

RUNNING HEAD: VOICE QUALITY AND BASIC TASTES

**Tasting prosody: Crossmodal correspondences**

**between voice quality and basic tastes**

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21 **HIGHLIGHTS**

- 22 • Associations between voice quality and basic tastes investigated
- 23 • Sweetness matched more strongly with falsetto than with other voice qualities
- 24 • Bitterness matched more strongly with creaky than with other voice qualities
- 25 • Modal voices matched more strongly with umami than creaky voices
- 26 • Emotional valence partially underlies sweet/bitter-voice quality associations

27

## **Abstract**

Voice quality, or type of phonation (e.g., a whispery voice) can prime specific sensory associations amongst consumers. In the realm of sensory and consumer science, a wide range of taste-sound correspondences have been documented. A growing body of research on crossmodal correspondences has revealed that people reliably associate sounds with basic taste qualities. Here, we examined the largely unexplored associations between basic tastes and sounds: namely taste-voice quality correspondences. Across three pre-registered studies, participants associated four types of voice qualities (modal, whispery, creaky, and falsetto) with the five basic tastes (sweet, sour, salty, bitter, and umami). Study 1 investigated the relations between voice qualities and taste words. Study 2 attempted to replicate the findings and revealed the underpinning psychological mechanisms in terms of semantic/emotional associations. Study 3 used the descriptions of food products that varied in terms of their taste in order to expand the applicability of the findings. The results demonstrated that participants reliably associate specific voice qualities with particular tastes. Falsetto voices are matched more strongly with sweetness than other voices. Creaky voices are matched more strongly with bitterness than with other voice qualities. Modal voices are matched more strongly with umami than creaky voices. Evaluation/positive valence might partially underlie the associations between sweet/bitter-voice quality correspondences. Taken together, these findings reveal a novel case of sound-taste correspondences and deepen our understanding of how people are able to associate attributes from different senses.

*Keywords:* Crossmodal correspondences; Prosody; Taste; Phonation; Food

## **INTRODUCTION**

Voice quality (or type of phonation) can be used to effectively convey specific meanings to consumers. Voices are often used in marketing communications (e.g., voiceover advertisements, broadcast advertising, salesperson-customer interaction). Speakers or communicators manipulate the quality of their voice (e.g., type of phonation, pitch, volume) explicitly or implicitly to convey specific meanings (e.g., Laukka et al., 2016; Whipple & McManamon, 2002). Furthermore, previous research has revealed that subtle variations of voice quality influence persuasion (Van Zant & Berger, 2020; Wang et al., 2021). It has also been suggested that brands, including food brands, use voice qualities such as emphasis, pitch, and rhythm in order to prime specific meanings (e.g., significance, emotional meaning) in their media platforms (Luangrath, Peck, & Barger, 2017). How can the quality of a voice be associated with food-related attributes? More specifically, which types of voices are associated with which basic tastes? These questions are explored in the current research.

## **Previous research on sound-taste correspondences**

Crossmodal correspondences (Spence, 2011, 2020) have been defined as “*the often surprising connections that people ... experience between simple features, attributes, or dimensions of experience, either physically present or else merely imagined, in different sensory modalities*” (Spence, 2019, p. 235). Relevant to the present research, crossmodal correspondences between sounds and basic tastes have frequently been reported (Knöferle & Spence, 2012). A growing body of empirical research now

demonstrates the crossmodal association between basic tastes and the relative pitch of sounds (Crisinel & Spence, 2009, 2010a; Velasco et al., 2014; Wang et al., 2016), tempo (Mesz et al., 2012), certain musical parameters (e.g., roughness, sharpness) (Knoeferle et al., 2015), speech sounds (Motoki et al., 2020, 2021; Ngo et al., 2011; Pathak et al., 2020, 2021, 2022; Pathak & Calvert, 2020, 2021; Simner et al., 2010), timbre (Crisinel & Spence, 2010b; Qi et al., 2020) and musical stimuli (Kontukoski et al., 2015; Mesz et al., 2011; Motoki et al., 2022; Peng-Li et al., 2020; Reinoso Carvalho et al., 2017; Wang et al., 2015; Wang & Spence, 2016).

People have been shown to associate basic tastes, especially sweetness and bitterness, with various auditory parameters. For example, sweetness tends to be associated with relatively higher pitch (Crisinel & Spence, 2010b, 2012), smoother, softer and continuous sounds (Bronner et al., 2012; Knoeferle et al., 2015; Mesz et al., 2011; Simner et al., 2010), lower spectral balance (Bronner et al., 2012; Simner et al., 2010), consonant melody (Bronner et al., 2012; Mesz et al., 2011), legato articulation (Bronner et al., 2012; Mesz et al., 2011), slower tempo (Bronner et al., 2012), the sound of the piano (Crisinel & Spence, 2010b, 2012), and classical music (Motoki et al., 2022).

Whereas bitterness is matched with lower pitch (Crisinel & Spence, 2009, 2012), rough

and dissonant sounds (Knoeferle et al., 2015; Simner et al., 2010) and brass instruments (Crisinel & Spence, 2010b).

### **Sound-taste correspondences, prosody and types of phonation**

Prosody (e.g., stresses, pauses) broadly involves those elements of speech that are not included in the phonetic (e.g., vowels, consonants) component of the speech yet are integral to it (Wagner & Watson, 2010). Prosodic parameters include pitch, phone duration, intensity, and type of phonation (e.g., husky voice; Nygaard et al., 2009; Wagner & Watson, 2010). Prosodic cues themselves have been shown to convey (or change) the intended meanings of words (e.g., ‘that is brilliant’ can be felt as complementary or sarcastic, based on the prosodic features used in speech; Christophe et al., 2003; Nygaard et al., 2009).

A change in the prosodic parameters of speech can influence consumer behaviour (e.g., Gélinas-Chebat, Chebat, & Vaninsky, 1996; Megehee, Dobie, & Grant, 2003; Peterson, Cannito, & Brown, 1995). For example, Peterson and colleagues revealed that certain voice characteristics of the salesperson (e.g., rate of speaking, average pause duration, and fundamental frequency contour) were associated with better sales performance. Though prior research has demonstrated the linkages of prosody with

consumer behaviour, little is known about the association of prosody with tastes and how the prosodic parameters present in speech can influence the expectation of tastes.

### **Previous research on the types of phonation (or voice quality)**

One of the important prosodic parameters that can influence the perception of speech is the type of phonation (e.g., husky vs. creaky voice). Recent research has investigated the association of four types of phonation (creaky, falsetto, whispery, and modal) with size/shape symbolism (Akita, 2021). In this research, Japanese participants listened to hypothetical words spoken with four different types of phonation and rated them on the expected size (from small to large) and shape (from round to pointed). Creaky sounds were rated as larger than modal sounds, while whispery sounds were rated as smaller. Creaky sounds were associated more with angular shapes than modal sounds, while falsetto and whispery sounds were rated as rounder. With the exception of the findings reported by Akita (2021), there is a paucity of research linking the types of phonation with sensory attributes such as basic tastes.

### **The present research**

The present research aimed to reveal crossmodal correspondences between prosody and basic tastes. Specifically, we investigated how different types of phonation (creaky,

falsetto, whispery, and modal) are associated with basic tastes (sweet, sour, salty, bitter, umami (Study 1). Study 2 replicated the findings of Study 1 while exploring the underlying mechanisms by using emotional and semantic measures. Study 3 investigated the association of four different types of phonation within a single taste category and also compared them across two taste categories (e.g., the association of types of phonation in sweet vs. salty foods).

## Study 1

Study 1 investigated the association between different types of phonation (modal, whispery, creaky, and falsetto) with basic tastes (sweet, sour, salty, bitter, and umami).

### *Participants*

One hundred participants ( $M_{\text{age}} = 42.73 \pm 9.20$  years, 70 males, 30 females) were recruited from Lancasters and completed an online survey created on Qualtrics. The sample size was determined by a priori power analysis (Faul et al., 2007). We estimated that a sample size of 100 for each study would be sufficient to detect an effect size ( $f = 0.15$ ) with 95% power at  $\alpha = 0.05$ . The methods and procedures were pre-registered



([https://aspredicted.org/TWR\\_3ZG](https://aspredicted.org/TWR_3ZG)) and the data of all the participants were used and analyzed.

### *Stimuli*

Twenty-four vocal stimuli differing in the types of phonation (six each of modal, whispery, creaky and falsetto) were selected from previous research (Akita, 2021). A vowel-consonant-vowel structure (i.e., VCV) was used to create the stimuli and included /ába/, /áda/, /ága/, /ápa/, /áta/, and /áka/. Our sound stimuli are available at <https://osf.io/jghs2/> (see Appendix Table A in supplementary materials for the details of the stimuli). Only a single vowel (i.e., /á/) was used to control for the potential confounds/known effects of vowels on taste-matching (e.g., Motoki et al., 2020). Each stimulus was spoken in a male voice by a native Japanese speaker in four distinct types of phonation (i.e., modal, creaky, falsetto, and whispery; Akita, 2021).

### *Procedure*

The participants were assigned to four conditions (modal, whispery, creaky, falsetto that were manipulated as within-participant factors) and were asked about the extent to which they associated the speech sounds with sweet, sour, salty, bitter, and umami tastes. The participants then matched each speech sound with the taste words (sweet,

sour, salty, bitter, and umami) on a visual analogue scale (VAS) ranging from 0 (not at all) to 100 (very much). Each participant completed 24 trials where the trial-presentation was randomized within-participants.

### *Statistical analyses and results*

A one-way, repeated-measures ANOVA was used to investigate the effect of the type of phonation on its expected taste. If the assumption of sphericity was violated, a Greenhouse–Geisser correction was applied. Post-hoc analysis was conducted to elucidate the details of the main effect of the phonation. This analysis was conducted using Shaffer's modified sequentially rejective Bonferroni procedure (Shaffer, 1986).

All of the ANOVAs and all of the subsequent multiple testing were conducted using anovakun, a function of R software (Iseki, 2013). Similar analyses were conducted in all studies unless explicitly mentioned. Figure 1 provides a summary of the results. All pairwise comparisons are presented in the supplementary materials (Appendix Table C).

