



Individual differences in sensitivity to taste-shape crossmodal correspondences

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ABSTRACT

People generally associate curved and symmetrical shapes with sweetness, while associating angular and asymmetrical shapes with the other basic tastes (e.g., sour, bitter). However, these group-level taste-shape correspondences likely conceal important variation at an individual-level. We examined the extent to which individuals vary in their sensitivity to crossmodal correspondence between curvature and symmetry, on the one hand, and the five basic taste qualities (sweet, bitter, salty, sour, and umami), on the other. In Experiment 1, participants matched shapes (curved vs. angular, symmetrical vs. asymmetrical) and taste words. In Experiment 2, participants performed a similar task, though this time using actual tastants. Given that people differ in their hedonic experience of such shapes and tastes, we also measured participants' liking for each taste and shape separately. The results replicate the general crossmodal correspondences between curved-sweet and symmetrical-sweet stimuli. Furthermore, participants tended to match sour and bitter tastes with angular and asymmetrical stimuli. However, these group-level taste-shape correspondences coexist alongside substantial variation at the level of the individual. While some participants consistently matched specific tastes with curved and symmetrical stimuli, others consistently matched these tastes with angular and asymmetrical stimuli, or else did not show these taste-shape correspondences. Liking for curved and symmetrical stimuli was higher than for angular and asymmetrical stimuli. However, participants also differed considerably in the extent to which these visual features affected their liking. Overall, our findings highlight the substantial individual differences that are associated with the degree to which people associate and like shapes and tastes.

1. Introduction

Most of our experiences are based on multisensory stimulation (Spence & Bayne, 2015). Our brains integrate sensory information from multiple senses in order to perceive and interact with the environment around us (Calvert et al., 2004). One of the mechanisms that has been shown to influence multisensory integration is referred to as crossmodal correspondences, that is, the associations that people appear to make between attributes or features across the senses (Motoki, Marks, & Velasco, 2023; Spence, 2011, 2022).

Relevant to the theme of the present study, the research shows that people associate visual attributes such as symmetry and curvature with sweetness, while typically associating angularity and asymmetry with the other tastes (sour, bitter, salty, and umami; Juravle et al., 2022; Pich et al., 2020; Salgado-Montejo et al., 2015; Turoman et al., 2017; Velasco

et al., 2015). This research has been observed and replicated in a number of contexts, such as those involving abstract shapes (e.g., Velasco, Woods, Marks, et al., 2016), the shape of packaging (e.g., Velasco et al., 2014), and the shape properties of plateware (e.g., Fairhurst et al., 2015), to mention but a few (for reviews, see Spence, 2023; Velasco, Woods, Petit, et al., 2016). Whilst it is not altogether clear under what conditions shapes influence taste perception (Piqueras-Fiszman et al., 2012), nevertheless the association between basic taste qualities and shapes appear to be robust (Motoki, Spence, et al., 2023).

Importantly, the literature also suggests that people prefer symmetrical and curved shapes over asymmetrical and angular shapes (Palmer et al., 2013) and sweet tastes more than the other tastes (Steiner et al., 2001). These group-level effects have partly been explained by the affective values that characterize visual symmetry, curvature, and basic taste qualities (e.g., Velasco et al., 2015).

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However, a growing number of studies now show that group-level effects frequently mask considerable variation in how people perceive and evaluate sensory stimuli (Bremner et al., 2013; Corradi et al., 2019, 2020; Marks, 1974). For instance, Marks (1974) evaluated crossmodal associations between light and sound, reporting that while most participants consistently matched increasing pitch with increasing brightness, some participants matched increasing loudness to increasing brightness, others matched increasing loudness to increasing darkness. Marks' results thus suggest that the correspondence between auditory and visual brightness might not be the same for all participants. In the context of shape perception, Corradi et al. (2020) recently found that while people generally prefer symmetrical and curved objects over asymmetrical and angular objects, these preferences once again coexist with remarkable individual differences. Clemente et al. (2021) also reported that people vary substantially in the extent to which their hedonic judgments of visual designs depend on symmetry and curvature. That is, some people do not exhibit a preference for curved and symmetrical objects, but are insensitive to those features or else prefer angular and asymmetrical objects instead. Similarly, in the context of taste (gustatory) perception, it is known that significant individual differences exist in terms of the liking for sweetness and the sensitivity to bitterness, to mention but two (Yeomans et al., 2022). For example, researchers characterize people in terms of how they respond to increasing concentrations of sweet solutions, suggesting that certain people (sweet dislikers) start disliking the solutions at lower concentrations than others (sweet likers and neutrals, see Iatridi et al., 2019).

The aforementioned variations in shape and taste preference could also characterize crossmodal correspondences between shapes and tastes since little is known about the extent to which taste-shape associations vary between people. Recently, Spence (2022) highlighted the growing interest in studying group and individual differences in crossmodal correspondences, revealing trends related to development, sensory loss, autistic tendencies, synaesthesia, creativity, and musical experience (Chen et al., 2021; Crisinel & Spence, 2012). For instance, Chen et al. (2021) investigated the influence of autistic traits on colour-taste, shape-taste, and shape-colour associations. While higher autistic traits predicted decreasing colour-taste, and shape-colour associations, these traits did not influence taste-shape associations. Hamamoto et al. (2020) found that eating disorder tendencies and personality traits influence taste-shape associations. Specifically, drive for thinness was related to an increased probability of matching sweetness to round shapes, and the obsessiveness trait mediated this relationship. Bremner et al. (2013) found cross-cultural differences in the way western participants and people from the Himba tribe associate flavours and shapes, albeit with a small sample size. Relatedly, Wan et al. (2014) found cross-cultural similarities and dissimilarities in the correspondence between tastes and visual features in Eastern and Western countries. Therefore, these authors highlighted that certain crossmodal correspondences might be more subject to people's cultural background than others. These differences, according to Spence (2022), affect the strength and expression of crossmodal correspondences, being typically multifaceted. However, since individual differences encompass multiple sources of variation, the field faces challenges such as limited data and debates concerning the very existence (or robustness) of various crossmodal correspondences at the individual and population level.

In two relevant studies, Corradi et al. (2020) and Clemente et al. (2021) inquired into the nature of individual differences in sensory valuation. These authors developed the concept of sensitivity or responsiveness as the degree to which a specific feature influences an individual evaluation of sensory input. Simultaneously, they provided a measure of individual variability in sensory valuation using the individual slopes of participants in linear mixed-effects models. This method provides a means of studying individual variation because it assesses the relevance of particular features in the computation of the hedonic value for each individual in a particular context (Clemente, 2022; Clemente et al., 2021; Corradi et al., 2020). Furthermore, it has been used in

multisensory research in the visual and musical domains (e.g., Clemente et al., 2021). However, the study of people's sensitivity to other attributes and sensory modalities remains unclear and constitutes an obvious line of study (Clemente, 2021). In the context of taste-shape correspondences, averaging shape ratings for a particular taste across participants (e.g., Velasco et al., 2015) could mask the degree to which a particular association is present and varies from one participant to another (see Fig. 1). That is, simply concluding that people generally associate, e.g., curvature with sweetness does not contribute much to the understanding of the psychological processes underlying this correspondence (Clemente, 2021). Given this scenario, the present research aims to examine the extent to which individuals vary in their sensitivity to taste-shape correspondences, a variable of individual differences that has not previously been studied in correspondences.

In two experiments, shape properties (contour and symmetry) and taste qualities (sweet, bitter, salty, sour, and umami) were manipulated. In Experiment 1, participants associated shapes and taste words using shape scales anchored by shapes that are either angular or curved (contour block) and either asymmetrical or symmetrical (symmetry block). In Experiment 2, participants associated the same shapes with real sweet, bitter, salty, sour, and umami solutions. In both experiments, the participants also rated their liking for each taste and shape. To examine individual differences in taste-shape crossmodal correspondences, we estimated participants' sensitivity to the consensual crossmodal association between curvature and symmetry with each taste quality (sweet, bitter, salty, sour, and umami). In this context, sensitivity refers to the individual slope of a participant in linear mixed-effects models (Clemente, 2022; Clemente et al., 2021; Corradi et al., 2020). Following the relevant literature (Corradi et al., 2019, 2020; Velasco et al., 2015), we expected to uncover considerable variation in how participants associate and evaluate shapes and tastes.

On the other hand, it is unclear whether people's sensitivities to crossmodal correspondences are related across the senses. That is, whether someone's sensitivity to a particular feature (e.g., curvature or symmetry) could also influence the crossmodal association between this feature and taste qualities, say. Clemente et al. (2022) found that visual and auditory liking judgments of contour but not symmetry were related. Thus, we explored whether this also occurs in the visual and taste domains. If comparable variability is unraveled in the crossmodal association and hedonic evaluation of shapes and tastes, this would suggest a kind of supramodal computation of the values associated with these sensory modalities.¹

2. Experiment 1

2.1. Methods

2.1.1. Participants

Ninety-eight participants (48 women, $M_{age} = 45.83$ years, $SD_{age} = 14.46$) were recruited via Prolific Academic (<https://app.prolific.com/>). All participants reported normal or corrected-to-normal vision. The study was conducted following the code of practice of the BPS guidelines, the [BLINDED] ethical guidelines as well as the Declaration of Helsinki (2008). All participants gave written informed consent prior to the experiment.

The final sample size was determined based on a *a priori* power analysis for linear mixed models using the *simr* package in R (Green & MacLeod, 2016), and following the considerations presented by Judd and colleagues (2017). First, we simulated a dataset considering a 2 (angular vs. curved or asymmetrical vs. symmetrical) x 5 (Taste: sweet, bitter, salty, sour, umami) within-participants factorial design. The

¹ The study was preregistered prior to data collection. The pre-registration can be found at the Open Science Framework: <https://osf.io/8v934> (<https://doi.org/10.17605/OSF.IO/8V934>).

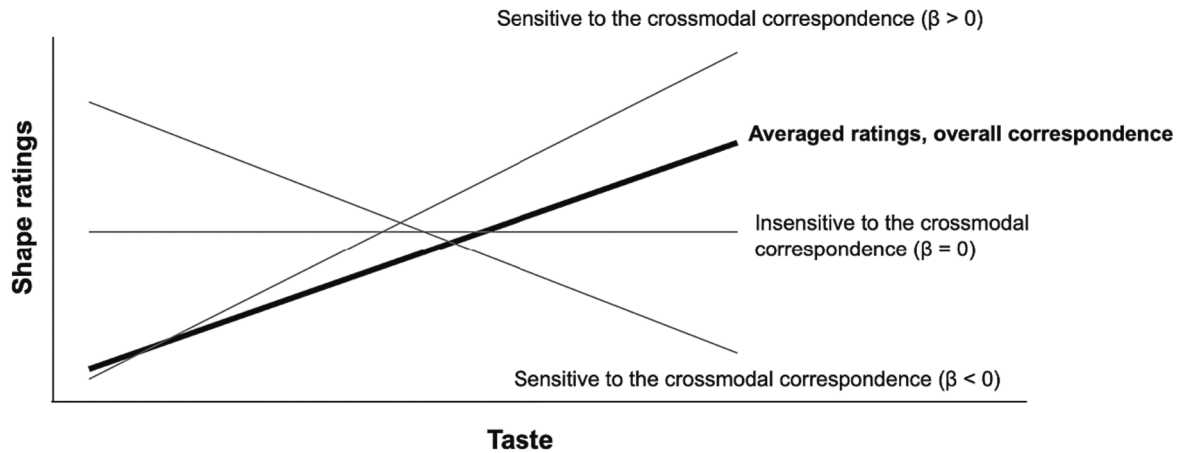


Fig. 1. Individual responsiveness or sensitivity to a particular taste-shape correspondence concealed by averaged trends. Figure adapted from Clemente (2021). X-axis represents any particular taste (e.g., sweet, bitter, salty, sour, or umami). Y-axis represents ratings for shape properties (symmetry and curvature). Each thin line represents the variability of an individual in shape ratings for a particular taste. The thick line corresponds to mean shape ratings across individuals. β stands for the individual slope in the model of shape ratings for the particular taste.

dataset included a sample of 10 participants providing 60 trials for a total of 600 observations. Second, the population parameters with a mean liking equal to 50, and a large coefficient for the crossmodal association between shapes and tastes (e.g., curvature and sweetness) ($b = 0.80$) were defined. The selection of these parameters followed the relevant literature (Salgado-Montejo et al., 2015; Velasco et al., 2015). Third, we applied mixed-effects modelling to the simulated dataset. The model was fitted using the `makeLmer` function in the R package `simr`. Ratings (contour or symmetry) were included as the outcome variable, and Taste (sweet, bitter, salty, sour, and umami) was specified as a fixed effect. Participant and stimulus were included as random effects, and random intercepts were specified for each random effect. Next, based on the model's results, we ran the simulation using the `powerSim` function with 300 simulations and an alpha level of 0.05. Finally, we estimated a power curve with 100 simulations and Satterthwaite approximation to determine statistical significance. Results indicated a sample size of 90 participants to reach the desired test power of 80 %.

2.1.2. Apparatus and materials

Visual stimuli. Curved and angular stimuli consisted of a set of 24

meaningless shapes, designed following the guidelines from Bertamini et al. (2016). Half of the stimuli had curved contours while the remainder had angular contours. Following previous studies (e.g., Corradi et al., 2020), we incorporated some variability in the stimuli by including equal numbers of figures with 22 and 26 vertices, and the same number of designs created from circles, ovals, and lobed ovals (Fig. 2a).

