psychiatric Res. 1975;12(3):189–98.
49. Coldwell SE, Mennella JA, Duffy VB, Pelchat ML, Griffith JW, Smutzer G, Cowart BJ, Breslin PA, Bartoshuk LM, Hastings L, Victorson D, Hoffman HJ. Gustation assessment using the NIH toolbox. Neurology. 2013;80(11 Suppl 3):S20–4. doi:10.1212/WNL.0b013e3182872e38.

50. National Institutes of Health. NIH toolbox for the assessment of neurological and behavioral function. 2012. www.nihtoolbox.org. Accessed 24 April 2013.
51. Green BG, Dalton P, Cowart B, Shaffer G, Rankin K, Higgins J. Evaluating the 'Labeled Magnitude Scale' for measuring sensations of taste and smell. Chem Senses. 1996;21(3):323–34. doi:10.1093/chemse/21.3.323.
52. Bartoshuk LM, Snyder DJ, Duffy VB. Hedonic gLMA: valid comparisons for food liking/disliking across obesity, age, sex and PROP status. Chem Senses. 2006;31(5):A50.
53. Kalva JJ. Comparison of the hedonic general labeled magnitude scale to the hedonic 9-point scale. Unpublished thesis, University of Florida, 2009.
54. Yau NJN, McDaniel MR. The effect of temperature on carbonation perception. Chem Senses. 1991;16(4):337–48. doi:10.1093/chemse/16.4.337.
55. Harper SJ, McDaniel MR. Carbonated water lexicon: temperature and CO_2 level influence on descriptive ratings. J Food Sci. 1993;58(4):893–8. doi:10.1111/j.1365-2621.1993.tb09386.x.
56. Green BG. The effects of temperature and concentration on the perceived intensity and quality of carbonation. Chem Senses. 1992;17(4):435–50. doi:10.1093/chemse/17.4.435.
57. Zumdahl SS. Chemical principles. 6th ed. Boston: Houghton Mifflin; 2009.
58. Dantas RO, Dodds WJ, Massey BT, Kern MK. The effect of high- vs low-density barium preparations on the quantitative features of swallowing. AJR Am J Roentgenol. 1989;153(6):1191–5.
59. Dantas RO, Kern MK, Massey BT, Dodds WJ, Kahrilas PJ, Brasseur JG, Cook IJ, Lang IM. Effect of swallowed bolus variables on oral and pharyngeal phases of swallowing. Am J Physiol. 1990;258(5 Pt 1):G675–81.
60. Steele CM, van Lieshout PH. Does barium influence tongue behaviors during swallowing? Am J Speech Lang Pathol. 2005; 14(1):27–39.
61. Gilmore MM, Murphy C. Aging is associated with increased weber ratios for caffeine, but not for sucrose. Percept Psychophys. 1989;46(6):555–9. doi:10.3758/BF03208152.
62. Murphy C, Gilmore MM. Quality-specific effects of aging on the human taste system. Percept Psychophys. 1989;45(2):121–8. doi:10.3758/BF03208046.
63. Drewnowski A, Mennella JA, Johnson SL, Bellisle F. Sweetness and food preference. J Nutr. 2012;142(6):1142S–8S. doi:10.3945/jn.111.149575.
64. Ventura AK, Mennella JA. Innate and learned preferences for sweet taste during childhood. Curr Opin Clin Nutr Metab Care. 2011;14(4):379–84. doi:10.1097/MCO.0b013e328346df65.
65. Mennella JA, Lukasewycz LD, Griffith JW, Beauchamp GK. Evaluation of the Monell forced-choice, paired-comparison tracking procedure for determining sweet taste preferences across the lifespan. Chem Senses. 2011;36(4):345–55. doi:10.1093/chemse/bjq134.
66. Mistry S, Rothwell JC, Thompson DG, Hamdy S. Modulation of human cortical swallowing motor pathways after pleasant and aversive taste stimuli. Am J Physiol Gastrointest Liver Physiol. 2006;291(4):G666–71. doi:10.1152/ajpgi.00573.2005.
67. Small DM, Gregory MD, Mak YE, Gitelman D, Mesulam MM, Parrish T. Dissociation of neural representation of intensity and affective valuation in human gustation. Neuron. 2003;39(4): 701–11. doi:10.1016/S0896-6273(03)00467-7.
68. Malandraki GA, Sutton BP, Perlman AL, Karampinos DC, Conway C. Neural activation of swallowing and swallowing-related tasks in healthy young adults: an attempt to separate the components of deglutition. Hum Brain Mapp. 2009;30(10): 3209–26. doi:10.1002/hbm.20743.
69. Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J Speech Lang Hear Res. 2008;51(1):S225–39. doi:10.1044/1092-4388(2008/018.
70. Michou E, Mastan A, Ahmed S, Mistry S, Hamdy S. Examining the role of carbonation and temperature on water swallowing performance: a swallowing reaction-time study. Chem Senses. 2012;37(9):799–807. doi:10.1093/chemse/bjs061.

Angela M. Dietsch PhD

Nancy Pearl Solomon PhD

Catriona M. Steele PhD

Cathy A. Pelletier PhD