### Sweetness

The results revealed the main effect of the type of phonation ( $F_{2.58, 255.13} = 71.308, p < .001, \eta^2_G = 0.247$ ). Falsetto voices ( $M = 49.94, SD = 17.24$ ) were matched more strongly with sweetness than were the other types of voice. Whispery voices ( $M = 43.09,$

$SD = 19.81$ ) were matched more strongly with sweetness than the modal ( $M = 37.37$ ,  $SD = 16.58$ ) and creaky ( $M = 22.76$ ,  $SD = 16.51$ ) voices. Modal voices were matched more strongly with sweetness than were the creaky voices.

#### Sourness

The results revealed the main effect of the type of phonation ( $F_{2.56, 253.91} = 21.016$ ,  $p < .001$ ,  $\eta^2_G = 0.092$ ). Creaky ( $M = 49.40$ ,  $SD = 17.75$ ) and falsetto ( $M = 46.84$ ,  $SD = 16.34$ ) voices were matched more strongly with sourness than the modal voices ( $M = 36.98$ ,  $SD = 15.53$ ), while whispery ( $M = 38.27$ ,  $SD = 17.70$ ) and modal voices did not differ significantly in terms of an association with sourness.

#### Saltiness

The results revealed the main effect of the type of phonation ( $F_{2.59, 256.55} = 30.199$ ,  $p < .001$ ,  $\eta^2_G = 0.115$ ). Creaky voices ( $M = 54.52$ ,  $SD = 14.06$ ) were matched more strongly with saltiness than the modal voices ( $M = 48.94$ ,  $SD = 13.72$ ). The modal voices were matched more with saltiness than either the falsetto ( $M = 39.66$ ,  $SD = 15.52$ ) or whispery ( $M = 44.16$ ,  $SD = 17.91$ ) voices.

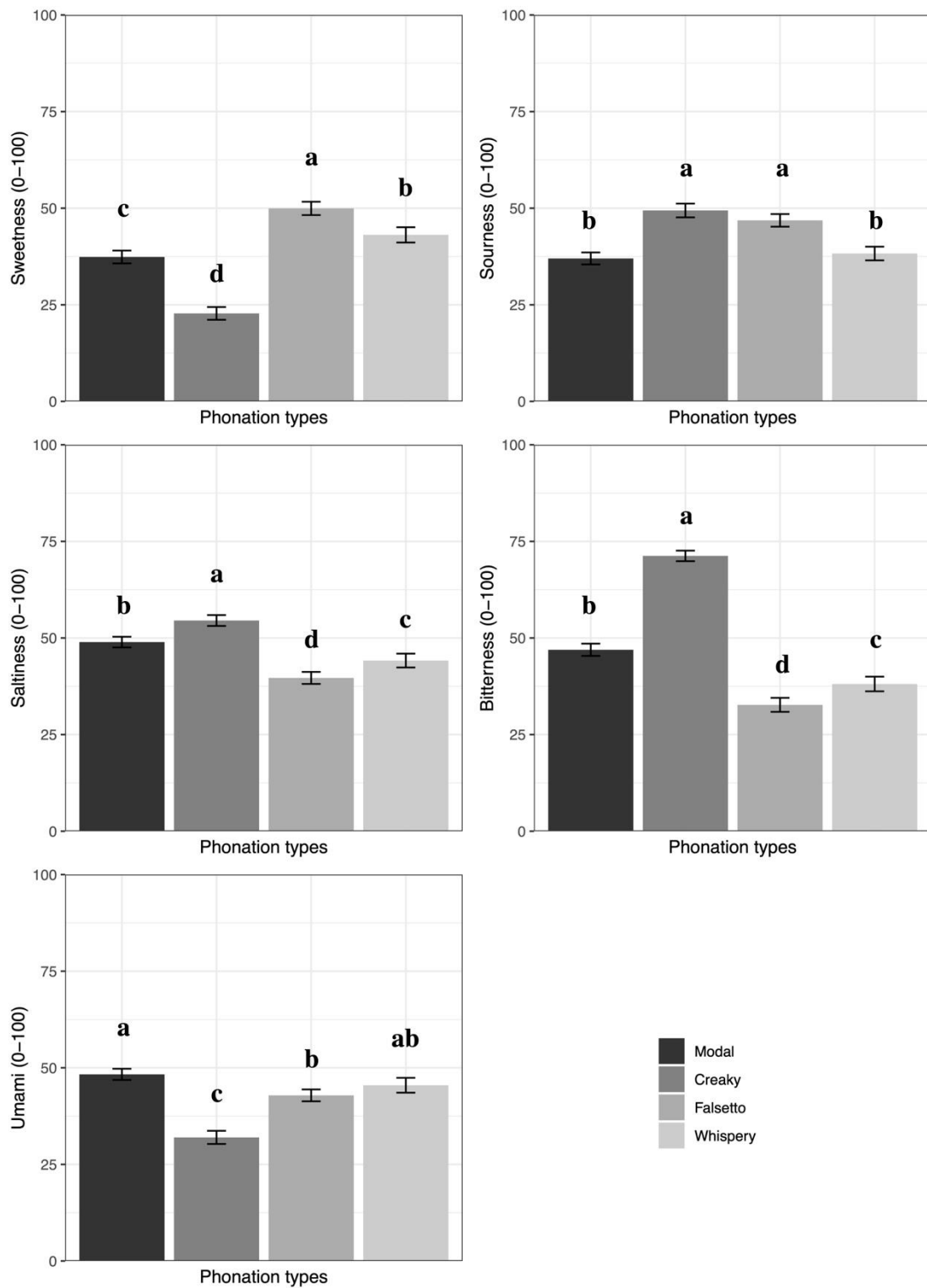
#### Bitterness

202 The results revealed the main effect of the type of phonation ( $F_{2.7, 266.82} = 140.342, p$   
203  $< .001, \eta^2_G = 0.439$ ). Creaky voices ( $M = 71.24, SD = 13.58$ ) were matched more with  
204 bitterness than the other voices. The modal voices ( $M = 46.95, SD = 15.92$ ) were  
205 matched more strongly with bitterness than were either the falsetto ( $M = 32.69, SD =$   
206  $18.12$ ) or whispery ( $M = 38.09, SD = 18.97$ ) voices.

207

#### 208 Umami

209 The results revealed the main effect of the type of phonation ( $F_{2.74, 270.86} = 37.029, p$   
210  $< .001, \eta^2_G = 0.123$ ). Modal voices ( $M = 48.30, SD = 14.47$ ) were matched more with  
211 umami than the falsetto ( $M = 42.86, SD = 15.37$ ) and creaky ( $M = 31.99, SD = 16.99$ )  
212 voices, while modal and whispery ( $M = 45.48, SD = 19.26$ ) voices did not differ  
213 significantly in terms of their expected association with the taste of umami.



**Figure 1.** Results of Study 1. Graphs highlight the relations between types of phonation and tastes. Ratings of taste-matching are on a 0–100 scale (‘not at all’ to ‘very much’). Error bars represent the standard errors of the mean. Different letters (e.g., a/b, b/c) indicate statistically significant differences among types of phonation within each taste

(adj.  $p < .05$  with Shaffer's modified sequentially rejective Bonferroni procedure; Shaffer, 1986).

## *Discussion*

The results of Study 1 revealed the existence of a number of crossmodal correspondences between the types of phonation and basic tastes. Falsetto voices were matched more strongly with sweetness than the other voices; creaky voices were matched more strongly with saltiness and bitterness than the other voices; creaky and falsetto voices were matched more strongly with sourness than were the modal voices; modal voices were matched more strongly with umami than were the falsetto and creaky voices.

## **Study 2**

Study 2 aimed to replicate the findings of Study 1 and explored the underlying mechanisms by emotional and semantic associations.

## *Participants*

One hundred participants ( $M_{\text{age}} = 42.82 \pm 9.72$  years, 63 males, 35 females, 2 preferred not to disclose their gender) were recruited on Lancers and participated in an online survey on Qualtrics. The methods and procedure were pre-registered

([https://aspredicted.org/YY4\\_C6X](https://aspredicted.org/YY4_C6X)) and the data from all participants were used and analyzed.

### *Stimuli*

Eight vocal stimuli (2 each of modal, whispery, creaky and falsetto) were selected from Study 1. The number of stimuli was reduced to shorten the overall length of the experiment, as Study 2 involved a taste-matching task as well as the semantic and emotional rating of the stimuli. The stimuli included /ába/ and /áta/ pronounced in four distinct types of phonation (modal, creaky, falsetto, and whispery). These two stimuli were selected as they differed in terms of voicing (voiced, voiceless) and the place of articulation (bilabial, alveolar) (i.e., /ába/ for voiced and bilabial; /áta/ for voiceless and alveolar). Though voicing and the place of articulation are not of particular interest in the present research, we chose these stimuli intending to test our findings with as diverse a pool of stimuli as possible.

### *Procedure*

The procedure used in the matching task was similar to Study 1. After the matching task, the participants were asked to rate the connotative meanings (evaluation, potency, activity; Osgood, 2009; Osgood et al., 1957) and emotions (arousal, valence; Motoki &

Velasco, 2021). The three dimensions of connotative meanings were measured on a seven-point bipolar semantic differential scale: evaluation (nice–awful, good–bad, mild–harsh, happy–sad;  $\alpha = .766$ ), potency (powerless–powerful, weak–strong, light–heavy, shallow–deep;  $\alpha = .808$ ), and activity (slow–fast, quiet–noisy, passive–active, dead–alive;  $\alpha = .699$ ) (Park et al., 2020; Velasco et al., 2016). Emotions were measured on a seven-point scale: valence (1: negative, 7: positive) and arousal (1: calming, 7: arousing).