Symmetrical and asymmetrical stimuli consisted of a set of 24 patterns from Jacobsen and Höfel's (2002) stimuli. These stimuli consist of a series of solid black circles with a centered white square containing triangles arranged to form designs that vary in mirror symmetry (i.e., with respect to vertical, horizontal, and diagonal axes) and complexity (defined as the number of elements). We selected 12 symmetrical and 12 asymmetrical stimuli matched for different degrees of complexity, corresponding to the number of constituent elements (simple–complex) (Fig. 2b). The image sizes of all visual stimuli were set to 450x450 pixels.

Taste stimuli. Taste stimuli consisted of taste words (sweet, bitter, salty, sour, and umami) presented in English on the computer screen in Courier New, font size 20 (Velasco et al., 2015).

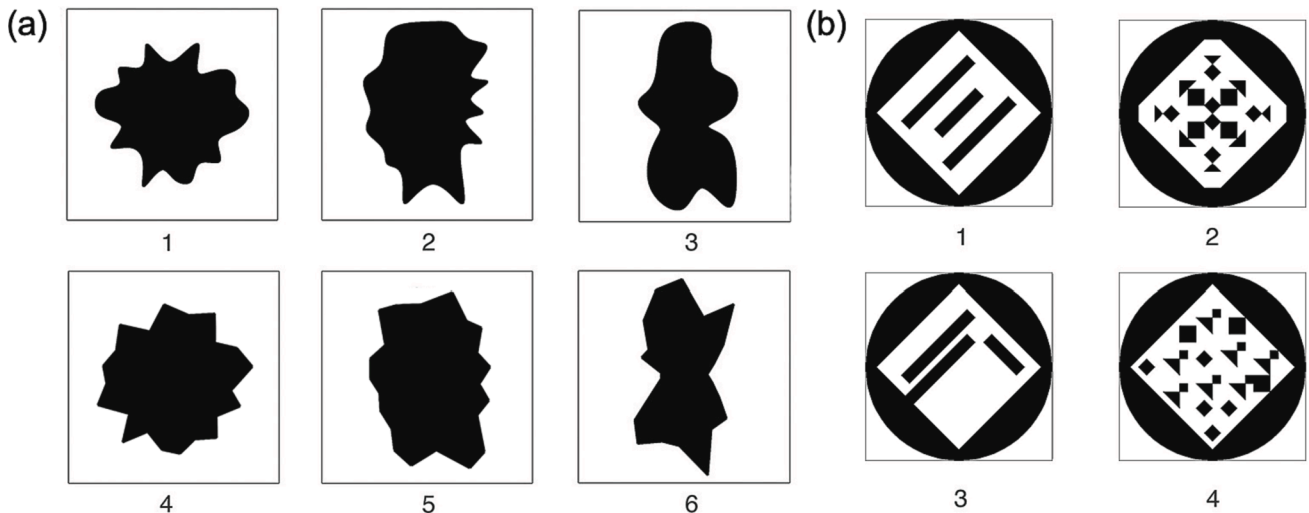


Fig. 2. Examples of the stimuli included in the two sets used in Experiments 1 and 2. (a) These shapes were used to assess aesthetic sensitivity to contour (Bertamini et al., 2016). Stimuli (1 to 3 on the top row) have curved contours, while stimuli on the bottom row (4 to 6) have angular contours. Stimuli 1 and 4 were designed based on circles, 2 and 5 on ovals, and 3 and 6 on lobed ovals. (b) These shapes were used to assess aesthetic sensitivity to symmetry (Jacobsen & Höfel, 2002). Stimuli on the top row (1 and 2) are symmetrical, while those on the bottom row (3 and 4) are asymmetrical.

2.1.3. Design and procedure

The experiment was conducted online and designed using the opensource Psytoolkit software (Stoet, 2017). In order to take part in the experiment, participants had to have a computer screen of at least 1,366 x 768 pixels resolution. First, they indicated their age, sex, and highest academic qualification. The task presented the five taste words along shape symbolic scales anchored with angular or curved (contour block) and asymmetrical or symmetrical (symmetry block) shapes. The instructions of the task included short definitions of each taste (e.g., umami comes from savoury foods and is meaty or brothy). Participants were instructed to match the tastes with one of two shapes using the mouse on a rating scale from 0 to 100. The more they clicked on the left-side, the more they associated the taste with the shape on the left-side, and the more they clicked on the right-side, the more they associated the taste with the shape on the right-side. The five taste names were paired with each of the 24 scale combinations (12 angular vs. curved pairs, and 12 asymmetrical vs. symmetrical pairs), giving rise to a total of 120 trials. The two sets of stimuli were presented in separate blocks of trials. Block and trial sequence were randomized. The position of the shapes in the scales (e.g., curved-angular, or angular-curved) was counter-balanced across participants. Afterwards, in a third block, the participants rated their liking for each taste word and shape presented individually on the computer screen.

2.1.4. Data analysis

Data analysis was conducted within the R environment for statistical computing (R Core Team, 2023) by means of linear mixed-effects models (Snijders & Bosker, 2012). The data from four participants were excluded from the analyses due to non-compliance with task instructions. Two models with contour and symmetry ratings as the dependent variable were fitted. Basic taste quality (sweet, bitter, salty, sour, and umami) was included as a fixed effect. Participant and stimulus were included as random effects. The random-effects structure of each model was kept maximal, unless model convergence could not be reached, or the model had a correlation equal to zero or one (Barr et al., 2013; Brauer & Curtin, 2018). Following the literature and for practical significance (Lee & Spence, 2022; Spence, 2023; Velasco et al., 2015; Velasco, Woods, Liu, et al., 2016), sweet was set as the reference level in both models. As our objective was to examine individual differences, we defined the sensitivity of each participant to the crossmodal association between shapes and tastes as the slope estimated from the models' random-effect structure. These slopes represent how the shape ratings of each participant for each taste deviate from the group-level estimate. Thus, after running each model, we extracted each participant's slope for all taste-shape associations (curved-sweet, curved-bitter, curved-salty, curved-sour, curved-umami, symmetrical-sweet, symmetrical-bitter, symmetrical-salty, symmetrical-sour, symmetrical-umami), and used them to describe their sensitivity to each correspondence. The distribution of these slopes was investigated, and we used Shapiro-Wilk tests to assess their normality. Finally, to determine whether sensitivities to each taste-shape correspondence were associated, participants' slopes obtained in the models were correlated.

Three additional models were fitted to analyze participants' liking ratings. The models included Contour (angular vs. curved), Symmetry (symmetrical vs. asymmetrical), and Taste (sweet, bitter, salty, sour, and umami) as fixed effects, respectively. Reference levels for each model were angular, asymmetrical, and sweet, respectively (Clemente et al., 2021; Corradi et al., 2020). Then, the hedonic sensitivity to curvature and symmetry of each participant was estimated by estimating the individual slopes of the model's random-effect structure as in the previous models. Finally, participants' hedonic sensitivities to these features were also correlated. All the materials required for the evaluation and reproduction of the results have been made available online at the Open Science Framework (<https://osf.io/hxe4s/>).

2.2. Results

2.2.1. Curvature ratings

The results of the curvature ratings are shown in Table 1. Participants rated sweet (M = 68.9, 95 % CI [65.6, 72.2]) as significantly more curved than umami (M = 54.1, 95 % CI [49.9, 58.4]), sour (M = 38.2, 95 % CI [34.9, 41.6]), salty (M = 37, 95 % CI [33.6, 40.4]), and bitter (M = 33.3, 95 % CI [30.1, 36.4]). They also rated umami as significantly more curved than sour, salty, and bitter (all *p*'s < 0.001). All other comparisons were non-significant.

2.2.2. Individual slopes for curvature-taste associations

The individual slopes of the crossmodal association between curvature and sweet (reference level) ranged from 37.91, indicating a lower association between curvature and sweetness, to 96.04, indicating a stronger association between curvature and sweetness (M = 68.86, SD = 13.15). The slopes of the correspondence between curvature and bitter ranged from -84.62, indicating a stronger association between angularity and bitterness, to 16.96, indicating a stronger association between curvature and bitterness (M = -35.57, SD = 21.95).

The individual slopes of the crossmodal association between curvature and salty ranged from -87.24, indicating a stronger association between angularity and saltiness, to 14.60, indicating a stronger association between curvature and saltiness (M = -31.90, SD = 22.01). The slopes of the association between curvature and sour ranged from -89.48, indicating a stronger association between angularity and sourness, to 20.81, indicating a stronger association between curvature and sourness (M = -30.63, SD = 22.53). Finally, the slopes of the correspondence between curvature and umami ranged from -88.42, indicating a stronger association between angularity and umami, to 48.18, indicating a stronger association between curvature and umami (M = -14.72, SD = 24.11). The individual slopes of all taste-curvature associations were normally distributed, except for umami (Fig. 3).

2.2.3. Symmetry ratings

The results of the symmetry ratings are shown in Table 2. Participants rated sweet (M = 67, 95 % CI [63.2, 70.8]) as significantly more symmetrical than umami (M = 52.9, 95 % CI [48.8, 57]), salty (M = 43.9, 95 % CI [40.2, 47.6]), sour (M = 40.3, 95 % CI [36.6, 44]), and bitter (M = 37.3, 95 % CI [33.7, 40.9]). They also rated umami as significantly more symmetrical than sour, salty, and bitter (all *p*'s < 0.001). All other comparisons were non-significant.

2.2.4. Individual slopes for symmetry-taste associations.

The individual slopes of the crossmodal association between symmetry and sweet (reference level) ranged from 37.20, indicating a lower association between symmetry and sweetness, to 99.01, indicating a stronger association between symmetry and sweetness (M = 66.98, SD = 14.34). The individual slopes of the crossmodal association between symmetry and bitter ranged from -92.28, indicating a stronger association between asymmetry and bitterness, to 20.02, indicating a stronger association between symmetry and bitterness (M = -29.70, SD = 25.50).

The individual slopes for the crossmodal association between symmetry and salty ranged from -83.89, indicating a stronger association between asymmetry and saltiness, to 26.83, indicating a stronger association between symmetry and saltiness (M = -23.09, SD = 23.17). The

Table 1
Fixed effect estimates from the LMM for curvature ratings.

Taste	β	SE	t	p	95 % CI
Sweet vs. Bitter	-35.57	2.55	-13.97	<0.001 ***	-40.56, -30.58
Sweet vs. Salty	-31.90	2.56	-12.44	<0.001 ***	-36.92, -26.87
Sweet vs. Sour	-30.63	2.61	-11.76	<0.001 ***	-35.74, -25.52
Sweet vs. Umami	-14.72	2.76	-5.33	<0.001 ***	-20.14, -9.31

Note. *** *p* ≤ 0.001.

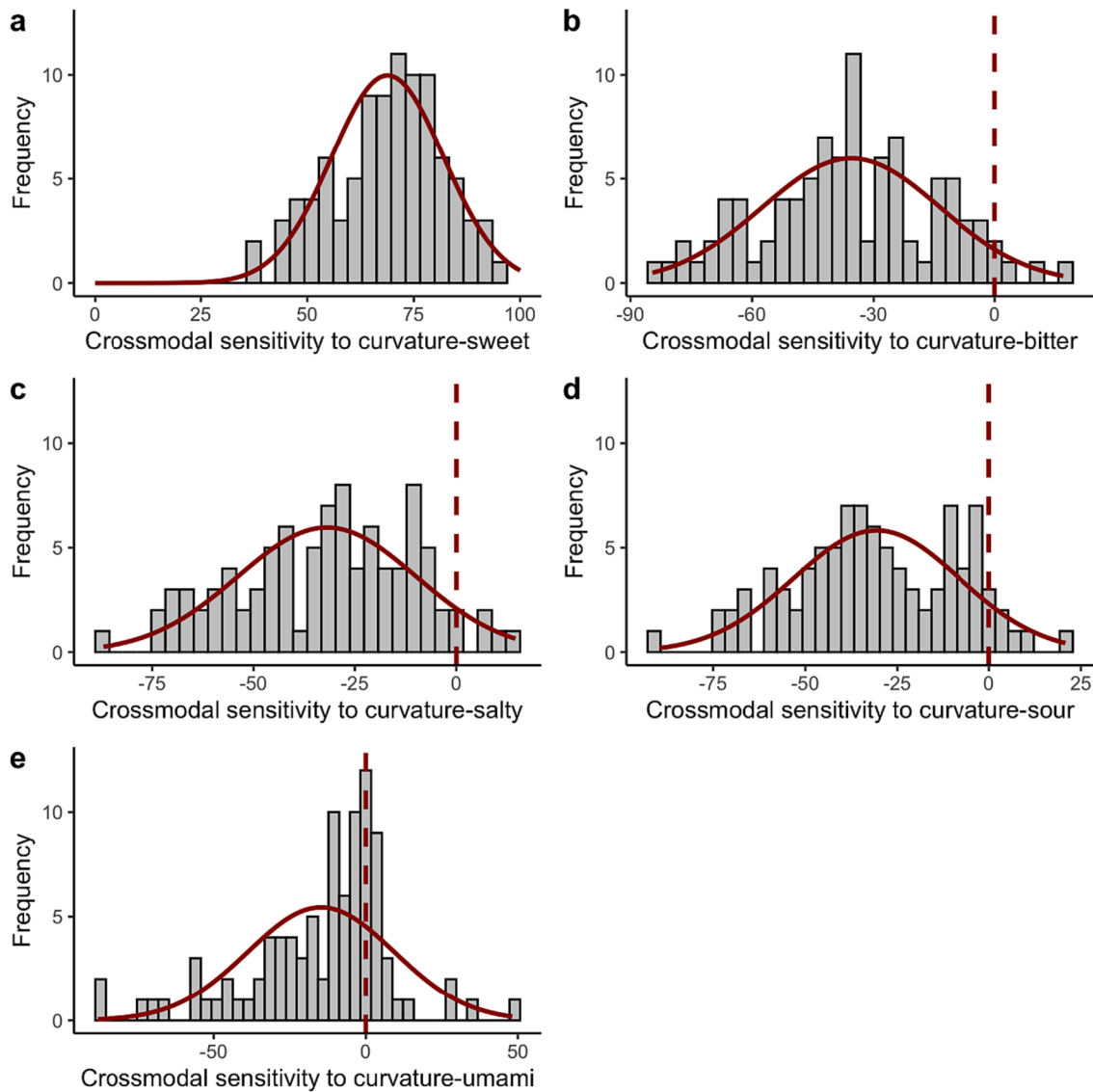


Fig. 3. Histograms of the sensitivities to the crossmodal correspondence between curvature and tastes in Experiment 1. Sensitivity to the crossmodal association between curvature-sweet (a), curvature-bitter (b), curvature-salty (c), curvature-sour (d), and curvature-umami (e). Vertical dashed lines (b-e) correspond to a slope of 0, indicating an absolute indifference towards each correspondence.