#### *Statistical analyses*

A one-way, repeated-measures ANOVA was used to investigate the effect of the type of phonation (modal, whispery, creaky, falsetto) on: 1) the association of each basic taste (sweet, sour, salty, bitter, and umami); and 2) emotions (valence and arousal) and connotative meanings (evaluation, potency, activity). Parallel mediation analyses (MEMORE macro; Montoya & Hayes, 2017) were also conducted to investigate how emotions (valence, arousal) and connotative meanings (evaluation, potency, activity) mediate the relationship between the type of phonation and the expected taste. For the analyses of connotative meaning, three measures of connotative meaning (evaluation, potency, activity) were simultaneously entered into the parallel mediation model as mediators. For the analyses of emotions, two measures of emotion (valence, arousal)



were simultaneously entered into the parallel mediation model as mediators. The indirect effects of connotative meaning and emotion were estimated using 95% bias-corrected bootstrap intervals with 5000 bootstrap samples.

#### *Results of the taste matching task*

Figure 2 provides a summary of the results of Study 2. All pairwise comparisons are presented in the supplementary materials (Appendix Table D).

#### Sweetness

The results revealed a main effect of the type of phonation ( $F_{2.64, 261.32} = 70.476, p < .001, \eta^2_G = 0.242$ ). Falsetto voices ( $M = 53.66, SD = 18.90$ ) were matched more strongly with sweetness than the other voice types. Whispery voices ( $M = 40.06, SD = 18.74$ ) were matched more with sweetness than the modal ( $M = 35.87, SD = 15.44$ ) and creaky ( $M = 26.23, SD = 16.83$ ) voices. Modal voices were matched more with sweetness than were the creaky voices. The results therefore replicated the findings of Study 1.

#### Sourness

296 The results revealed a main effect of type of phonation ( $F_{2.84, 280.9} = 5.109, p < .001, \eta^2_G$   
297  $= 0.018$ ). Creaky voices ( $M = 45.45, SD = 17.23$ ) were matched more with sourness  
298 than the modal ( $M = 41.36, SD = 16.20$ ) and whispery ( $M = 38.83, SD = 17.99$ ) voices.  
299 Creaky voices did not differ from falsetto voices ( $M = 41.45, SD = 18.03$ ) in terms of  
300 their matching with sourness.

301

### 302 Saltiness

303 The results revealed a main effect of the type of phonation ( $F_{2.6, 257.66} = 8.220, p < .001,$   
304  $\eta^2_G = 0.035$ ). Modal ( $M = 49.31, SD = 17.07$ ) and creaky ( $M = 47.43, SD = 18.12$ )  
305 voices were matched more with saltiness than the falsetto voices ( $M = 40.32, SD =$   
306  $17.50$ ). The whispery voices were ( $M = 44.71, SD = 18.68$ ) not significantly different  
307 from the other voices in terms of their association with saltiness.

308

### 309 Bitterness

310 The results revealed a main effect of the type of phonation ( $F_{2.66, 263.79} = 96.070, p$   
311  $< .001, \eta^2_G = 0.341$ ). Creaky voices ( $M = 64.55, SD = 8.61$ ) were matched more with  
312 bitterness than the other types of voice. Modal voices ( $M = 47.32, SD = 16.67$ ) were  
313 matched more with bitterness than the whispery ( $M = 37.74, SD = 19.53$ ) and falsetto

( $M = 30.55$ ,  $SD = 16.18$ ) voices. Whispery voices were matched more with bitterness than the falsetto voices.

#### Umami

The results revealed a main effect of the type of phonation ( $F_{2.71, 268.51} = 18.069$ ,  $p < .001$ ,  $\eta^2_G = 0.065$ ). Modal ( $M = 44.23$ ,  $SD = 17.09$ ), falsetto ( $M = 45.96$ ,  $SD = 17.70$ ), and whispery ( $M = 41.65$ ,  $SD = 19.55$ ) voices were matched more with umami than with creaky voices ( $M = 33.49$ ,  $SD = 18.29$ ).

#### *Results of the semantic and emotional associations*

Figure 3 provides a summary of the results of Study 2. All pairwise comparisons are presented in the Supplementary Materials (see Appendix Table D).

#### Valence

The results revealed a main effect of the type of phonation ( $F_{3, 297} = 34.636$ ,  $p < .001$ ,  $\eta^2_G = 0.111$ ). Modal voices ( $M = 3.77$ ,  $SD = 1.07$ ) were rated as more positive than creaky ( $M = 2.66$ ,  $SD = 1.19$ ), falsetto ( $M = 3.30$ ,  $SD = 1.19$ ), and whispery ( $M = 3.31$ ,  $SD = 1.06$ ) voices. Whispery and falsetto voices were rated as more positive than the creaky voices.

#### Arousal

The results revealed a main effect of the type of phonation ( $F_{3, 297} = 6.546, p < .001, \eta^2_G = 0.017$ ). Creaky ( $M = 3.09, SD = 1.01$ ) and falsetto ( $M = 3.06, SD = 1.08$ ) voices were rated as more arousing than the whispery ( $M = 2.75, SD = 1.06$ ) voices. Modal voices ( $M = 2.91, SD = 1.05$ ) did not differ from the other voices.

#### Evaluation

The results revealed a main effect of the type of phonation ( $F_{3, 297} = 58.924, p < .001, \eta^2_G = 0.218$ ). Modal ( $M = 3.91, SD = 0.68$ ), falsetto ( $M = 3.72, SD = 0.85$ ), and whispery ( $M = 3.90, SD = 0.74$ ) voices were rated as higher in evaluation than creaky ( $M = 2.92, SD = 0.80$ ) voices. Modal voices were also rated as higher in evaluation than were the falsetto voices.

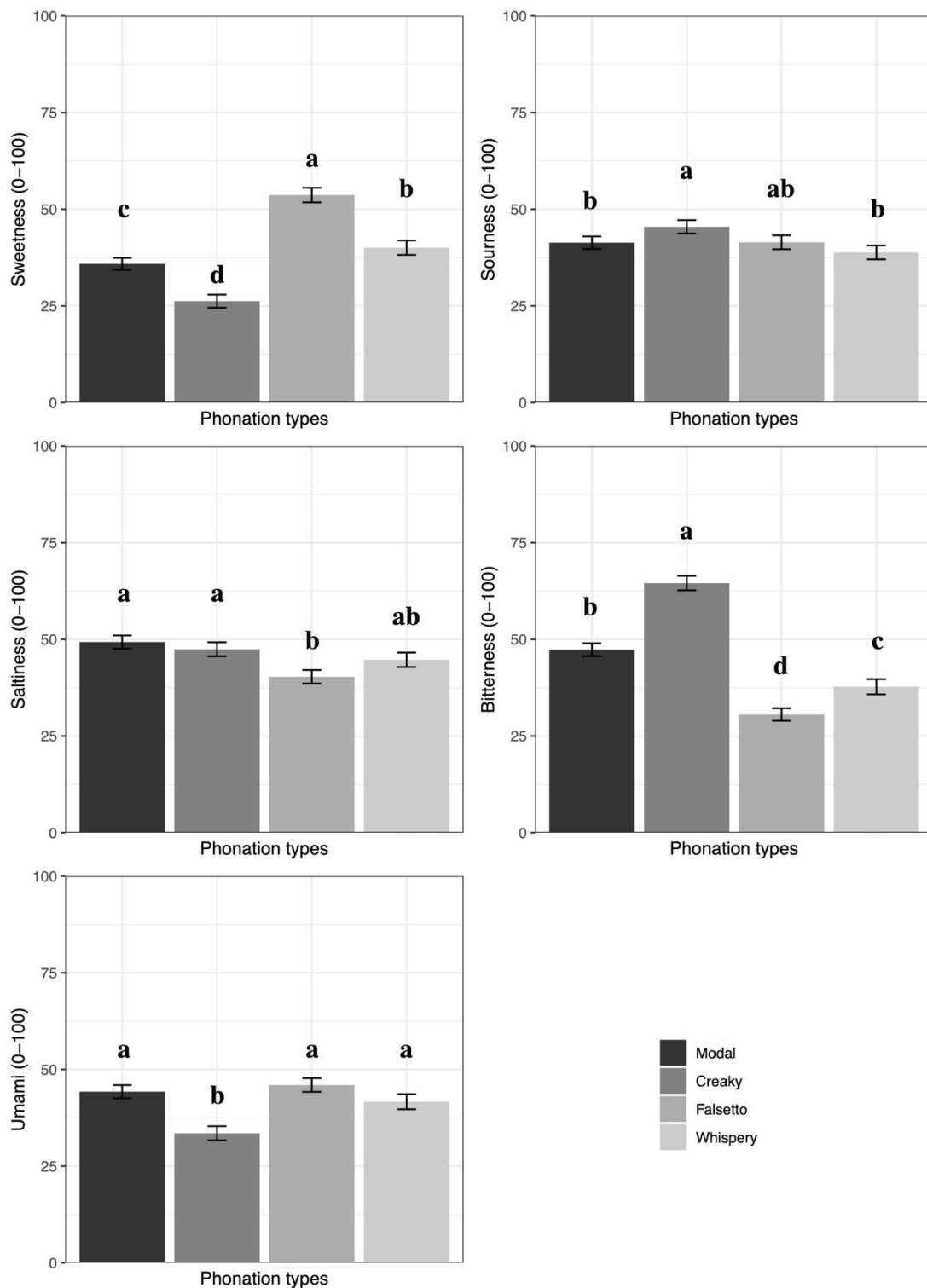
#### Potency

The results revealed a main effect of the type of phonation ( $F_{2.71, 268.68} = 67.323, p < .001, \eta^2_G = 0.270$ ). Modal voices ( $M = 4.00, SD = 0.82$ ) were rated as higher in potency than were the other voices. Creaky voices ( $M = 3.80, SD = 0.98$ ) were rated as higher in potency than the falsetto ( $M = 3.03, SD = 0.76$ ) and whispery ( $M = 2.73, SD = 0.89$ ) voices. Falsetto voices were also rated as higher in potency than the whispery voices.

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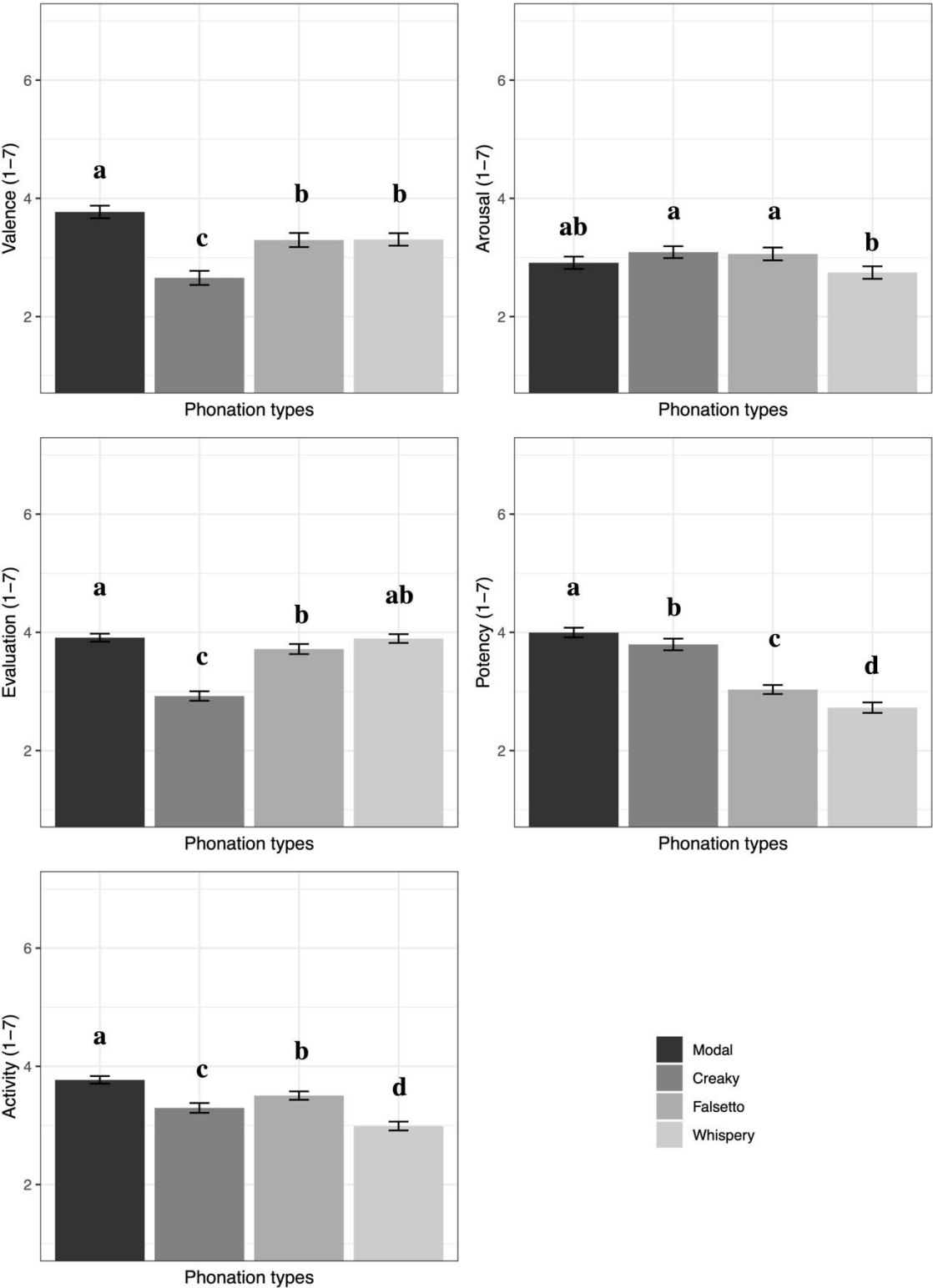
354 Activity

355 The results revealed a significant main effect of the type of phonation ( $F_{3, 297} = 33.188$ ,  
356  $p < .001$ ,  $\eta^2_G = 0.133$ ). Modal voices ( $M = 3.77$ ,  $SD = 0.64$ ) were rated as higher in  
357 activity than the other voices. Falsetto voices ( $M = 3.51$ ,  $SD = 0.71$ ) were rated as  
358 higher in activity than creaky ( $M = 3.30$ ,  $SD = 0.82$ ) and whispery ( $M = 2.99$ ,  $SD =$   
359  $0.74$ ) voices. Creaky voices were also rated as higher in activity than whispery voices.



**Figure 2.** Graphs highlight the relations between the types of phonation and basic tastes in Study 2. Ratings of taste-matching are on a 0–100 scale (‘not at all’ to ‘very much’). Error bars represent the standard errors of the mean. Different letters (e.g., a/b, b/c) indicate statistically significant differences between types of phonation within each taste

365 (adj.  $p < .05$  with Shaffer's modified sequentially rejective Bonferroni procedure;  
366 Shaffer, 1986).  
367



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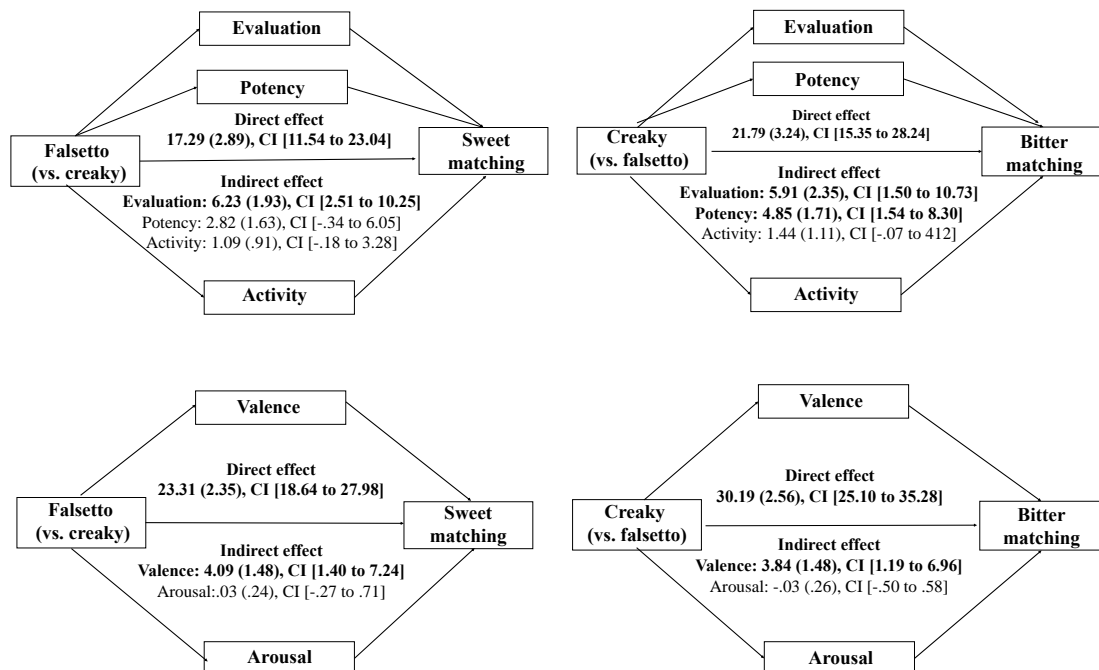
**Figure 3.** Results of Study 2. Graphs highlight the relations between the types of phonation and connotative meaning/emotions. Ratings on a 1–7 scale (‘not at all’ to ‘very much’). Error bars represent the standard errors of the mean. Different letters (e.g., a/b, b/c) indicate statistically significant differences among types of phonation within each taste (adj.  $p < .05$  with Shaffer's modified sequentially rejective Bonferroni procedure; Shaffer, 1986).

#### *Results of the mediation analyses*

First, we examined how connotative meanings mediate the association between the types of phonation and tastes. Indirect effects of falsetto (vs. creaky) voices on sweetness through evaluation were significant ( $B = 6.229$ ,  $SE = 1.934$ , 95% CI [2.514, 10.247]). Falsetto (vs. creaky) voices were rated higher in terms of evaluation and the evaluation was positively associated with sweetness. Indirect effects of creaky (vs. falsetto) voices on bitterness through evaluation and potency were also significant (Evaluation:  $B = 5.912$ ,  $SE = 2.453$ , 95% CI [1.496, 10.734]; Potency:  $B = 4.855$ ,  $SE = 1.714$ , 95% CI [1.543, 8.302]). Creaky (vs. falsetto) voices were rated lower in evaluation (and higher in potency), which was negatively associated with bitterness. Moreover, indirect effects of creaky (vs. modal) voices on bitterness through evaluation were also significant ( $B = 6.504$ ,  $SE = 2.848$ , 95% CI [.778, 12.154]). Creaky (vs. modal) voices were rated lower in evaluation, which was negatively associated with bitterness.



Next, we examined how emotions mediate the association between the types of phonation and tastes (e.g., Motoki, Takahashi, Velasco, & Spence, 2022; Wang, Wang, & Spence, 2016). Indirect effects of falsetto (vs. creaky) voices on sweetness through valence were significant ( $B = 4.008$ ,  $SE = 1.483$ , 95%CI [1.397, 7.238]). Falsetto (vs. creaky) voices increased positivity, which was positively associated with sweetness. Indirect effects of creaky (vs. falsetto or modal) voices on bitterness through valence were also significant (creaky vs. falsetto:  $B = 3.835$ ,  $SE = 1.482$ , 95% CI [1.192, 6.956]; creaky vs. modal:  $B = 8.128$ ,  $SE = 2.194$ , 95% CI [4.228, 12.711]). Creaky (vs. falsetto or modal) voices were rated lower in positivity, which was negatively associated with bitterness. No significant mediations were observed for the other comparisons. The details of the results of the analyses are shown in supplementary materials (Appendix Tables F-R). The graphical illustrations of the results of the mediation analyses (falsetto versus creaky voices) are shown in Figure 4.



**Figure 4.** Graphical illustrations of the results of the mediation analyses in Study 2. Mediation role of connotative meanings and emotions between falsetto versus creaky voices and sweet/bitter matching. Unstandardized coefficients are represented. The value in parentheses indicates the standard error.

## Discussion

Falsetto voices were matched more with sweetness than the other voice types; creaky sounds were matched more with sourness than the modal and whispery voices; modal and creaky voices were matched more with saltiness than the falsetto voices; creaky voices were matched more with bitterness than the other voices; modal, falsetto, and whispery voices were matched more with umami than creaky voices.