Table 2

Fixed effect estimates from the LMM for symmetry ratings in Experiment 1.

Taste	β	SE	t	p	95 % CI
Sweet vs. Bitter	-29.70	2.96	-10.03	<0.001 ***	-35.51, -23.90
Sweet vs. Salty	-23.09	2.75	-8.38	<0.001 ***	-28.48, -17.69
Sweet vs. Sour	-26.68	2.99	-8.89	<0.001 ***	-32.56, -20.80
Sweet vs. Umami	-14.08	2.41	-5.84	<0.001 ***	-18.80, -9.35

Note. *** $p \leq 0.001$.

slopes of the crossmodal association between symmetry and sour ranged from -92.58, indicating a stronger association between asymmetry and sourness, to 18.85, indicating a stronger association between symmetry and sour ($M = -26.68$, $SD = 25.96$). Finally, the individual slopes of the crossmodal association between symmetry and umami ranged from -70.81, indicating a stronger association between asymmetry and umami, to 22.90, indicating a stronger association between symmetry and umami ($M = -14.08$, $SD = 19.23$).

The individual slopes of symmetry-sweet and symmetry-bitter associations were normally distributed. In contrast, the slopes of symmetry-

salty, symmetry-sour, and symmetry-umami associations were not normally distributed (Fig. 4).

2.2.5. Relationship between individual slopes for taste-shape correspondences

Correlation results between taste-shape sensitivities are presented in Table 3. A positive association was found between sensitivity slopes for curved-sweet and symmetry-sweet (Fig. 5). Similarly, sensitivity to curved-bitter and symmetry-bitter, curved-salty and symmetry-salty, curved-sour and symmetry-sour, and curved-umami and symmetry-umami were positively associated. Slopes for curved-sweet and symmetry-sweet were negatively associated with the slopes of the correspondence of these shapes with the other four basic taste qualities.

2.2.6. Liking ratings

In terms of shape liking, the participants liked the curved stimuli ($M = 50.7$, 95 % CI [46.7, 54.6]) significantly more than the angular stimuli ($M = 34.8$, 95 % CI [31.2, 38.5]) (Table 4). The individual slopes ranged from -36.40, indicating a stronger liking for angular stimuli, to 87.79, indicating a stronger liking for curved stimuli ($M = 15.84$, $SD = 18.46$).

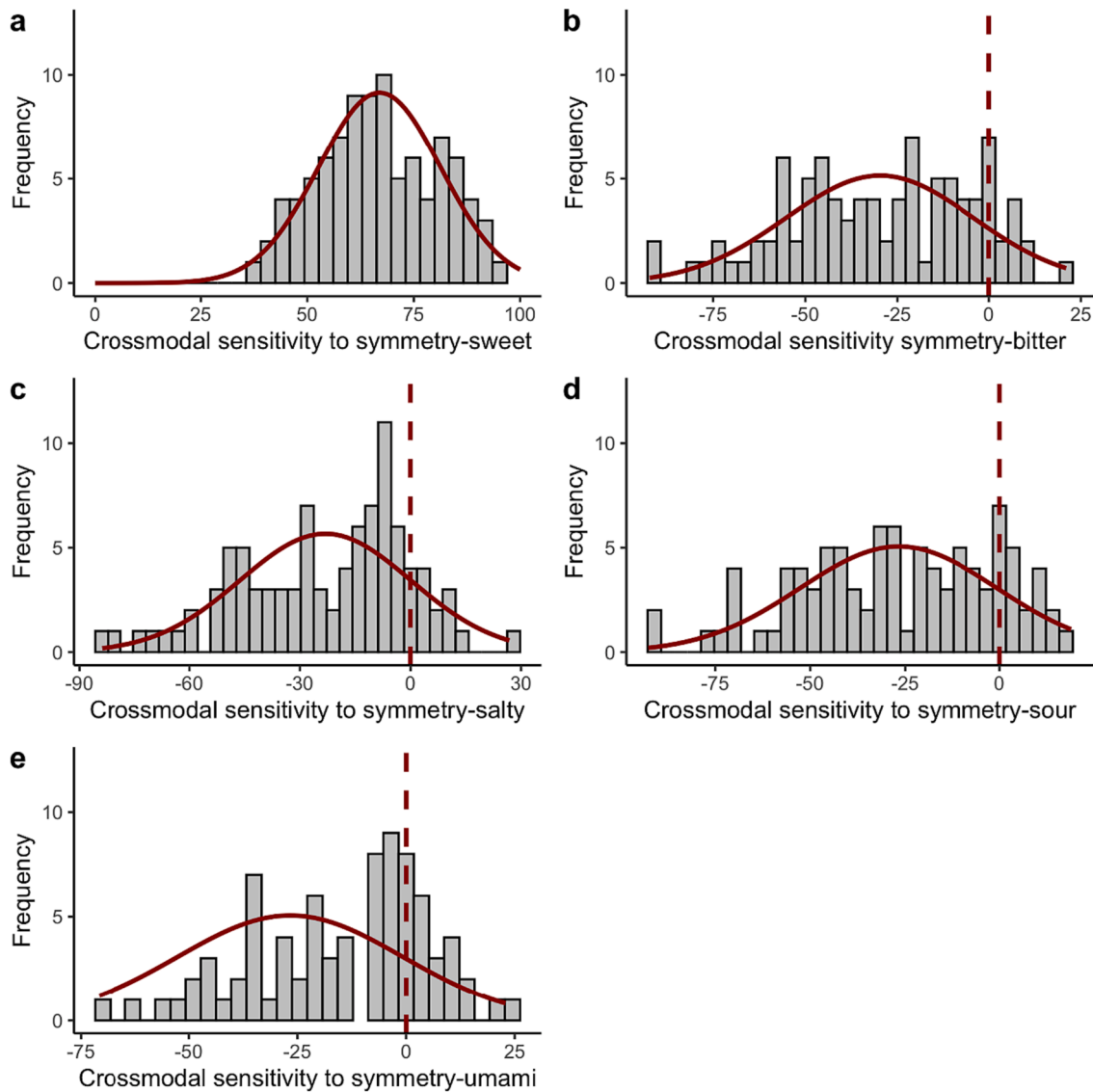


Fig. 4. Histograms of the sensitivities to the crossmodal correspondence between symmetry and tastes in Experiment 1. Sensitivity to the crossmodal association between symmetry-sweet (a), symmetry-bitter (b), symmetry-salty (c), symmetry-sour (d), and symmetry-umami (e). Vertical dashed lines (b-e) correspond to a slope of 0, meaning absolute indifference towards each correspondence.

Table 3
Correlations between individual crossmodal taste-shape slopes in Experiment 1.

Curvature	Curvature					Symmetry				
	Sweet	Bitter	Salty	Sour	Umami	Sweet	Bitter	Salty	Sour	Umami
Sweet _p	–									
Bitter _p	–0.86	–								
Salty _p	–0.80	0.85	–							
Sour _p	–0.83	0.94	0.74	–						
Umami _s	–0.65	0.62	0.54	0.51	–					
Symmetry										
Sweet _p	0.50	–0.51	–0.38	–0.55	–0.59	–				
Bitter _p	–0.47	0.55	0.41	0.58	0.66	–0.94	–			
Salty _s	–0.43	0.52	0.49	0.51	0.57	–0.85	0.87	–		
Sour _s	–0.48	0.55	0.39	0.59	0.57	–0.92	0.98	0.86	–	
Umami _s	–0.33	0.48	0.30	0.42	0.52	–0.57	0.66	0.56	0.57	–

Note. All correlations are statistically significant ($p < 0.001$). p: Pearson. s: Spearman.

The individual slopes were not normally distributed (Fig. 6a). Participants also liked the symmetrical stimuli ($M = 56.9$, 95 % CI [52.5, 61.2]) significantly more than the asymmetrical stimuli ($M = 37.8$, 95 % CI

[33.5, 42.1]) (Table 4). The individual slopes ranged from -44.18 , indicating a stronger liking for asymmetrical stimuli, to 82.04 , indicating a stronger liking for symmetrical stimuli ($M = 19.05$, SD =

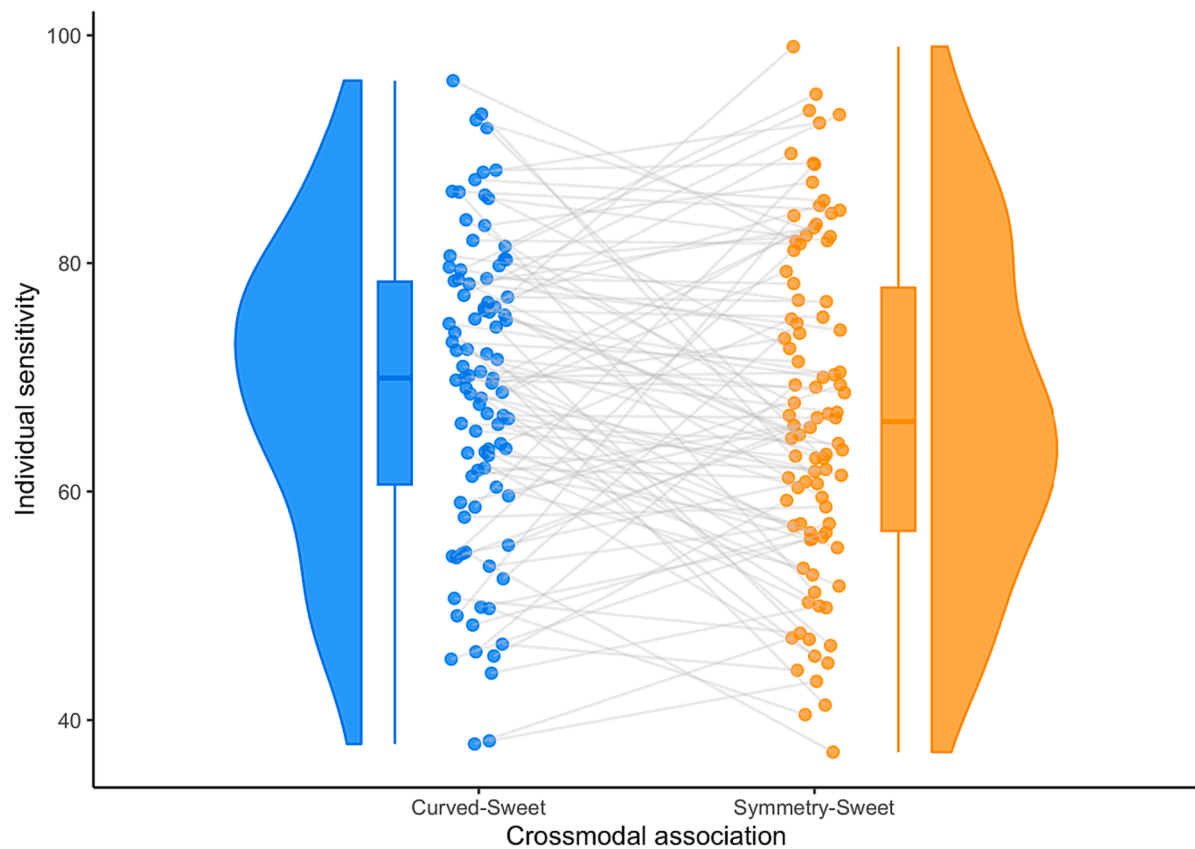


Fig. 5. Raincloud plots of the relationship between sensitivity to curvature-sweet and symmetry-sweet correspondences in Experiment 1. Dots correspond to each participant. Error bars represent minimum and maximum values for individual slopes.

Table 4
Fixed effect estimates from the models for liking ratings in Experiment 1.