### Study 3

Study 3 was designed to reveal how four types of phonation (creaky, falsetto, whispery, and modal) were associated with the distinct tastes of foods (e.g., sweet vs. salty foods).

#### *Participants*

One hundred participants ( $M_{\text{age}} = 40.98 \pm 9.17$  years, 60 males, 38 females, 2 preferred not to disclose their gender) were recruited on Lancers and participated in an online survey on Qualtrics (one participant did not answer the demographic information). The methods and procedures were pre-registered ([https://aspredicted.org/HXP\\_9K5](https://aspredicted.org/HXP_9K5)) and the data from all of the participants were used and analyzed.

#### *Stimuli and procedure*

The stimuli used were the same as in Study 2 and the participants were assigned to all four conditions (modal, whispery, creaky, falsetto, which were manipulated as within-participant factors). First, similar to Studies 1-2, the participants were asked to match each speech sound with food products associated with different tastes (e.g., cake (sweet), black coffee (bitter)) on a visual analogue scale (VAS) ranging from 0 (not at all) to 100 (very much). The details of food products and tastes used were sweet foods

(cake, cookie), sour foods (lemon extract, sour cream), salty foods (salty chips, salt-grilled fish), bitter foods (black coffee, beer) and foods with a distinctive umami taste (umami dashi, konbu dashi; e.g., Meier, et al., 2012). Each participant took part in eight trials (2 each with modal, whispery, creaky, and falsetto voices) where he/she matched the vocal stimuli with ten food items (2 each of sweet, sour, salty, bitter food images) presented on the screen. All the ten images of food items were presented on-screen with all types of voices. Next, the participants rated the taste expectation of food products that they saw before. They were asked to answer taste expectations of each of the ten food products (sweet/sour/salty/bitter/umami; 1: not at all to 7: very much). The order in which the food products and taste ratings were presented was randomized within-participants. The results of taste expectations of the food products are shown in Supplementary Materials (see Appendix Tables S and T).

## *Results*

A one-way, repeated-measures ANOVA was used to investigate the effect of the type of phonation (modal, whispery, creaky, falsetto) on taste expectations (sweet, sour, salty, bitter, and umami). A summary of the results is presented in Figure 4. All pairwise comparisons are presented in the Supplementary Materials (see Appendix Tables E).

457 Sweet foods

458 The results revealed a main effect of the type of phonation ( $F_{2.27, 224.38} = 47.436, p$   
459  $< .001, \eta^2_G = 0.150$ ). Falsetto ( $M = 41.95, SD = 22.29$ ) voices were matched more with  
460 sweet foods than the other voices. Whispery voices ( $M = 32.41, SD = 17.81$ ) were  
461 matched more with sweet foods than the modal ( $M = 27.86, SD = 16.39$ ) and creaky  
462 voices ( $M = 20.97, SD = 15.73$ ). Modal voices were matched more with sweet foods  
463 than the creaky voices.

464

465 Sour foods

466 The results revealed a main effect of the type of phonation ( $F_{2.38, 235.75} = 27.589, p$   
467  $< .001, \eta^2_G = 0.075$ ). Falsetto ( $M = 41.73, SD = 19.13$ ) voices were matched more with  
468 sour foods than with the other voices. Whispery voices ( $M = 36.29, SD = 19.27$ ) were  
469 matched more with sour foods than the modal ( $M = 30.90, SD = 17.75$ ) and creaky  
470 voices ( $M = 27.94, SD = 18.53$ ). Modal voices were matched more with sour foods than  
471 were the creaky voices.

472

473 Salty foods

474 The results revealed a main effect of the type of phonation ( $F_{2.5, 247.47} = 23.190, p$   
475  $< .001, \eta^2_G = 0.047$ ). Modal ( $M = 45.07, SD = 19.66$ ) voices were matched more with

476 salty foods than the other voices. Creaky ( $M = 37.51$ ,  $SD = 20.45$ ) and whispery voices  
477 ( $M = 37.62$ ,  $SD = 18.65$ ) were matched more with salty foods than the falsetto voices  
478 ( $M = 33.52$ ,  $SD = 16.25$ ).

479

#### 480 Bitter foods

481 The results revealed a significant main effect of the type of phonation ( $F_{2.61, 258.83} =$   
482  $48.603$ ,  $p < .001$ ,  $\eta^2_G = 0.139$ ). Modal ( $M = 49.68$ ,  $SD = 21.19$ ) voices were matched  
483 more with bitter foods than were the other voices. Creaky ( $M = 43.00$ ,  $SD = 21.57$ )  
484 voices were matched more with bitter foods than the whispery ( $M = 37.14$ ,  $SD = 17.57$ )  
485 and falsetto voices ( $M = 28.46$ ,  $SD = 17.18$ ). Whispery voices were matched more with  
486 bitter foods than were the falsetto voices.

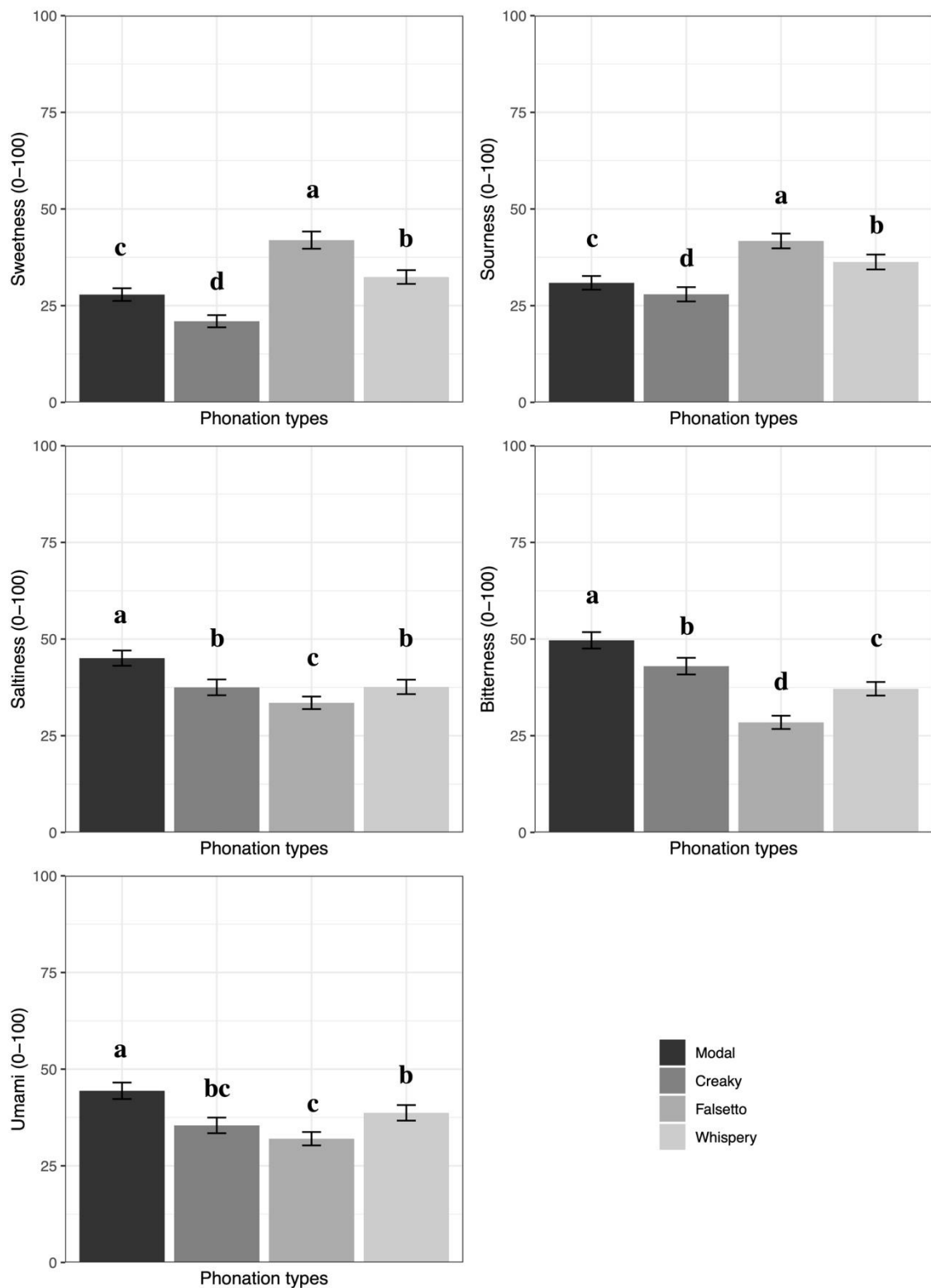
487

#### 488 Umami foods

489 The results revealed a main effect of the type of phonation ( $F_{2.75, 271.76} = 19.862$ ,  $p$   
490  $< .001$ ,  $\eta^2_G = 0.051$ ). Modal ( $M = 44.41$ ,  $SD = 21.27$ ) voices were matched more with  
491 bitter foods than the other voices. Whispery ( $M = 38.70$ ,  $SD = 20.10$ ) voices were  
492 matched more with umami foods than the falsetto voices ( $M = 32.01$ ,  $SD = 17.23$ ). No  
493 differences were found for the whispery and creaky ( $M = 35.45$ ,  $SD = 20.22$ ) voices.

494

495



**Figure 4.** Results of Study 3. Graphs highlight the relations between the types of phonation and tastes. Ratings are on a 0–100 scale (‘not at all’ to ‘very much’). Error bars represent the standard errors of the mean. Different letters (e.g., a/b, b/c) indicate

statistically significant differences among types of phonation within each taste (adj.  $p < .05$  with Shaffer's modified sequentially rejective Bonferroni procedure; Shaffer, 1986).