Liking	β	SE	t	p	95 % CI
Curved vs. Angular	15.84	2.46	6.45	<0.001 ***	11.02, 20.67
Symmetrical vs. Asymmetrical	19.05	3.23	5.90	<0.001 ***	12.72, 25.38
Sweet vs. Bitter	-41.55	3.25	-12.77	<0.001 ***	-47.91, -35.19
Sweet vs. Salty	-14.79	3.25	-4.54	<0.001 ***	-21.15, -8.43
Sweet vs. Sour	-32.36	3.25	-9.95	<0.001 ***	-38.72, -26
Sweet vs. Umami	-11.96	3.25	-3.67	<0.001 ***	-18.32, -5.60

Note. *** $p \leq 0.001$.

21.21). The individual slopes were normally distributed (Fig. 6b). Finally, correlation analyses revealed a significant positive association between hedonic sensitivity to curvature and symmetry, $r_p = 0.51$, $p < 0.001$ (Fig. 6c).

When it comes to tastes, the participants liked sweet ($M = 73.4$, 95 % CI [68.5, 78.3]) significantly more than umami ($M = 61.4$, 95 % CI [56.5, 66.4]), salty ($M = 58.6$, 95 % CI [53.7, 63.5]), sour ($M = 41$, 95 % CI [36.1, 46]), and bitter ($M = 31.8$, 95 % CI [26.9, 36.8]) (Table 4). They also liked umami and salty significantly more than sour and bitter (all p 's < 0.001).

2.2.7. Relationship between sensitivity to taste-shape correspondences and hedonic sensitivity

With the aim of exploring the relationship between sensitivity to taste-shape correspondences and liking, we ran exploratory multiple

regressions. Individual slopes for taste-shape correspondences were set as dependent variables. Hedonic sensitivity to curvature, symmetry, and tastes were included as predictor variables. The results revealed that hedonic sensitivity to curvature positively predicted sensitivity to curved-sweet, $\beta = 6.03$, $t = 4.95$, $p < 0.001$, 95 % CI [3.61, 8.45]. Similarly, sensitivity to sweet positively predicted sensitivity to curved-sweet, $\beta = 2.74$, $t = 2.25$, $p = 0.027$, 95 % CI [0.32, 5.16]. As liking slopes for curvature and sweet increased, slopes for curved-sweet correspondence also increased.

Nevertheless, hedonic sensitivity to curvature negatively predicted sensitivity to curved-bitter, $\beta = -12.08$, $t = -6.29$, $p < 0.001$, 95 % CI [-15.89, -8.26], curved-salty, $\beta = -8.18$, $t = -3.82$, $p < 0.001$, 95 % CI [-12.44, -3.93], curved-sour, $\beta = -12.40$, $t = -6.28$, $p < 0.001$, 95 % CI [-16.33, -8.48], and curved-umami, $\beta = -9.48$, $t = -4.05$, $p < 0.001$, 95 % CI [-14.12, -4.83]. Likewise, sensitivity to bitter and sensitivity to sour negatively predicted sensitivity to curved-bitter, $\beta = -4.21$, $t = -2.19$, $p = 0.031$, 95 % CI [-8.02, -0.39], and curved-sour, $\beta = -3.96$, $t = -2.01$, $p = 0.048$, 95 % CI [-7.88, -0.038], respectively.

On the other hand, hedonic sensitivity to symmetry positively predicted sensitivity to symmetry-sweet, $\beta = 6.81$, $t = 5.34$, $p < 0.001$, 95 % CI [4.28, 9.34]. Sensitivity to sweet also positively predicted sensitivity to symmetry-sweet, $\beta = 3.20$, $t = 2.51$, $p = 0.014$, 95 % CI [0.67, 5.73]. As liking slopes for symmetry and sweet increased, slopes for symmetry-sweet correspondence also increased. In contrast, sensitivity to symmetry negatively predicted sensitivity to symmetry-bitter, $\beta = -12.18$, $t = -5.26$, $p < 0.001$, 95 % CI [-16.78, -7.58], symmetry-salty, $\beta = -8.82$, $t = -4.01$, $p < 0.001$, 95 % CI [-13.19, -4.44], symmetry-sour, $\beta = -12.41$, $t = -5.28$, $p < 0.001$, 95 % CI [-17.09, -7.74], and symmetry-umami, $\beta = -4.27$, $t = -2.18$, $p = 0.032$, 95 % CI [-8.16, -0.38].

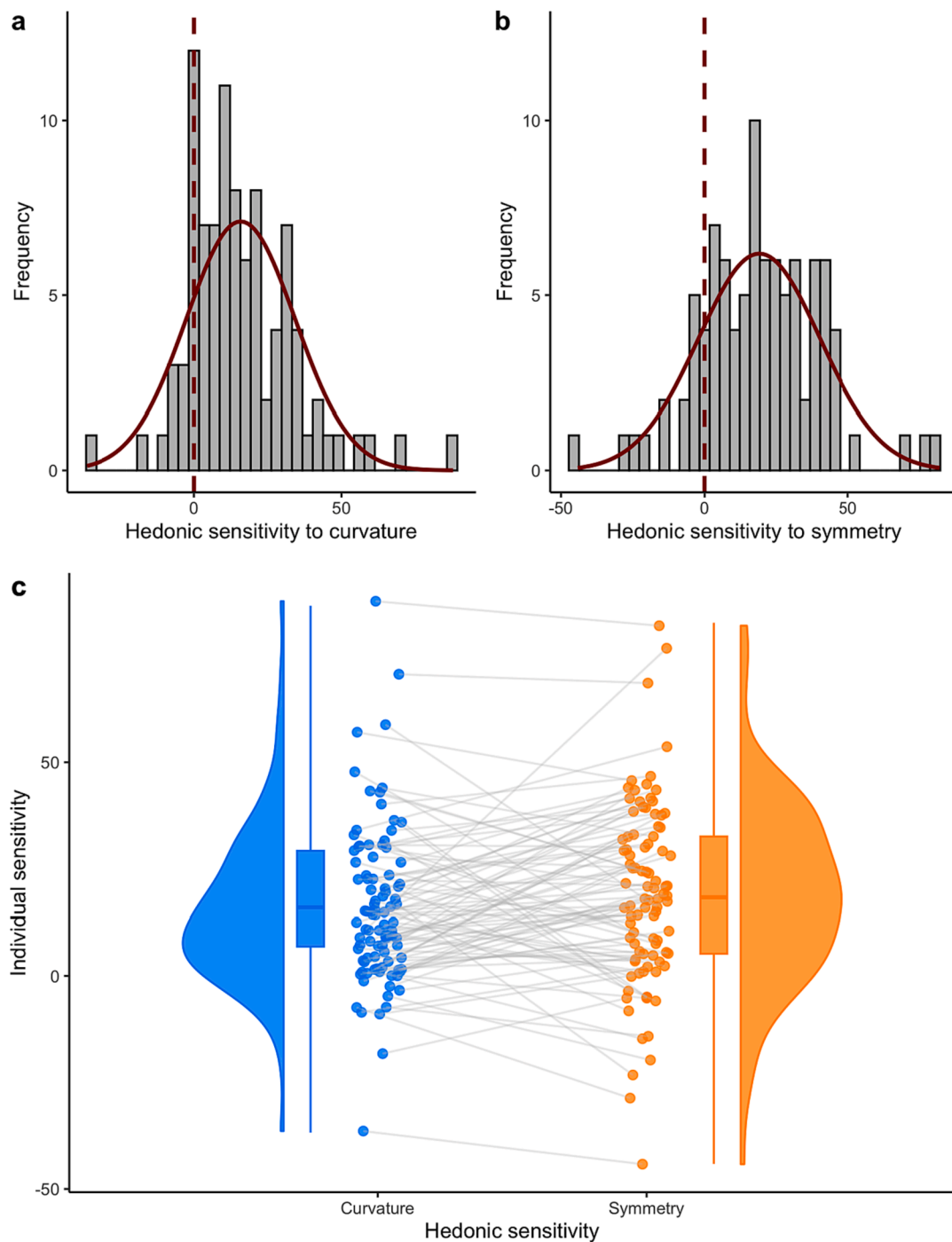


Fig. 6. Histograms of individual slopes of liking for curvature (a) and symmetry (b) in Experiment 1. Vertical dashed lines correspond to a slope (sensitivity) of 0, meaning absolute indifference towards each feature. (c) Raincloud plots of the relationship between the hedonic sensitivity to curvature and symmetry. Dots correspond to each participant. Error bars represent minimum and maximum values for individual slopes.

2.3. Discussion

The results of Experiment 1 demonstrate that participants associate curvature and symmetry with sweetness more than with the other four basic tastes. These results support previous literature showing that among the basic tastes, sweetness has a special character in that it is consistently matched with curved and symmetrical shapes (Spence, 2023; Velasco et al., 2015). On the other hand, participants associated angular and asymmetrical shapes with sour, salty, and bitter more than with sweet and umami.

The results of Experiment 1 also highlight how these group-level

associations are characterized by substantial variation at an individual level. Specifically, sensitivity to the curved-sweet correspondence ranged from 37.91 to 96.04. Since this correspondence was set as the reference level, the slopes range from lower (0) to higher (100) curvature values. Thus, whereas most participants consistently matched sweet with curved stimuli (higher slopes), some participants did not and tended to match sweet with angular stimuli (lower slopes). Individual slopes for symmetry-sweet showed a similar distribution with slopes ranging from 37.20 to 99.01. This shows that despite most participants consistently matched sweet with symmetrical stimuli (higher ratings), some of them tended to match sweet with asymmetrical stimuli (lower

ratings). Correlation results further supported a positive association between sensitivity to curved-sweet and symmetry-sweet. This shows that participants who consistently paired curved stimuli with sweet also tended to pair symmetrical stimuli with sweet.

Regarding the correspondence of curvature with the other four basic tastes, individual slopes for bitter ranged from -84.62 to 16.96 , slopes for salty ranged from -87.24 to 14.60 , slopes for sour ranged from -89.48 to 20.81 , and slopes for umami ranged from -88.42 to 48.18 . These results show that most participants consistently matched bitter, salty, sour, and umami with angular stimuli (negative slopes). However, some participants were insensitive to these correspondences (slopes around 0) and matched these tastes with curved stimuli (positive slopes). Regarding symmetry and the other four basic tastes, individual slopes followed similar distributions. That is, slopes for symmetry-bitter ranged from -92.28 to 20.02 , slopes for symmetry-salty ranged from -83.89 to 26.83 , slopes for symmetry-sour ranged from -92.58 to 18.85 , and slopes for symmetry-umami ranged from -70.81 to 22.90 . These results showed that most participants matched these tastes with asymmetrical stimuli. However, some participants did not show these correspondences and, instead, tended to match bitter, salty, sour, and umami with symmetrical stimuli.

On the other hand, participants liked curved and symmetrical stimuli more than angular and asymmetrical stimuli. They also liked sweet more than umami, salty, sour, and bitter. These results support the well-documented human preference for curvature, symmetry, and sweet tastes (for reviews, see Chuquichambi et al., 2022; Spence, 2023). Importantly, individual slopes for hedonic sensitivity to curvature and symmetry ranged from -36.40 to 87.79 and from -44.18 to 82.04 , respectively, and were positively associated. These results further support the literature on hedonic or aesthetic sensitivity to these features (Clemente et al., 2021; Corradi et al., 2020). Finally, hedonic sensitivity to curvature, symmetry, and sweet predicted sensitivity to the curved-sweet and symmetry-sweet correspondences, respectively. This result might support the claim that participants who prefer curved, symmetrical, and sweet stimuli also have strong associations between these stimuli.

3. Experiment 2

In Experiment 2, we examined individual differences in taste-shape crossmodal correspondences using actual taste solutions. Participants matched sweet, bitter, salty, sour, and umami solutions with curved or angular (contour block) and symmetrical or asymmetrical (symmetry block) shapes using the same rating scales as in Experiment 1. Moreover, participants rated their liking for each taste and shape. Following the results of Experiment 1, we expected to strengthen the notion of a general crossmodal correspondence between curvature and symmetry with sweetness using real tastes (Velasco et al., 2015; Velasco, Woods, Liu, et al., 2016). However, we also expected to show that these group-level crossmodal effects are characterized by substantial variation at an individual-level.

3.1. Methods

3.1.1. Participants

Sample size was determined following the power analysis of Experiment 1. Ninety-nine adult students (61 women, $M_{\text{age}} = 23.89$ years, $SD_{\text{age}} = 4.41$) at the [Blinded for peer review] volunteered to participate in the study. Before the experiment, participants reported that they did not have any potential sensory dysfunction (visual or gustatory) and provided written informed consent. Participants also were instructed not to wear any fragrances on the day of the experiment and not to have a meal, coffee, or to smoke at least 30 min before the experimental session.

3.1.2. Apparatus and materials

Taste stimuli. Stimuli consisted of sweet (sucrose, 24.00 g/L), sour

(citric acid, 1.20 g/L), bitter (caffeine, 0.54 g/L), salty (sodium chloride, 4.00 g/L), and umami (monosodium glutamate, 2.00 g/L) solutions. The tastes were prepared following the relevant literature (Hoehl et al., 2010; Velasco et al., 2015; Velasco, Woods, Liu, et al., 2016). Each taste was prepared as an odourless and colourless solution (distilled water, Fresenius Kabi AG, D-61346, Bad Homburg, Germany) as specified by ISO 3972. Participants received 20 ml of each taste in a 30 ml transparent cup. Additional details about the taste concentrations can be found in the [supplementary materials \(Supplement 1\)](#).

Visual stimuli. Each taste was coded with a three-digit number presented on the computer screen of Courier New, font size 20. These numbers were visually uninformative to the participants and were as follows: 523, 325, and 235 for sweet, 382, 823, and 238 for bitter, 414, 441, and 144 for salty, 991, 199, and 919 for sour, and 346, 634, and 436 for umami. The numbers were presented along with the same shape scales anchored with angular or curved (contour block) and asymmetrical or symmetrical (symmetry block) shapes of Experiment 1 (see Fig. 1).

3.1.3. Design and procedure

The experiment was designed and conducted using the opensource Psytoolkit software (Stoet, 2017). The task was implemented in computers equipped with 21-inch screens set at $1,920 \times 1,080$ pixels. Participants were presented with fifteen taste solutions, three of each corresponding to the same taste (i.e., sweet, bitter, sour, salty, and umami). The task had three blocks. In each block, the three-digit numbers indicated participants which solution to sample, and they sampled the five different tastes once per block. In the first two blocks, participants rated the tastes along the shape scales anchored with angular or curved (contour block) and asymmetrical or symmetrical (symmetry block) shapes. Each taste was paired with each of the 24 scale combinations (12 angular vs. curved pairs, 12 asymmetrical vs. symmetrical pairs), giving rise to a total of 120 trials (60 per block). In the third block, participants sampled the tastes again and rated their liking for each taste and shape individually on the computer screen.

Before and during the task, participants were instructed to hold each taste in their mouth for at least five seconds and then expectorate it into a glass. Next, they were instructed to match the taste with one of two shapes by using the mouse on a rating scale from 0 to 100. The more they clicked on the left-side of the scale, the more they associated the taste with the left-side shape, the more they clicked on the right-side of the scale, the more they associated the taste with the right-side shape. After responding to the scales for a particular taste, participants cleaned their palette using distilled water and spit it into a paper cup before moving on to the next taste. All participants went through the same experimental conditions. Block and trial sequence were randomized. The position of the shapes in the scales (i.e., left or right) was counterbalanced across participants.

3.1.4. Data analysis

As in Experiment 1, we fitted two linear mixed-effects models with Contour and Symmetry ratings as the dependent variables. Taste solution (sweet, bitter, salty, sour, and umami) was included as a fixed effect. Participant and stimulus were included as random effects. The random-effects structure of each model was kept maximal, unless model convergence was not reached, or model had a correlation equal to zero or one (Barr et al., 2013; Brauer & Curtin, 2018). Following the strategy of Experiment 1, sweet was set as the reference level in both models, and we obtained the sensitivity of each participant to the crossmodal correspondence between shapes and tastes by extracting the slope of each participant from the model's random-effects structure. Then, we investigated the distribution of these slopes, and Shapiro-Wilk tests were used to assess their normality. Finally, we correlated participants' values obtained in each model to determine the relation between sensitivities to taste-shape correspondences.

As in Experiment 1, we also fitted three additional models

corresponding to the liking ratings to the shapes (curved vs. angular and symmetrical vs. asymmetrical) and tastes (sweet, bitter, salty, sour, and umami). Reference levels for each model were angular, asymmetrical, and sweet, respectively. Finally, the hedonic sensitivity to curvature and symmetry of each participant was estimated and correlated.

3.2. Results

3.2.1. Curvature ratings

The results of the curvature ratings are shown in Table 5. Participants rated sweet ($M = 69.6$, 95 % CI [65.5, 73.8]) as significantly more curved than salty ($M = 54.4$, 95 % CI [49.7, 59.2]), umami ($M = 51.5$, 95 % CI [46.3, 56.7]), bitter ($M = 40.1$, 95 % CI [34.9, 45.3]), and sour ($M = 37.6$, 95 % CI [32.8, 42.4]). They also rated salty and umami as significantly more curved than sour and bitter (all p 's < 0.001). None of the other comparisons was significant.

3.2.2. Individual slopes for curvature-taste associations

The individual slopes of the crossmodal association between curvature and sweet ranged from 12.24, indicating a lower association between curvature and sweetness, to 97.39, indicating a stronger association between curvature and sweetness ($M = 69.63$, $SD = 18.98$). Those of the correspondence between curvature and bitter ranged from -94.31, indicating a stronger association between angularity and bitterness, to 50.52, indicating a stronger association between curvature and bitterness ($M = -29.53$, $SD = 31.88$).

The individual slopes of the crossmodal association between curvature and salty ranged from -73.40, indicating a stronger association between angularity and saltiness, to 47.39, indicating a stronger association between curvature and saltiness ($M = -15.19$, $SD = 28.65$). The slopes of the correspondence between curvature and sour ranged from -94.77, indicating a stronger association between angularity and sourness, to 49.66, indicating a stronger association between curvature and sourness ($M = -32$, $SD = 30.44$). Finally, the slopes of the correspondence between curvature and umami ranged from -91.34, indicating a stronger association between angularity and umami, to 56.76, indicating a stronger association between curvature and umami ($M = -18.13$, $SD = 31.26$). The individual slopes of all taste-curvature associations were normally distributed, except for sweet (Fig. 7).

3.2.3. Symmetry ratings

The results of the symmetry ratings are shown in Table 6. Participants rated sweet ($M = 61.4$, 95 % CI [56.4, 66.4]) as significantly more symmetrical than salty ($M = 48.7$, 95 % CI [43.6, 53.8]), umami ($M = 47.5$, 95 % CI [42.5, 52.5]), bitter ($M = 41.3$, 95 % CI [36.2, 46.4]), and sour ($M = 41.2$, 95 % CI [36.5, 45.9]). They also rated salty and umami as significantly more symmetrical than sour and bitter (all p 's < 0.05).

3.2.4. Individual slopes for symmetry-taste associations

The individual slopes of the crossmodal association between symmetry and sweet ranged from 11.81, indicating a lower association between symmetry and sweetness, to 96.14, indicating a stronger association between symmetry and sweetness ($M = 61.40$, $SD = 17.76$). For the correspondence between symmetry and bitter, slopes ranged from -82.28, indicating a stronger association between asymmetry and bitterness, to 47.98, indicating a stronger association between symmetry

and bitterness ($M = -20.10$, $SD = 29.10$). The individual slopes of the correspondence between symmetry and salty ranged from -80.08, indicating a stronger association between asymmetry and saltiness, to 70.03, indicating a stronger association between symmetry and saltiness ($M = -12.70$, $SD = 24.11$). The slopes of the correspondence between symmetry and sour ranged from -89.42, indicating a stronger association between asymmetry and sourness, to 66.18, indicating a stronger association between symmetry and sourness ($M = -20.21$, $SD = 27.61$). Finally, the slopes of the correspondence between symmetry and umami ranged from -83.92, indicating a stronger association between asymmetry and umami, to 50.78, indicating a stronger association between symmetry and umami ($M = -13.93$, $SD = 23.08$). The individual slopes of all taste-symmetry associations in Experiment 2 were normally distributed, except for salty (Fig. 8).

3.2.5. Relationship between individual slopes for taste-shape correspondences

Correlation analyses revealed a significant positive relationship between sensitivity to curved-sweet and sensitivity to symmetry-sweet, $r_s = 0.27$, $p = 0.0080$ (Fig. 9). Sensitivity to the curved-bitter sensitivity to symmetry-bitter were also significant and positively associated, $r_p = 0.25$, $p = 0.013$. Sensitivity to curved-sweet and sensitivity to symmetry-sweet were negatively correlated with the correspondence between the shapes and the other four tastes (all p 's < 0.001). Finally, an independent t -test revealed that sensitivity to curved-sweet was higher than sensitivity to symmetry-sweet, $t = 3.15$, $p = 0.0018$, 95 % CI [3.08, 13.39].

3.2.6. Liking ratings

In terms of shape liking, the participants liked the curved stimuli ($M = 58.9$, 95 % CI [55.3, 62.4]) significantly more than the angular stimuli ($M = 32.2$, 95 % CI [28.6, 35.8]) (Table 7). The individual slopes ranged from -20.54, indicating a stronger liking for angular stimuli, to 71.38, indicating a stronger liking for curved stimuli ($M = 26.66$, $SD = 16.28$). The individual slopes were normally distributed (Fig. 10a). Participants also liked the symmetrical stimuli ($M = 60.7$, 95 % CI [55.9, 65.6]) significantly more than the asymmetrical stimuli ($M = 33$, 95 % CI [28.6, 37.4]) (Table 7). The individual slopes ranged from -10.83, indicating a stronger liking for asymmetrical stimuli, to 78.31, indicating a stronger liking for symmetrical stimuli ($M = 27.74$, $SD = 17.54$). The individual slopes were normally distributed (Fig. 10b). Finally, correlation analyses revealed no relationship between the hedonic sensitivity to curvature and the hedonic sensitivity to symmetry, $r_p = 0.0053$, $p = 0.96$ (Fig. 10c).

When it comes to tastes, the participants liked the sweet tastant ($M = 59.9$, 95 % CI [54.2, 65.7]) significantly more than the umami ($M = 33.1$, 95 % CI [27.4, 38.8]), salty ($M = 31.6$, 95 % CI [26, 37.2]), sour ($M = 28.4$, 95 % CI [22.6, 34.2]), and bitter tastants ($M = 19.6$, 95 % CI [13.8, 25.3]) (Table 7). They also liked the umami, salty, and sour tastants significantly more than the bitter tastant (all p 's < 0.05).

3.2.7. Relationship between sensitivity to taste-shape correspondences and hedonic sensitivity

As in Experiment 1, multiple regression analyses were conducted to explore the relationship between sensitivity to taste-shape correspondences and liking. The results showed that hedonic sensitivity to curvature positively predicted sensitivity to curved-sweet, $\beta = 4.51$, $t = 2.42$, $p = 0.017$, 95 % CI [0.82, 8.21]. As liking slopes for curvature increased, slopes for curved-sweet correspondence also increased. However, contrary to the result of Experiment 1, sensitivity to sweet did not significantly predict sensitivity to curved-sweet, $\beta = 2.61$, $t = 1.40$, $p = 0.16$, 95 % CI [-1.08, 6.31]. In addition, sensitivity to curvature negatively predicted sensitivity to curved-bitter, $\beta = -8.38$, $t = -2.67$, $p = 0.0090$, 95 % CI [-14.61, -2.14], curved-salty, $\beta = -7.61$, $t = -2.72$, $p = 0.0078$, 95 % CI [-13.17, -2.05], curved-sour, $\beta = -8.03$, $t = -2.68$, $p = 0.0087$, 95 % CI [-13.98, -2.08], and curved-umami, $\beta = -6.68$, $t =$

Table 5
Fixed effect estimates from the LMM for curvature ratings in Experiment 2.

Taste	B	SE	t	p	95 % CI
Sweet vs. Bitter	-29.53	3.41	-8.65	<0.001 ***	-36.22, -22.84
Sweet vs. Salty	-15.19	3.11	-4.89	<0.001 ***	-21.28, -9.09
Sweet vs. Sour	-32	3.28	-9.77	<0.001 ***	-38.42, -25.57
Sweet vs. Umami	-18.13	3.36	-5.40	<0.001 ***	-24.71, -11.55

Note. *** $p \leq 0.001$.