## General discussion

### *Summary of findings*

The present research revealed crossmodal correspondences between prosody and tastes. Specifically, three pre-registered studies investigated how people match the type of phonation with basic tastes. The results demonstrate that: (1) falsetto voices were matched more with sweetness than the other voice types; (2) creaky voices were matched more with bitterness than certain of the other voices (i.e., falsetto, whispery); (3) modal voices were matched more strongly with umami than were the creaky voices. Moreover, psychological mechanisms underlying the associations between prosody and basic tastes were partially identified. Specifically, evaluation and positivity mediated the relationship between prosody and tastes. These findings demonstrate how different types of voices can be associated with basic tastes and enhance our understanding of taste-speech correspondences.

### *Acoustic properties of sound-taste correspondences*



520 The results contribute to our understanding of the acoustic properties behind well-  
521 known sound-taste correspondences. Previous research on crossmodal correspondences  
522 has demonstrated that various sounds can be associated with different tastes (Crisinel &  
523 Spence, 2009, 2010a; Knoeferle et al., 2015; Knöferle & Spence, 2012; Motoki et al.,  
524 2019, 2020). For example, higher-pitched sounds are matched with sweet and sour  
525 tastes, while lower-pitched sounds are associated with bitter tastes (Crisinel & Spence,  
526 2009, 2010a; Knoeferle et al., 2015; Motoki et al., 2019, 2020). Consistent with the  
527 previous findings (Crisinel & Spence, 2009, 2010a), our results demonstrate that higher-  
528 pitched vocals (i.e., falsetto voices) are matched more strongly with sweet and sour  
529 tastes than relatively lower-pitched vocals (e.g., creaky voices).

530 Different types of phonation vary in the pressure of the associated sound waves (see  
531 Akita, 2021, Fig. 4 for a visual illustration of waveforms), which possibly accounts for  
532 the differing associations of the types of phonation with tastes. Falsetto voices have a  
533 smoother and more gradual change in pressure while whispery voices involve almost no  
534 pressure variation. In contrast, creaky voices are characterized by sharp pressure  
535 changes due to irregular vocal-fold vibrations (Akita, 2021). Previous research on  
536 sound-taste correspondences has revealed similar findings where smoother sounds have  
537 been associated with sweet tastes, whereas rougher sounds have been linked with

bitterness (and sourness) instead (Knoeferle et al., 2015). It has also been suggested that the irregular glottal pulse of a creaky voice is perceived as "vocal roughness" (Lacey et al., 2020). This suggests a similar association between creaky voices and rough music with bitterness. These acoustic properties might also be linked to differences in the emotions that are evoked by different types of phonation (see below).

#### *Psychological mechanisms*

Our findings reveal some of the psychological mechanisms behind the association between the types of phonation and tastes. Prior literature has identified four putative types of crossmodal correspondences (structural, statistical, semantic, and emotional) (Spence, 2011, 2020). Among them, we examined whether connotative meanings and emotions mediate our findings (e.g., Motoki et al., 2022; Wang et al., 2016). The results demonstrated that our results could partially be explained by semantic and emotional associations. For example, evaluation and positive valence mediated the relationship between falsetto (vs. creaky) voices and sweetness. However, the majority of the results of the mediation analyses did not reveal the significant indirect effects; further research could investigate other psychological underpinnings in more depth.

#### *Practical applications*

Our findings provide insights for practitioners and brand managers. Sounds (including voices) and music have often been used to promote and advertise foods. Brand managers could use the congruity between the type of phonation used in the ad, with the taste of food that they plan to advertise using that voice. Such a practice might enhance customer preferences toward the ads. Falsetto voices are often used in popular music (Wise & Others, 2007). Pieces of music with falsetto voices (<https://listcaboodle.com/best-falsetto-songs/>) might be expected to bias consumers toward sweet foods (e.g., chocolate, cake) than those with other types of voice. Given the results of the mediation analysis, it seems that falsetto voices induce positive feelings which in turn enhance the consumers' preference for sweet foods. For salty, umami, and bitter foods, modal sounds were better matched than the other voices, specifically in Study 3. Voiceover advertisements with modal voices seem to be more appropriate for promoting salty, umami, and bitter foods.

#### *Limitations and future directions*

We acknowledge a few potential limitations of the current paper. Firstly, the fatigue of the participants might have influenced the results, for example, we used 24 trials in Study 1, which was higher than usual for an online experiment. Though we randomised

the trial presentation on a within-participants basis to induce variability, this nonetheless remains a limitation that future research can address. Secondly, we used short non-words comprising a VCV (vowel-consonant-vowel) structure as the stimuli. Whether our results can be extended to a wider pool of words/stimuli (e.g., longer words or sentences) is yet to be tested and cannot be ascertained from our findings. Thirdly, we used only Japanese participants as a sample. Most languages use different types of phonetic tools (e.g., whisper, falsetto) in regular speech and future research can test the generalizability of our results to a wider linguistic sample.

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727

**Supplementary materials**

728

**729 Appendix Table A. Stimuli used in Study 1**

<b>Types of phonation</b>	<b>Stimulus No.</b>	<b>Phonetic symbol</b>
modal1	stim1	/ába/
modal2	stim2	/áda/
modal3	stim3	/ága/
modal4	stim7	/ápa/
modal5	stim8	/áta/
modal6	stim9	/áka/
whispery1	stim13	/ába/
whispery2	stim14	/áda/
whispery3	stim15	/ága/
whispery4	stim19	/ápa/
whispery5	stim20	/áta/
whispery6	stim21	/áka/
creaky1	stim25	/ába/
creaky2	stim26	/áda/
creaky3	stim27	/ága/

creaky4	stim31	/ápa/
creaky5	stim32	/áta/
creaky6	stim33	/áka/
falsetto1	stim37	/ába/
falsetto2	stim38	/áda/
falsetto3	stim39	/ága/
falsetto4	stim43	/ápa/
falsetto5	stim44	/áta/
falsetto6	stim45	/áka/

730 *Note:* The stimuli number corresponds with the stimuli number of Akita (2021)

731 (<https://osf.io/jghs2/>)

732

733 **Appendix Table B. Stimuli used in Studies 2 and 3**

Types of phonation	Stimulus No.	Phonetic symbol
modal1	stim1	/ába/
modal2	stim8	/áta/
whispery1	stim13	/ába/
whispery2	stim20	/áta/
creaky1	stim25	/ába/
creaky2	stim32	/áta/

falsetto1                      stimi37                      /ába/

falsetto2                      stimi44                      /áta/

734

735 *Note:* The stimuli number corresponds with the stimuli number of Akita (2021)

736 (<https://osf.io/jghs2/>)

737

738 **Appendix Table C.** Statistical summaries of pairwise comparisons in Study 1:

739 Associations between types of phonation and basic tastes.

Sweetness	Pair	Diff	t-value	adj.p
	Falsetto-Creaky	27.180	13.962	<.001
	Whispery-Creaky	20.323	10.206	<.001
	Modal-Creaky	14.608	9.434	<.001
	Falsetto-Modal	12.572	5.820	<.001
	Whispery-Modal	5.715	3.533	.001
	Falsetto-Whispery	6.857	3.053	.003
Sourness	Pair	Diff	t-value	adj.p
	Creaky-Modal	12.417	7.679	<.001
	Creaky-Whispery	11.135	5.470	<.001
	Falsetto-Modal	9.858	4.788	<.001
	Falsetto-Whispery	8.577	4.498	<.001
	Creaky-Falsetto	2.558	1.150	.506
	Whispery-Modal	1.282	0.870	.506
Saltiness	Pair	Diff	t-value	adj.p
	Creaky-Falsetto	14.860	8.568	<.001
	Modal-Falsetto	9.280	5.877	<.001
	Creaky-Whispery	10.363	5.302	<.001
	Creaky-Modal	5.580	3.901	<.001

Bitterness	Modal-Whispery	4.783	3.587	.001
	Whispery-Falsetto	4.497	2.582	.011
	Pair	Diff	t-value	adj.p
	Creaky-Falsetto	38.555	17.915	<.001
	Creaky-Whispery	33.150	14.147	<.001
	Creaky-Modal	24.298	12.460	<.001
	Modal-Falsetto	14.257	6.804	<.001
	Modal-Whispery	8.852	4.983	<.001
	Whispery-Falsetto	5.405	2.944	.004
Umami	Pair	Diff	t-value	adj.p
	Modal-Creaky	16.312	10.461	<.001
	Whispery-Creaky	13.493	6.941	<.001
	Falsetto-Creaky	10.875	6.762	<.001
	Modal-Falsetto	5.437	3.266	.005
	Modal-Whispery	2.818	1.805	.148
	Whispery-Falsetto	2.618	1.661	.148

740

741 **Appendix Table D.** Statistical summaries of pairwise comparisons in Study 2:

742 Associations between the types of phonation and tastes/semantic meanings/emotions.

Sweetness	Pair	Diff	t-value	adj.p
	Falsetto-Creaky	27.430	12.587	<.001
	Falsetto-Modal	17.795	9.072	<.001
	Whispery-Creaky	13.825	7.397	<.001
	Modal-Creaky	9.635	6.813	<.001
	Falsetto-Whispery	13.605	6.554	<.001
	Whispery-Modal	4.190	2.185	.031
Sourness	Pair	Diff	t-value	adj.p
	Creaky-Whispery	6.620	4.096	<.001
	Creaky-Modal	4.090	2.614	.031
	Creaky-Falsetto	4.000	2.082	.120