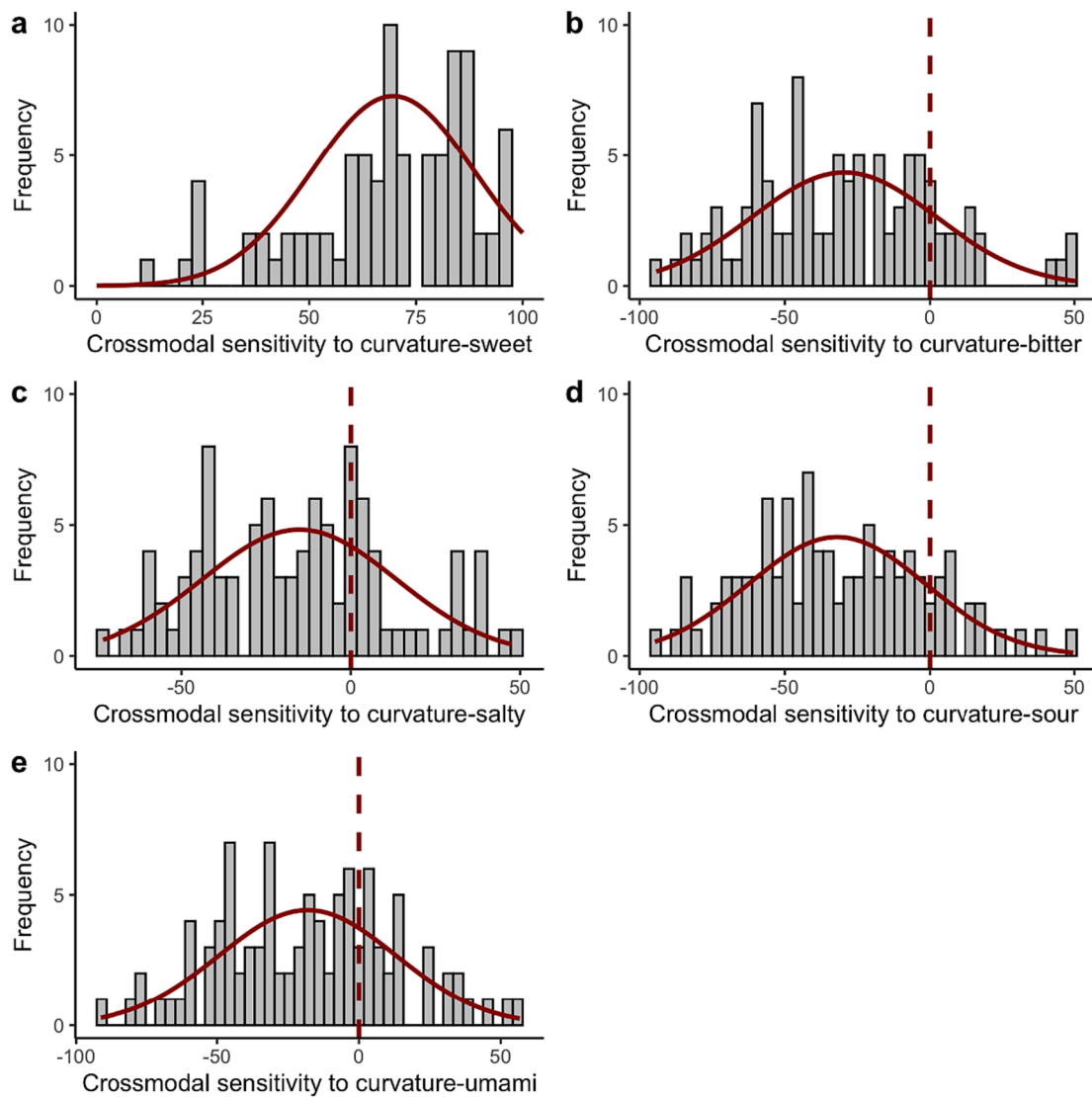


Fig. 7. Histograms of the sensitivities to the crossmodal correspondence between curvature and tastes in Experiment 2. Sensitivity to the crossmodal association between curvature-sweet (a), curvature-bitter (b), curvature-salty (c), curvature-sour (d), and curvature-umami (e). Vertical dashed lines (b-e) correspond to a slope of 0, meaning absolute indifference towards each correspondence.

Table 6

Fixed effect estimates from the LMM for symmetry ratings in Experiment 2.

Taste	β	SE	t	P	95 % CI
Sweet vs. Bitter	-20.10	3.32	-6.06	<0.001 ***	-26.61, -13.60
Sweet vs. Salty	-12.70	2.88	-4.41	<0.001 ***	-18.33, -7.06
Sweet vs. Sour	-20.20	3.18	-6.35	<0.001 ***	-26.44, -13.97
Sweet vs. Umami	-13.93	2.79	-5	<0.001 ***	-19.40, -8.46

Note. *** $p \leq 0.001$.

-2.17, $p = 0.033$, 95 % CI [-12.80, -0.56].

On the other hand, hedonic sensitivity to symmetry positively predicted sensitivity to symmetry-sweet, $\beta = 4.96$, $t = 2.90$, $p = 0.0046$, 95 % CI [1.57, 8.36]. Similarly, sensitivity to sweet tended to predict sensitivity to symmetry-sweet, $\beta = 3.21$, $t = 1.88$, $p = 0.063$, 95 % CI [-0.18, 6.61]. As liking slopes for symmetry and sweet increased, slopes for symmetry-sweet correspondence also increased. In contrast, sensitivity to symmetry negatively predicted sensitivity to symmetry-bitter, $\beta = -6.84$, $t = -2.39$, $p = 0.019$, 95 % CI [-12.52, -1.16], symmetry-sour, $\beta = -10.37$, $t = -4.01$, $p < 0.001$, 95 % CI [-15.50, -5.24], and symmetry-umami, $\beta = -5.69$, $t = -2.49$, $p = 0.014$, 95 % CI [-10.22, -1.16].

3.3. Discussion

The results of Experiment 2, like those of Experiment 1, revealed that participants associate curvature and symmetry with sweet solutions more than with solutions of the other four basic tastes. This experiment thus replicates, with a larger sample size and more robust experimental design, the results from previous studies using real tastants (Velasco et al., 2015; Velasco, Woods, Liu, et al., 2016), strengthening the notion of a general crossmodal correspondence between curvature and sweetness and symmetry and sweetness. Additionally, participants also associated angular and asymmetrical stimuli with sour and bitter solutions more than with sweet, salty, and umami solutions.

As in Experiment 1, these results also revealed that these crossmodal correspondences coexist with considerable variation among participants. Specifically, sensitivity to curved-sweet ranged from 12.24 to 97.39. This shows that while most participants consistently matched the sweet solution with curved stimuli (higher slopes), some participants did not and matched sweet with angular stimuli (lower slopes). Regarding symmetry-sweet, individual slopes showed a similar distribution and ranged from 11.81 to 96.14. Most participants consistently matched the sweet solution with symmetrical stimuli. However, some participants

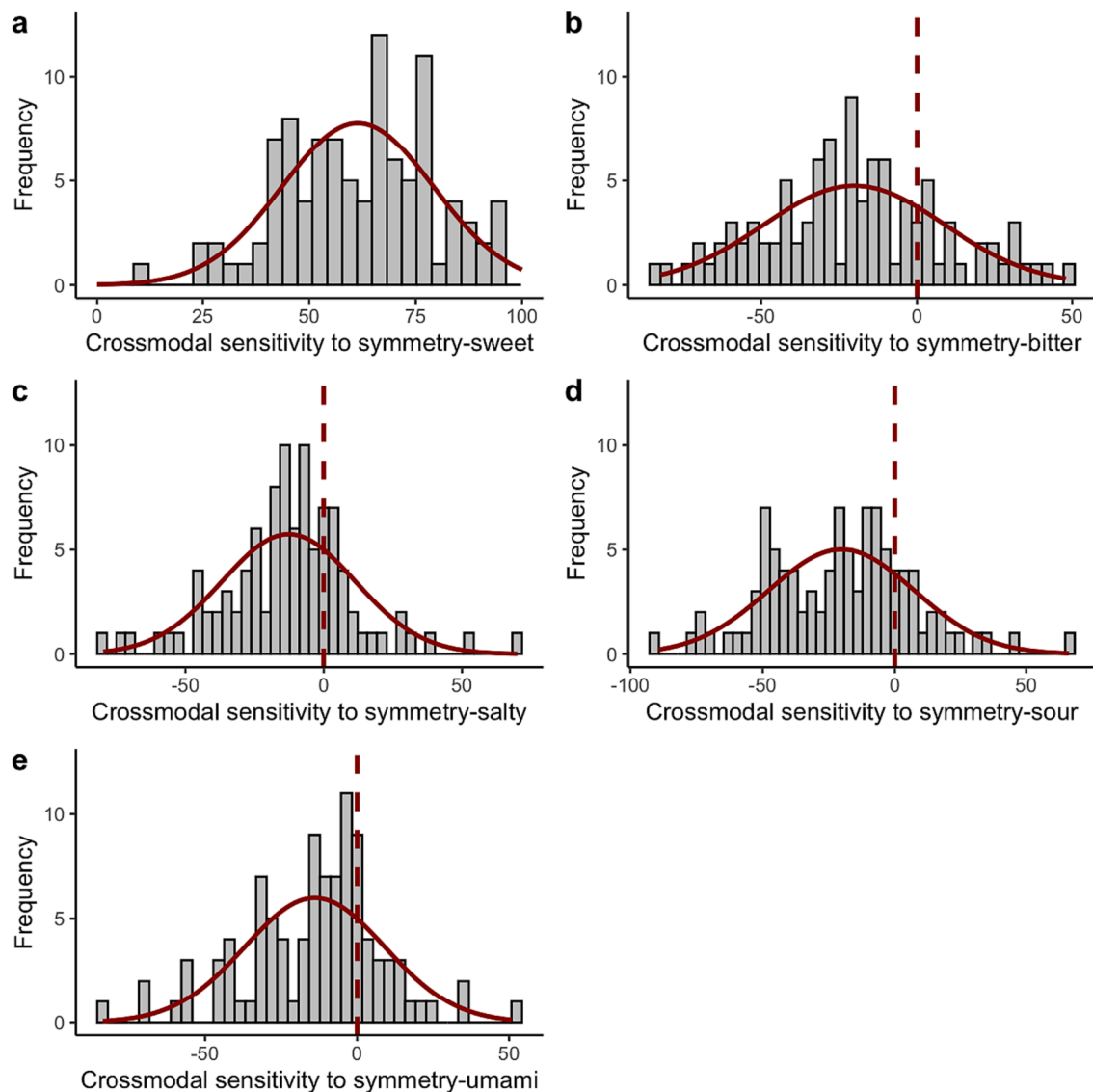


Fig. 8. Histograms of the sensitivities to the crossmodal correspondence between symmetry and tastes in Experiment 2. Sensitivity to the crossmodal association between symmetry-sweet (a), symmetry-bitter (b), symmetry-salty (c), symmetry-sour (d), and symmetry-umami (e). Vertical dashed lines (b-e) correspond to a slope of 0, meaning absolute indifference towards each correspondence.

matched sweet with asymmetrical stimuli. Correlation results supported a positive relationship between sensitivity to curved-sweet and symmetry-sweet. This shows that participants who consistently paired curved stimuli with sweet also tended to pair symmetrical stimuli with sweet.

Regarding the correspondence of curvature with the other four basic tastes, individual slopes for curved-bitter ranged from -94.31 to 50.52 , slopes for curved-salty ranged from -73.40 to 47.39 , slopes for curved-sour ranged from -89.42 to 66.18 , and slopes for curved-umami ranged from -91.34 to 56.76 . These results revealed that most participants tended to match the bitter, salty, sour, and umami solutions with angular stimuli. However, some participants were insensitive to these correspondences, and associated these solutions with curved stimuli. Regarding symmetry and the other four basic tastes, individual slopes for symmetry-bitter ranged from -82.28 to 47.9 , slopes for symmetry-umami ranged from -83.92 to 50.78 , and slopes for symmetry-sour ranged from -92.91 to 66.18 . These results revealed that most participants consistently matched the bitter, umami, and sour solutions with asymmetrical stimuli. However, they also showed that some participants were insensitive to these correspondences and tended to match bitter,

umami, and sour with symmetrical stimuli. Finally, individual slopes for symmetry-salty ranged from -80 to 70.03 . This result suggest that participants matched the salty solution with asymmetrical and symmetrical stimuli to a similar degree.

The liking results for Experiment 2 revealed that participants liked curved and symmetrical stimuli more than angular and asymmetrical stimuli, as might have been expected based on previous research. Participants also liked sweet more than umami, salty, sour, and bitter. These results support those from Experiment 1, and the general effects of preference for curved and symmetrical shapes, and sweet tastes (Chuquichambi et al., 2022; Lee & Spence, 2022; Spence, 2023). Individual slopes for hedonic sensitivity to curvature and symmetry ranged from -20.54 to 71.38 and -10.83 to 78.31 , respectively. As in Experiment 1, these results support that the hedonic or aesthetic sensitivity to curvature and symmetry coexist with substantial individual variation. Finally, hedonic sensitivity to curvature and symmetry predicted sensitivity to the curved-sweet and symmetry-sweet correspondences, respectively. Though it was not significant, sensitivity to sweet also showed a tendency to predict these correspondences.

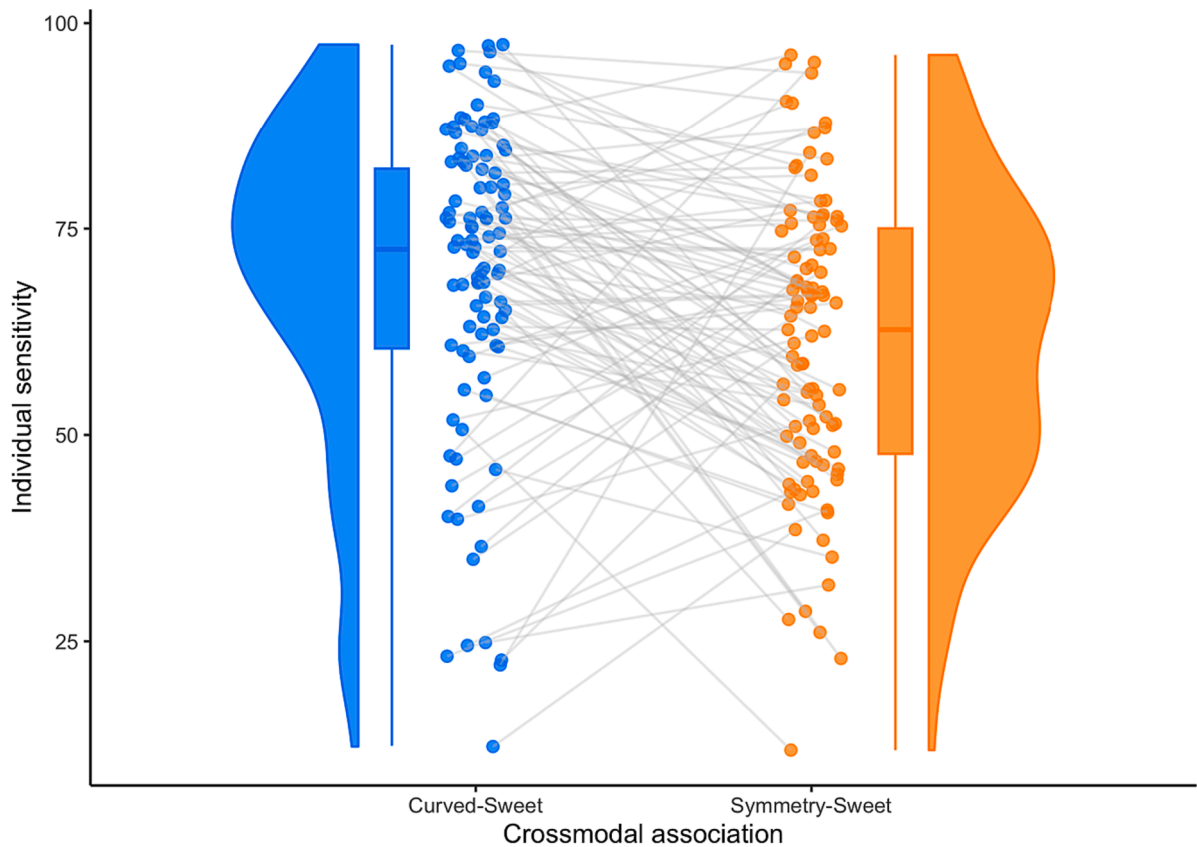


Fig. 9. Raincloud plots of the relationship between sensitivity to curvature-sweet and symmetry-sweet in Experiment 2. Dots correspond to each participant. Error bars represent minimum and maximum values for individual slopes.

Table 7
Fixed effect estimates from the models for liking ratings in Experiment 2.

Liking	β	SE	t	p	95 % CI
Curved vs. Angular	26.66	2.57	10.36	<0.001 ***	21.62, 31.71
Symmetrical vs. Asymmetrical	27.74	3.26	8.51	<0.001 ***	21.35, 34.12
Sweet vs. Bitter	-40.38	4.04	10	<0.001 ***	-48.27, -32.49
Sweet vs. Salty	-28.36	3.99	-7.10	<0.001 ***	-36.17, -20.56
Sweet vs. Sour	-31.53	4.06	-7.77	<0.001 ***	-39.47, -23.60
Sweet vs. Umami	-26.86	4.02	-6.69	<0.001 ***	-34.71, -19.01

Note. *** $p \leq 0.001$.

4. General discussion

The present study was designed to examine how people differ in terms of their sensitivity to the crossmodal correspondence between tastes and shapes in two experiments. In Experiment 1, participants rated taste words (i.e., sweet, bitter, salty, sour, and umami) along shape scales anchored with curved and angular (contour block) or symmetrical and asymmetrical (symmetry block) shapes. In Experiment 2, participants rated sweet, bitter, salty, sour, and umami taste solutions using the same shape scales as in Experiment 1. In both experiments, participants also rated their liking for each taste and shape. In Experiment 1, participants associated curvature and sweet more than curvature with the other four basic tastes. Similarly, participants associated symmetry and sweet more than symmetry with the other four basic tastes. In Experiment 2, similar results were obtained using sweet, bitter, salty, sour, and

umami taste solutions. Together, these results replicate and extend those from previous studies, supporting a general crossmodal correspondence between curved-sweet and symmetrical-sweet stimuli (Velasco et al., 2015; Velasco, Woods, Liu, et al., 2016).

Our main objective, however, was to uncover and compare participants' sensitivity to the correspondences between taste and shape. Therefore, following the literature, we measured the sensitivity of participants to these correspondences as their individual slopes in linear mixed-effects models (Clemente, 2022; Clemente et al., 2021; Corradi et al., 2019, 2020). This method allowed us to estimate the overall effect of correspondence between tastes and shapes (fixed effect), and the variations in this effect from participant to participant (random effect). In this context, sensitivity to taste-shape correspondences represents the variation of taste perception from one shape to another (the opposite one) and from participant to participant. For example, some participants might have strong associations between specific shapes and tastes (e.g., curved-sweet). However, others might show a weak correspondence to the same shapes and tastes.

As expected, taste-shape group-level correspondences were found to coexist with substantial variation at an individual level. Specifically, while most participants were sensitive to the curved-sweet correspondence, other participants were insensitive or tended to be sensitive to the angular-sweet correspondence. Individual slopes for symmetry-sweet showed comparable results. While most participants consistently matched sweet with symmetrical stimuli, other participants were insensitive to this correspondence and tended to match sweet with asymmetrical stimuli. Interestingly, the individual slopes for sweet-curved were higher than those for symmetry-sweet with real tastants (Experiment 2), but not with taste words (Experiment 1).

On the other hand, most participants were negatively sensitive to the correspondence between curvature and symmetry with bitter, salty, sour, and umami. This means that participants consistently matched

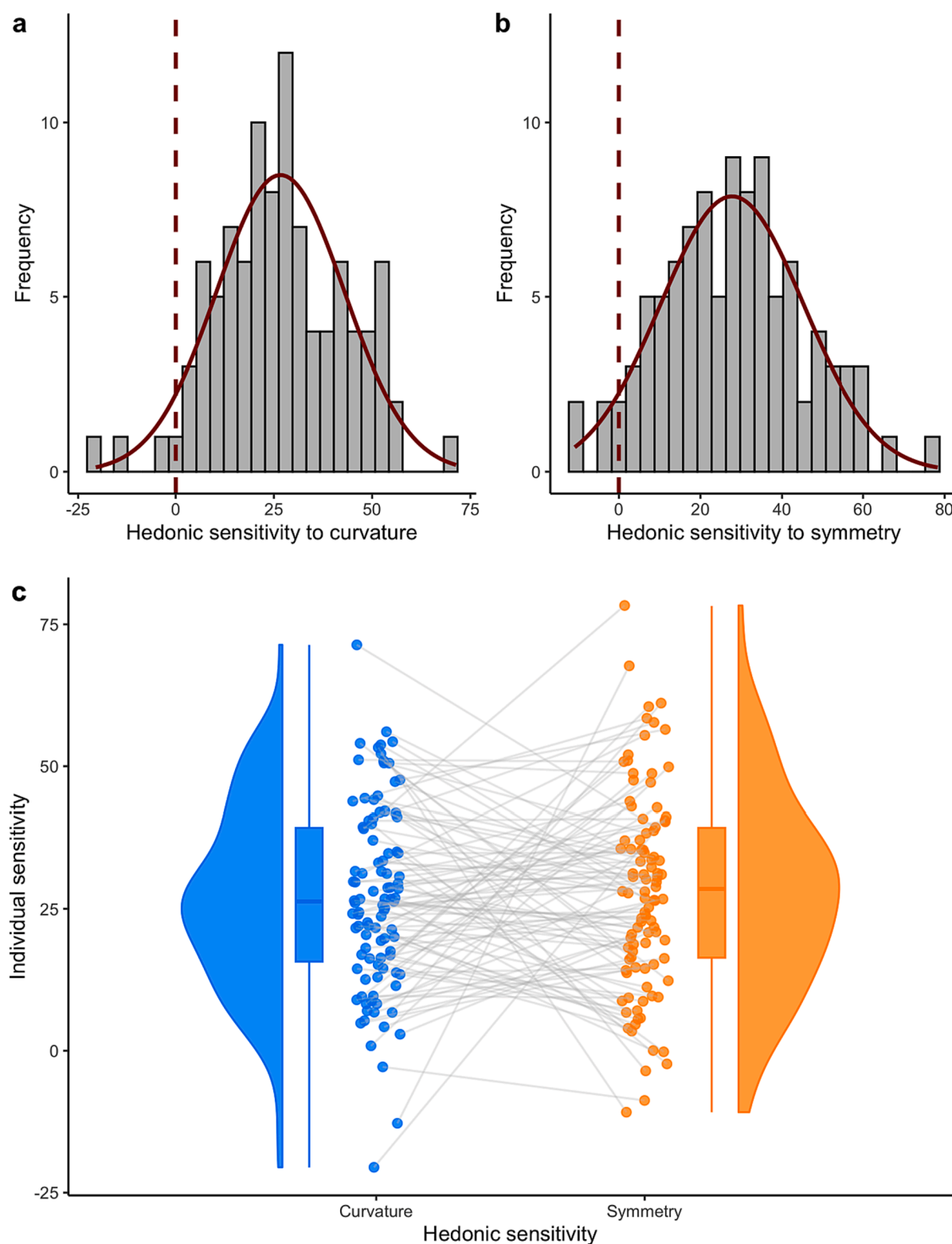


Fig. 10. Histograms of individual slopes of liking for curvature (a) and symmetry (b) in Experiment 2. Vertical dashed lines correspond to a slope of 0, meaning absolute indifference towards each feature. (c) Raincloud plots of the relationship between the hedonic sensitivity to curvature and symmetry. Dots correspond to each participant. Error bars represent minimum and maximum values for individual slopes.

angular and asymmetrical stimuli with these tastes. However, some participants had positive slopes and matched these tastes with curved and symmetrical stimuli. Interestingly, the positive slopes for the correspondence between curvature and symmetry with bitter, salty, sour, and umami were higher with taste solutions (Experiment 2) than with

taste words (Experiment 1).

A positive relationship was also found between sensitivity to curvature-sweet and symmetry-sweet in both experiments. This relationship was higher when using taste words (Experiment 1) than when using solutions (Experiment 2). Similarly, the relationship between the

slopes of the correspondence of curvature and symmetry with the other four tastes (i.e., bitter, salty, sour, and umami) was significant with taste words, but not with taste solutions. A possible explanation for these differences could be related to the more abstract representation of taste words. That is, their representation might have been based on the linguistic characteristics, knowledge, and experience of the participants with the tastes (e.g., different intensities associated with the taste words). Complimentary, these differences could also be explained because the perception of real tastants provided a direct and more integrated sensory experience than the taste words. This convergence of sensory information could have led the participants to stronger and more nuanced taste-shape associations.

Regarding liking, participants liked the curved stimuli more than the angular stimuli, and the symmetrical stimuli more than the asymmetrical stimuli. However, participants also differed considerably in the extent to which these features affected their liking. That is, our two samples included participants who were highly sensitive to curvature and symmetry, participants insensitive to these features, and participants sensitive to angularity and asymmetry. Together, these results highlight the presence of considerable heterogeneity underlying general preferences (Chuquichambi et al., 2022), and that people vary substantially in the degree to which they value shapes.

But why is it that people associate tastes and shapes in the way they do and what explains the variation between participants in terms of their association? Shedding light on these questions, we conducted analyses in which individual sensitivity to taste-shape correspondences was the dependent variable, while hedonic sensitivity to curvature, symmetry, and tastes served as predictor variables. The findings revealed that a positive correlation existed between hedonic sensitivity to curvature and sensitivity to curved-sweet correspondences, as well as between sensitivity to sweet and curved-sweet correspondences. Conversely, hedonic sensitivity to curvature negatively correlated with sensitivity to curved-bitter, curved-salty, curved-sour, and curved-umami correspondences, while sensitivity to bitter also had a negative relationship with sensitivity to curved-bitter correspondences. Additionally, hedonic sensitivity to symmetry positively correlated with symmetry-sweet correspondences and sensitivity to sweet positively correlated with curved-sweet correspondences, but both negatively correlated with their respective bitter, salty, sour, and umami correspondences. Together, these results shed light on the psychological explanation underlying the phenomenon of crossmodal correspondences. That is, they support and echo previous suggestions whereby liking of both tastes and shapes might be explained by the common affective properties of the individual tastes and shapes being matched (e.g., Velasco et al., 2015, 2016).

4.1. Limitations and future directions

Several limitations should be acknowledged in the study. First, our experiments were conducted using a specific concentration of tastants, which may not fully capture the complexities of suprathreshold everyday tastes found in food consumption. Future research should explore a broader range of taste concentrations to provide a more comprehensive understanding of taste-shape correspondences in real-life contexts. For instance, since we used near-threshold solutions, future studies could extend our design using solutions with different stimulus intensities. Second, the shapes used in our experiments were chosen to help pull apart the roles of curvature and symmetry in taste-shape associations. However, future research could extend these findings by incorporating shape cues that are more representative of specific food-related stimuli, such as packaging and product design, to better simulate real-world scenarios (e.g., Juravle et al., 2022; Velasco et al., 2016). Third, the mechanistic evidence in our study is correlational in nature, as we used regression analyses to explore associations between taste, shape, and liking. Future research could benefit from experimental designs that manipulate variables, such as changes in taste concentration or shape curvature identity, to determine causal relationships

between these factors and changes in liking: For instance, one might investigate how extreme concentrations of sugar (which might not necessarily be pleasant) influence taste-shape correspondences and liking. Likewise, one might investigate these correspondences recruiting people with different taster statuses (e.g., sweet-likers, sweet-dislikers, etc.).

Lastly, our study primarily focused on assessing individual differences in sensitivity to taste-shape correspondences. However, other individual differences, such as those related to personality dimensions, may also play a role in shaping these associations. Future research should therefore consider exploring the influence of personality traits and other individual factors on taste-shape correspondences to provide a more comprehensive understanding of the underlying mechanisms (e.g., Motoki, Nakahara, et al., 2023). Along similar lines, collecting participants' responses on the 'why' they associate specific shapes with tastes could provide a deeper understanding of individual differences, why some of them may show unique associations, and how personal experiences and preferences shape multisensory experiences. It is noteworthy that this qualitative approach could complement our quantitative method to represent individual variation and provide valuable insights into the personal, cultural, and contextual factors underlying taste-shape associations.