Saltiness	Modal-Whispery	2.530	1.603	.337
	Falsetto-Whispery	2.620	1.525	.337
	Falsetto-Modal	0.090	0.049	.961
	Pair	Diff	t-value	adj.p
	Modal-Falsetto	8.985	4.754	<.001
	Creaky-Falsetto	7.105	3.067	.008
	Modal-Whispery	4.595	2.361	.061
	Whispery-Falsetto	4.390	2.320	.067
	Creaky-Whispery	2.715	1.562	.243
Bitterness	Modal-Creaky	1.880	1.109	.270
	Pair	Diff	t-value	adj.p
	Creaky-Falsetto	34.000	14.001	<.001
	Creaky-Whispery	26.810	11.165	<.001
	Creaky-Modal	17.230	8.710	<.001
	Modal-Falsetto	16.770	8.215	<.001
	Modal-Whispery	9.580	4.881	<.001
	Whispery-Falsetto	7.190	3.883	<.001
	Pair	Diff	t-value	adj.p
Umami	Falsetto-Creaky	12.470	7.221	<.001
	Modal-Creaky	10.745	6.637	<.001
	Whispery-Creaky	8.160	3.745	<.001
	Falsetto-Whispery	4.310	2.269	.076
	Modal-Whispery	2.585	1.354	.358
	Falsetto-Modal	1.725	1.062	.358
	Pair	Diff	t-value	adj.p
	Whispery-Creaky	0.973	11.264	<.001
	Modal-Creaky	0.988	11.030	<.001
Evaluation	Falsetto-Creaky	0.795	8.189	<.001
	Modal-Falsetto	0.193	2.447	.049
	Whispery-Falsetto	0.178	2.157	.067
	Modal-Whispery	0.015	0.184	.854
	Pair	Diff	t-value	adj.p
Potency				

Activity	Modal-Whispery	1.270	11.019	<.001
	Modal-Falsetto	0.964	10.370	<.001
	Creaky-Whispery	1.069	9.371	<.001
	Creaky-Falsetto	0.763	6.913	<.001
	Falsetto-Whispery	0.306	3.364	.002
	Modal-Creaky	0.201	2.016	.047
	Pair	Diff	t-value	adj.p
	Modal-Whispery	0.780	9.503	<.001
	Falsetto-Whispery	0.515	6.411	<.001
	Modal-Creaky	0.474	5.689	<.001
	Creaky-Whispery	0.306	3.847	<.001
	Modal-Falsetto	0.265	3.776	<.001
	Falsetto-Creaky	0.209	2.341	.021
	Pair	Diff	t-value	adj.p
Valence	Modal-Creaky	1.115	8.928	<.001
	Whispery-Creaky	0.650	5.910	<.001
	Falsetto-Creaky	0.640	5.563	<.001
	Modal-Whispery	0.465	4.915	<.001
	Modal-Falsetto	0.475	4.375	<.001
	Whispery-Falsetto	0.010	0.095	.924
	Pair	Diff	t-value	adj.p
	Creaky-Whispery	0.345	4.183	<.001
Arousal	Falsetto-Whispery	0.315	3.530	.002
	Creaky-Modal	0.180	2.226	.085
	Modal-Whispery	0.165	1.865	.196
	Falsetto-Modal	0.150	1.682	.196
	Creaky-Falsetto	0.030	0.318	.752

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745 **Appendix Table E.** Statistical summaries of pairwise comparisons in Study 3:

746 Associations between the types of phonation and basic tastes.

Sweetness	Pair	Diff	t-value	adj.p
	Falsetto-Creaky	20.983	9.656	<.001
	Whispery-Creaky	11.435	6.744	<.001
	Falsetto-Modal	14.090	6.486	<.001
	Modal-Creaky	6.893	5.499	<.001
	Falsetto-Whispery	9.548	5.422	<.001
	Whispery-Modal	4.543	2.822	.006
Sourness	Pair	Diff	t-value	adj.p
	Falsetto-Creaky	13.798	7.566	<.001
	Falsetto-Modal	10.830	6.022	<.001
	Whispery-Creaky	8.358	4.580	<.001
	Falsetto-Whispery	5.440	4.014	<.001
	Whispery-Modal	5.390	3.253	.003
	Modal-Creaky	2.968	2.306	.023
Saltiness	Pair	Diff	t-value	adj.p
	Modal-Falsetto	11.555	7.500	<.001
	Modal-Whispery	7.450	6.536	<.001
	Modal-Creaky	7.563	6.252	<.001
	Whispery-Falsetto	4.105	3.111	.007
	Creaky-Falsetto	3.993	2.336	.043
	Whispery-Creaky	0.113	0.075	.940
Bitterness	Pair	Diff	t-value	adj.p
	Modal-Falsetto	21.225	10.551	<.001
	Modal-Whispery	12.543	7.671	<.001
	Creaky-Falsetto	14.543	6.794	<.001
	Whispery-Falsetto	8.683	5.416	<.001
	Modal-Creaky	6.683	4.052	<.001
	Creaky-Whispery	5.860	3.159	.002
Umami	Pair	Diff	t-value	adj.p

Modal-Falsetto	12.395	7.277	<.001
Modal-Creaky	8.955	6.216	<.001
Whispery-Falsetto	6.685	3.842	.001
Modal-Whispery	5.710	3.791	.001
Creaky-Falsetto	3.440	2.019	.092
Whispery-Creaky	3.245	1.707	.092

**Appendix Table F. Connotative meanings mediate the association between falsetto (vs. creaky) voices and sweet tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Falsetto (vs. creaky) →Sweet matching	27.430	2.179	12.587	<.001	23.106	31.754
Falsetto (vs. creaky) →Evaluation	.795	.097	8.189	<.001	.602	.988
Falsetto (vs. creaky) →Potency	-.763	.110	-6.913	<.001	-.981	-.544
Falsetto (vs. creaky) →Activity	.209	.089	2.341	.021	.032	.386
Total effect of Falsetto (vs. creaky) on sweet matching	27.430	2.179	12.587	<.001	23.106	31.754
Direct effect of Falsetto (vs. creaky) on sweet matching	17.291	2.894	5.975	<.001	11.5438	23.038
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
<b>Evaluation</b>	<b>6.229</b>	<b>1.934</b>	<b>2.514</b>	<b>10.247</b>		
Potency	2.817	1.632	-.339	6.050		
Activity	1.093	.9110	-.182	3.277		
<b>Total</b>	<b>10.139</b>	<b>2.547</b>	<b>5.255</b>	<b>15.209</b>		

Note: Figures in bold indicate significant indirect effect.

**Appendix Table G. Connotative meanings mediate the association between falsetto (vs. whispery) voices and sweet tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Falsetto (vs. whispery) →Sweet matching	13.605	2.076	6.554	<.001	9.486	17.724
Falsetto (vs. whispery) →Evaluation	-.178	.082	-2.157	.0334	-.341	-.014
Falsetto (vs. whispery) →Potency	.306	.091	3.364	.001	.126	.487
Falsetto (vs. whispery) →Activity	.515	.080	6.411	<.001	.356	.674
Direct effect of Falsetto (vs. whispery) on sweet matching	12.221	2.657	4.599	<.001	6.944	17.498
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
Evaluation	-.537	.692	-2.138	.673		
Potency	.586	1.149	-1.548	3.239		
Activity	1.335	2.191	-2.936	5.630		
Total	1.384	2.051	-2.500	5.559		

**Appendix Table H. Connotative meanings mediate the association between falsetto (vs. modal) and sweet tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Falsetto (vs. modal) →Sweet matching	17.795	1.962	9.072	<.001	13.903	21.687
Falsetto (vs. modal) →Evaluation	-.193	.079	-2.447	.016	-.349	-.036
Falsetto (vs. modal) →Potency	-.964	.093	-10.370	<.001	-1.148	-.779
Falsetto (vs. modal) →Activity	-.265	.070	-3.776	<.001	-.404	-.126
Direct effect of Falsetto (vs. modal) on sweet matching	16.398	2.849	5.755	<.001	10.740	22.056

Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
Evaluation	-.959	.615	-2.197	.246		
Potency	2.714	2.427	-1.834	7.635		
Activity	-.358	.928	-2.292	1.489		
Total	1.397	2.264	-2.825	6.002		

**Appendix Table I. Emotions mediate the association between falsetto (vs. creaky) voices and sweet tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Falsetto (vs. creaky) →Sweet matching	27.4300	2.179	12.587	<.001	23.106	31.754
Falsetto (vs. creaky) →Valence	.640	.115	5.563	<.001	.412	.868
Falsetto (vs. creaky) →Arousal	-.030	.095	-.318	.752	-.218	.158
Direct effect of Falsetto (vs. creaky) on sweet matching	23.312	2.352	9.914	<.001	18.644	27.980
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
<b>Valence</b>	<b>4.088</b>	<b>1.483</b>	<b>1.397</b>	<b>7.238</b>		
Arousal	.030	.242	-.273	.709		
<b>Total</b>	<b>4.118</b>	<b>1.525</b>	<b>1.416</b>	<b>7.391</b>		

Note: Figures in bold indicate significant indirect effect.

**Appendix Table J. Emotions mediate the association between falsetto (vs. whispery) voices and sweet tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Falsetto (vs. whispery) →Sweet matching	13.605	2.076	6.554	<.001	9.486	17.724
Falsetto (vs. whispery) →Valence	-.010	.105	-.095	.924	-.218	.198

Falsetto (vs. whispery) →Arousal	.315	.089	3.530	.001	.138	.492
Direct effect of Falsetto (vs. whispery) on sweet matching	13.643	2.205	6.186	<.001	9.264	18.021
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
Valence	-.035	.417	-.693	1.061		
Arousal	-.003	.929	-1.916	1.855		
Total	-.038	.981	-1.898	2.003		

**Appendix Table K. Emotions mediate the association between falsetto (vs. modal) voices and sweet tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Falsetto (vs. modal) →Sweet matching	17.795	1.962	9.072	<.001	13.903	21.687
Falsetto (vs. modal) →Valence	-.475	.109	-4.375	<.001	-.690	-.260
Falsetto (vs. modal) →Arousal	.150	.089	1.682	.096	-.027	.327
Direct effect of Falsetto (vs. modal) on sweet matching	19.676	2.126	9.255	<.001	15.456	23.897
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
Valence	-1.432	.788	-2.990	.187		
Arousal	-.449	.532	-1.541	.707		
Total	-1.881	.926	-3.559	.133		

Note: Figures in bold indicate significant indirect effect.

**Appendix Table L. Connotative meanings mediate the association between creaky (vs. falsetto) voices and bitter tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
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Creaky (vs. falsetto) →Bitter matching	34.000	2.428	14.001	<.001	29.181	38.819
Creaky (vs. falsetto) →Evaluation	-.795	.097	-8.189	<.001	-.988	-.602
Creaky (vs. falsetto) →Potency	.763	.110	6.913	<.001	.544	.981
Creaky (vs. falsetto) →Activity	-.209	.089	-2.341	.021	-.386	-.032
Direct effect of Creaky (vs. falsetto) on bitter matching	21.794	3.244	6.719	<.001	15.353	28.235
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
<b>Evaluation</b>	<b>5.912</b>	<b>2.354</b>	<b>1.496</b>	<b>10.734</b>		
<b>Potency</b>	<b>4.855</b>	<b>1.714</b>	<b>1.543</b>	<b>8.302</b>		
Activity	1.438	1.108	-.074	4.121		
<b>Total</b>	<b>12.206</b>	<b>2.698</b>	<b>6.898</b>	<b>17.462</b>		

Note: Figures in bold indicate significant indirect effect.

**Appendix Table M. Connotative meanings mediate the association between creaky (vs. whispery) voices and bitter tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Creaky (vs. whispery) →Sweet matching	26.810	2.401	11.165	<.001	22.045	31.575
Creaky (vs. whispery) →Evaluation	-.973	.086	-11.264	<.001	-1.144	-.801
Creaky (vs. whispery) →Potency	1.069	.114	9.371	<.001	.843	1.295
Creaky (vs. whispery) →Activity	.306	.080	3.847	<.001	.148	.464
Direct effect of creaky (vs. whispery) on bitter matching	20.122	4.150	4.849	<.001	11.881	28.362
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		



Evaluation	3.070	3.506	-3.528	10.181		
Potency	4.928	3.074	-1.298	10.820		
Activity	-1.309	1.292	-4.017	1.192		
Total	6.688	4.216	-1.905	14.742		

**Appendix Table O. Connotative meanings mediate the association between creaky (vs. modal) voices and bitter tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Creaky (vs. modal) →Bitter matching	17.230	1.978	8.710	<.001	13.305	21.155
Creaky (vs. modal) →Evaluation	-.988	.090	-11.030	<.001	-1.165	-.810
Creaky (vs. modal) →Potency	-.201	.100	-2.016	.047	-.399	-.003
Creaky (vs. modal) →Activity	-.474	.083	-5.689	<.001	-.639	-.309
Direct effect of creaky (vs. modal) on bitter matching	10.012	2.935	3.411	.001	4.183	15.841
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
<b>Evaluation</b>	<b>6.504</b>	<b>2.848</b>	<b>.778</b>	<b>12.154</b>		
Potency	.352	.532	-.600	1.585		
Activity	.362	1.499	-2.589	3.404		
<b>Total</b>	<b>7.218</b>	<b>2.683</b>	<b>1.860</b>	<b>12.444</b>		

Note: Figures in bold indicate significant indirect effect.

**Appendix Table P. Emotions mediate the association between creaky (vs. falsetto) voices and bitter tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Creaky (vs. falsetto) →Bitter matching	34.000	2.428	14.001	<.001	29.181	38.819
Creaky (vs. falsetto) →Valence	-.640	.115	-5.563	<.001	-.8683	-.412

Creaky (vs. falsetto) →Arousal	.030	.095	.318	.7516	-.1575	.218
Direct effect of creaky (vs. falsetto) on bitter matching	30.193	2.564	11.777	<.001	25.104	35.283
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
<b>Valence</b>	<b>3.835</b>	<b>1.482</b>	<b>1.192</b>	<b>6.956</b>		
Arousal	-.028	.256	-.503	.584		
<b>Total</b>	<b>3.807</b>	<b>1.520</b>	<b>1.110</b>	<b>7.045</b>		

Note: Figures in bold indicate significant indirect effect.

**Appendix Table Q. Emotions mediate the association between creaky (vs. whispery) voices and bitter tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
Creaky (vs. whispery) →Bitter matching	26.810	2.401	11.165	<.001	22.045	31.575
Creaky (vs. whispery) →Valence	-.650	.110	-5.910	<.001	-.868	-.432
Creaky (vs. whispery) →Arousal	.345	.083	4.183	<.001	.181	.509
Direct effect of creaky (vs. whispery) on bitter matching	24.451	2.917	8.383	<.001	18.661	30.242
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
Valence	1.991	1.515	-.848	5.094		
Arousal	.368	1.324	-2.050	3.257		
Total	2.359	2.299	-2.000	6.954		

Note: Figures in bold indicate significant indirect effect.

**Appendix Table R. Emotions mediate the association between creaky (vs. modal) voices and bitter tastes in Study 2**

	Effect	SE	t	p	LLCI	ULCI
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Creaky (vs. modal) →Bitter matching	17.230	1.978	8.710	<.001	13.305	21.155
Creaky (vs. modal) →Valence	-1.115	.125	-8.928	<.001	-1.363	-.867
Creaky (vs. modal) →Arousal	.180	.081	2.226	.028	.020	.341
Direct effect of creaky (vs. modal) on bitter matching	8.965	2.459	3.645	<.001	4.082	13.847
Indirect effect	Effect	Boot SE	Boot LLCI	Boot ULCI		
<b>Valence</b>	<b>8.128</b>	<b>2.194</b>	<b>4.228</b>	<b>12.711</b>		
Arousal	.138	.424	-.713	1.070		
<b>Total</b>	<b>8.266</b>	<b>2.293</b>	<b>4.105</b>	<b>13.031</b>		

*Note:* Figures in bold indicate significant indirect effect.

794 **Appendix Table S.** Basic statistics of Study 3: Associations between the taste of foods

795 and taste expectations.

Sweetness	Taste of foods	Mean	S.D.
	Sweet	6.74	0.53
	Sour	2.32	1.17
	Salty	1.85	0.89
	Bitter	2.95	0.93
	Umami	3.21	1.92
Sourness	Taste of foods	Mean	S.D.
	Sweet	3.35	1.19
	Sour	6.09	0.82
	Salty	2.86	1.12
	Bitter	2.83	1.22
	Umami	3.08	1.45
Saltiness	Taste of foods	Mean	S.D.
	Sweet	2.74	1.23
	Sour	2.16	1.06
	Salty	6.21	0.60
	Bitter	2.87	0.90
	Umami	4.97	1.20
Bitterness	Taste of foods	Mean	S.D.
	Sweet	2.08	1.03
	Sour	3.75	1.22
	Salty	1.62	0.88
	Bitter	6.40	0.67
	Umami	3.24	1.70
Umami	Taste of foods	Mean	S.D.
	Sweet	3.54	1.43
	Sour	2.18	1.19
	Salty	4.42	1.28
	Bitter	2.34	1.07

Umami 6.57 0.64

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797 **Appendix Table T.** Statistical summaries of pairwise comparisons of Study 3:

798 Associations between the taste of foods and taste expectations.

Sweetness	Results of ANOVA	Pair	Diff	t-value	adj.p
	$F_{2,46,241.21} = 319.066,$	Sweet-Salty	4.889	42.768	<.001
	$p < .001,$	Sweet-Sour	4.414	31.624	<.001
	$\eta^2_g = 0.683$	Sweet-Bitter	3.788	30.561	<.001
		Sweet-Umami	3.525	17.939	<.001
		Bitter-Salty	1.101	11.216	<.001
		Umami-Salty	1.364	7.533	<.001
		Bitter-Sour	0.626	5.525	<.001
		Sour-Salty	0.475	4.870	<.001
		Umami-Sour	0.889	4.458	<.001
		Umami-Bitter	0.263	1.265	.209
Sourness	Results of ANOVA	Pair	Diff	t-value	adj.p
	$F_{4,392} = 164.203,$	Sour-Salty	3.227	21.474	<.001
	$p < .001,$	Sour-Bitter	3.253	19.900	<.001
	$\eta^2_g = 0.526$	Sour-Umami	3.010	18.513	<.001
		Sour-Sweet	2.732	16.832	<.001
		Sweet-Bitter	0.520	3.728	.002
		Sweet-Salty	0.495	3.395	.004
		Sweet-Umami	0.278	1.680	.384
		Umami-Salty	0.217	1.566	.384
		Umami-Bitter	0.242	1.555	.384
		Salty-Bitter	0.025	0.183	.855
Saltiness	Results of ANOVA	Pair	Diff	t-value	adj.p
	$F_{3,51,343.8} = 346.810,$	Salty-Sour	4.051	31.666	<.001
	$p < .001,$	Salty-Bitter	3.333	29.787	<.001
	$\eta^2_g = 0.696$	Salty-Sweet	3.470	25.587	<.001

Bitterness	$F_{3.04, 298.26} = 313.524,$ $p < .001,$ $\eta^2_G = 0.680$	Umami-Sour	2.813	18.754	<.001
		Umami-Sweet	2.232	16.073	<.001
		Umami-Bitter	2.096	15.818	<.001
		Salty-Umami	1.237	9.586	<.001
		Bitter-Sour	0.717	7.485	<.001
		Sweet-Sour	0.581	4.202	<.001
		Bitter-Sweet	0.136	0.983	.328
		Pair	Diff	t-value	adj.p
		Bitter-Salty	4.783	41.226	<.001
		Bitter-Sweet	4.323	32.268	<.001
		Bitter-Sour	2.652	20.136	<.001
		Bitter-Umami	3.167	16.672	<.001
		Sour-Salty	2.131	14.760	<.001
		Sour-Sweet	1.672	12.462	<.001
		Umami-Salty	1.616	9.185	<.001
		Umami-Sweet	1.157	7.640	<.001
		Sweet-Salty	0.460	4.179	<.001
		Sour-Umami	0.515	2.759	.007
Umami	$F_{3.45, 338.24} = 317.801,$ $p < .001,$ $\eta^2_G = 0.662$	Pair	Diff	t-value	adj.p
		Umami-Bitter	4.227	29.544	<.001
		Umami-Sour	4.389	28.963	<.001
		Umami-Sweet	3.025	19.011	<.001
		Salty-Sour	2.242	16.409	<.001
		Umami-Salty	2.147	14.415	<.001
		Salty-Bitter	2.081	14.115	<.001
		Sweet-Sour	1.364	9.747	<.001
		Sweet-Bitter	1.202	7.842	<.001
		Salty-Sweet	0.879	6.230	<.001
		Bitter-Sour	0.162	1.786	.077

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