5. General conclusions

Our two experiments provide insights about individual differences in the sensitivity to crossmodal correspondence between shapes and basic tastes. Our results have demonstrated that participants tend to associate curvature and symmetry with sweetness more strongly than with other basic tastes. However, the remarkable variability in individual sensitivity to these correspondences highlights the complexity of the underlying phenomenon. Some participants displayed robust links between specific shapes and tastes, while others exhibited weaker or even contrasting associations, emphasizing the diversity of perceptual experiences.

Furthermore, our findings revealed a noteworthy sensitivity to angular and asymmetrical shapes when paired with bitter, salty, sour, and umami tastes, although exceptions were observed. Interestingly, this effect was more pronounced when participants encountered taste solutions rather than mere taste words, suggesting that sensory experiences play a pivotal role in shaping these associations. Moreover, the positive relationship between sensitivity to curvature-sweet and symmetry-sweet correspondences, especially when using taste words, underscores the intricate interplay between different crossmodal associations. Lastly, our research unveiled the influence of hedonic sensitivity on taste-shape correspondences, hinting at a possible link between individual liking preferences and these associations.

In essence, our study contributes to a deeper understanding of the multifaceted nature we perceive and connect tastes and shapes, with potential implications for the affective mechanism associated with this correspondence.

Ethical statement

The experiments were conducted following BI Norwegian Business School ethical guidelines as well as the Declaration of Helsinki (2008). The study was explained to participants at the beginning of both the online and laboratory experiments. They were informed that they would participate in the surveys using their personal computer (online experiment) and the laboratory computers (laboratory experiment), and that all data would be de-identified. All participants acknowledged an informed consent statement in order to participate in the experiments. They were financially compensated for their participation with different amounts of GBPs (Experiment 1, online) and NOK (Experiment 2, laboratory) as a function of the experiment duration.

CRediT authorship contribution statement

Erick G. Chuquichambi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Enric Munar:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Conceptualization. **Charles Spence:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Carlos Velasco:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have shared the link to my data/code.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.foodqual.2024.105110>.

References

- Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of Memory and Language*, 68(3), 255–278. <https://doi.org/10.1016/j.jml.2012.11.001>
- Bertamini, M., Palumbo, L., Gheorghes, T. N., & Galatsidas, M. (2016). Do observers like curvature or do they dislike angularity? *British Journal of Psychology*, 107(1), 154–178. <https://doi.org/10.1111/bjop.12132>
- Brauer, M., & Curtin, J. J. (2018). Linear mixed-effects models and the analysis of nonindependent data: A unified framework to analyze categorical and continuous independent variables that vary within-subjects and/or within-items. *Psychological Methods*, 23(3), 389–411. <https://doi.org/10.1037/met0000159>
- Bremner, A. J., Caparos, S., Davidoff, J., Fockert, J. D., Linnell, K. J., & Spence, C. (2013). “Bouba” and “Kiki” in Namibia? A remote culture make similar shape-sound matches, but different shape-taste matches to Westerners. *Cognition*, 126(2), 165–172. <https://doi.org/10.1016/j.cognition.2012.09.007>
- Calvert, G. A., Spence, C., & Stein, B. E. (Eds.). (2004). *The Handbook of Multisensory Processes*. MIT Press.
- Chen, N., Watanabe, K., & Wada, M. (2021). People with high autistic traits show fewer consensual crossmodal correspondences between visual features and tastes. *Frontiers in Psychology*, 12, Article 714277. <https://doi.org/10.3389/fpsyg.2021.714277>
- Chuquichambi, E. G., Vartanian, O., Skov, M., Corradi, G. B., Nadal, M., Silvia, P. J., & Munar, E. (2022). How universal is preference for visual curvature? A systematic review and meta-analysis. *Annals of the New York Academy of Sciences*, 1518(1), 151–165. <https://doi.org/10.1111/NYAS.14919>
- Clemente, A. (2021). *Aesthetic sensitivity*. University of the Balearic Islands [Doctoral dissertation].
- Clemente, A. (2022). Aesthetic sensitivity: Origin and development. In M. Skov, & M. Nadal (Eds.), *The Routledge International Handbook of Neuroaesthetics* (1st Ed., pp. 240–253). Routledge.
- Clemente, A., Friberg, A., & Holzapfel, A. (2022). Relations between perceived affect and liking for melodies and visual designs. *Emotion*, 23(6), 1584. <https://doi.org/10.1037/EMO0001141>
- Clemente, A., Pearce, M. T., Skov, M., & Nadal, M. (2021). Evaluative judgment across domains: Liking balance, contour, symmetry and complexity in melodies and visual designs. *Brain and Cognition*, 151, Article 105729. <https://doi.org/10.1016/j.BANDC.2021.105729>
- Corradi, G., Belman, M., Currò, T., Chuquichambi, E. G., Rey, C., & Nadal, M. (2019). Aesthetic sensitivity to curvature in real objects and abstract designs. *Acta Psychologica*, 197, 124–130. <https://doi.org/10.1016/j.actpsy.2019.05.012>
- Corradi, G., Chuquichambi, E. G., Barrada, J. R., Clemente, A., & Nadal, M. (2020). A new conception of visual aesthetic sensitivity. *British Journal of Psychology*, 111(4), 630–658. <https://doi.org/10.1111/bjop.12427>
- Crisinel, A.-S., & Spence, C. (2012). The impact of pleasantness ratings on crossmodal associations between food samples and musical notes. *Food Quality and Preference*, 24(1), 136–140. <https://doi.org/10.1016/J.FOODQUAL.2011.10.007>
- Fairhurst, M. T., Pritchard, D., Ospina, D., & Deroy, O. (2015). Bouba-Kiki in the plate: Combining crossmodal correspondences to change flavour experience. *Flavour*, 4(1), 22. <https://doi.org/10.1186/s13411-015-0032-2>
- Green, P., & MacLeod, C. J. (2016). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, 7(4), 493–498. <https://doi.org/10.1111/2041-210X.12504>
- Hamamoto, Y., Motoki, K., & Sugiura, M. (2020). Assessing the relationship between drive for thinness and taste-shape correspondences. *Multisensory Research*, 34(1), 69–92. <https://doi.org/10.1163/22134808-bja10030>
- Hoehl, K., Schoenberger, G. U., & Busch-Stockfisch, M. (2010). Water quality and taste sensitivity for basic tastes and metallic sensation. *Food Quality and Preference*, 21(2), 243–249. <https://doi.org/10.1016/j.foodqual.2009.06.007>
- Iatridi, V., Hayes, J. E., & Yeomans, M. R. (2019). Reconsidering the classification of sweet taste liker phenotypes: A methodological review. *Food Quality and Preference*, 72, 56–76. <https://doi.org/10.1016/J.FOODQUAL.2018.09.001>
- Jacobsen, T., & Höfel, L. (2002). Aesthetic judgments of novel graphic patterns: Analyses of individual judgments. *Perceptual and Motor Skills*, 95(3), 755–766. <https://doi.org/10.2466/pms.2002.95.3.755>
- Judd, C. M., Westfall, J., & Kenny, D. A. (2017). Experiments with more than one random factor: Designs, analytic models, and statistical power. *Annual Review of Psychology*, 68, 601–625. <https://doi.org/10.1146/ANNUREV-PSYCH-122414-033702>
- Juravle, G., Olari, E.-L., & Spence, C. (2022). A taste for beauty: On the expected taste, hardness, texture, and temperature of geometric shapes. *I-Perception*, 13(5). <https://doi.org/10.1177/20416695221120948>
- Lee, B. P., & Spence, C. (2022). Crossmodal correspondences between basic tastes and visual design features: A narrative historical review. *I-Perception*, 13(5). <https://doi.org/10.1177/20416695221127325>
- Marks, L. E. (1974). On associations of light and sound: The mediation of brightness, pitch, and loudness. *The American Journal of Psychology*, 87(1–2), 173–188. <https://doi.org/10.2307/1422011>
- Motoki, K., Marks, L. E., & Velasco, C. (2023). Reflections on crossmodal correspondences: Current understanding and issues for future research. *Multisensory Research*. Advance online publication. <https://doi.org/10.1163/22134808-bja10114>
- Motoki, K., Nakahara, T., & Velasco, C. (2023). Tasting brands: Associations between brand personality and tastes. *Journal of Business Research*, 156, Article 113509. <https://doi.org/10.1016/J.JBUSRES.2022.113509>
- Motoki, K., Spence, C., & Velasco, C. (2023). When visual cues influence taste/flavour perception: A systematic review. *Food Quality and Preference*, 111, Article 104996. <https://doi.org/10.1016/J.FOODQUAL.2023.104996>
- Palmer, S. E., Schloss, K. B., & Sammartino, J. (2013). Visual aesthetics and human preference. *Annual Review of Psychology*, 64(1), 77–107. <https://doi.org/10.1146/annurev-psych-120710-100504>
- Pich, J., Chuquichambi, E. G., Blay, N. T., Corradi, G. B., & Munar, E. (2020). Sweet and bitter near-threshold solutions activate cross-modal correspondence between taste and shapes of cups. *Food Quality and Preference*, 83, Article 103891. <https://doi.org/10.1016/j.foodqual.2020.103891>
- Piqueras-Fiszman, B., Alcaide, J., Roura, E., & Spence, C. (2012). Is it the plate or is it the food? Assessing the influence of the color (black or white) and shape of the plate on the perception of the food placed on it. *Food Quality and Preference*, 24(1), 205–208. <https://doi.org/10.1016/j.foodqual.2011.08.011>
- R Core Team. (2023). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. <https://www.r-project.org/>.
- Salgado-Montejo, A., Alvarado, J. A., Velasco, C., Salgado, C. J., Hasse, K., & Spence, C. (2015). The sweetest thing: The influence of angularity, symmetry, and the number of elements on shape-valence and shape-taste matches. *Frontiers in Psychology*, 6, 1382. <https://doi.org/10.3389/fpsyg.2015.01382/BIBTEX>
- Snijders, T. A. B., & Bosker, R. J. (2012). *Multilevel analysis. An introduction to basic and advanced multilevel modeling*. Sage Publications.
- Spence, C. (2011). Crossmodal correspondences: A tutorial review. *Attention, Perception, & Psychophysics* 73(4), 73(4), 971–995. <https://doi.org/10.3758/S13414-010-0073-7>
- Spence, C. (2022). Exploring group differences in the crossmodal correspondences. *Multisensory Research*, 35(6), 495–536. <https://doi.org/10.1163/22134808-bja10079>
- Spence, C. (2023). Explaining visual shape–taste crossmodal correspondences. *Multisensory Research*, 36(4), 313–345. <https://doi.org/10.1163/22134808-bja10096>
- Spence, C., & Bayne, T. (2015). Is consciousness multisensory? In D. Stokes, M. Matthen, & S. Biggs (Eds.), *Perception and its modalities* (pp. 95–132). Oxford: Oxford University Press.

- Steiner, J. E., Glaser, D., Hawilo, M. E., & Berridge, K. C. (2001). Comparative expression of hedonic impact: Affective reactions to taste by human infants and other primates. *Neuroscience & Biobehavioral Reviews*, 25(1), 53–74. [https://doi.org/10.1016/S0149-7634\(00\)00051-8](https://doi.org/10.1016/S0149-7634(00)00051-8)
- Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology*, 44(1), 24–31. <https://doi.org/10.1177/0098628316677643>
- Turoman, N., Velasco, C., Chen, Y. C., Huang, P. C., & Spence, C. (2017). Symmetry and its role in the crossmodal correspondence between shape and taste. *Attention, Perception, & Psychophysics*, 80(3), 738–751. <https://doi.org/10.3758/S13414-017-1463-X>
- Velasco, C., Salgado-Montejo, A., Marmolejo-Ramos, F., & Spence, C. (2014). Predictive packaging design: Tasting shapes, typefaces, names, and sounds. *Food Quality and Preference*, 34, 88–95. <https://doi.org/10.1016/J.FOODQUAL.2013.12.005>
- Velasco, C., Woods, A. T., Deroy, O., & Spence, C. (2015). Hedonic mediation of the crossmodal correspondence between taste and shape. *Food Quality and Preference*, 41, 151–158. <https://doi.org/10.1016/j.foodqual.2014.11.010>
- Velasco, C., Woods, A. T., Liu, J., & Spence, C. (2016). Assessing the role of taste intensity and hedonics in taste-shape correspondences. *Multisensory Research*, 29, 209–221. <https://doi.org/10.1163/22134808-00002489>
- Velasco, C., Woods, A. T., Marks, L. E., Cheok, A. D., & Spence, C. (2016). The semantic basis of taste-shape associations. *PeerJ*, 4, e1644.
- Velasco, C., Woods, A. T., Petit, O., Cheok, A. D., & Spence, C. (2016). Crossmodal correspondences between taste and shape, and their implications for product packaging: A review. *Food Quality and Preference*, 52, 17–26. <https://doi.org/10.1016/j.foodqual.2016.03.005>
- Wan, X., Woods, A. T., van den Bosch, J. J., McKenzie, K. J., Velasco, C., & Spence, C. (2014). Cross-cultural differences in crossmodal correspondences between basic tastes and visual features. *Frontiers in Psychology*, 5, 1365.
- Yeomans, M. R., Vi, C., Mohammed, N., & Armitage, R. M. (2022). Re-evaluating how sweet-liking and PROP-tasting are related. *Physiology & Behavior*, 246, Article 113702. <https://doi.org/10.1016/J.PHYSBEH.2022.113702>