Attention, Perception, & Psychophysics (2018) 80:738–751
https://doi.org/10.3758/s13414-017-1463-x

Symmetry and its role in the crossmodal correspondence between shape and taste

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Published online: 19 December 2017

Abstract
Despite the rapid growth of research on the crossmodal correspondence between visually presented shapes and basic tastes (e.g., sweet, sour, bitter, and salty), most studies that have been published to date have focused on shape contour (roundness/angularity). Meanwhile, other important features, such as symmetry, as well as the underlying mechanisms of the shape–taste correspondence, have rarely been studied. Over two experiments, we systematically manipulated the symmetry and contours of shapes and measured the influences of these variables on shape–taste correspondences. Furthermore, we investigated a potential underlying mechanism, based on the common affective appraisal of stimuli in different sensory modalities. We replicated the results of previous studies showing that round shapes are associated with sweet taste, whereas angular shapes are associated with sour and bitter tastes. In addition, we demonstrated a novel effect that the symmetry group of a shape influences how it is associated with taste. A significant relationship was observed between the taste and appraisal scores of the shapes, suggesting that the affective factors of pleasantness and threat underlie the shape–taste correspondence. These results were consistent across cultures, when we compared participants from Taiwanese and Western (UK, US, Canada) cultures. Our findings highlight that perceived pleasantness and threat are culturally common factors involved in at least some crossmodal correspondences.

Keywords Crossmodal correspondences · Shape · Symmetry · Taste · Pleasantness · Threat

It has long been observed that people make systematic associations between seemingly unrelated features across sensory modalities (Deroy & Spence, 2016; Marks, 1978; Parise, 2016; Spence, 2011). In recent years, evidence has been growing of a correspondence between visually presented shape and taste, whereby, when asked to think about the taste that they would associate with particular visual stimuli, people typically match rounded shapes with a sweet taste, and angular shapes with sour or bitter tastes. These results have been replicated using basic taste solutions (e.g., Velasco, Woods, Deroy, & Spence, 2015; Velasco, Woods, Liu, & Spence, 2016a), taste-related words (e.g., Salgado-Montejo et al., 2015; Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014),[1] and food and drink products found in the marketplace (e.g., Deroy & Valentin, 2011; Ngo et al., 2013; Spence & Gallace, 2011; Spence, Ngo, Percival, & Smith, 2013). Over and above broadening the knowledge on correspondences related to the chemical senses (see Spence & Deroy, 2013), research on the shape–taste correspondence may potentially help elucidate the origins of crossmodal correspondences—a standing issue in the field that has remained largely unresolved. Another issue that requires attention is the overreliance of visual–gustatory research on contour—that is, roundness and angularity—as the key visual shape attribute (Spence & Deroy, 2013; Spence & Ngo, 2012;

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[1] Since crossmodal correspondences are assumed to be bidirectional (Deroy, Crisinel, & Spence, 2013; Spence, 2011), the findings of these studies are relevant in this context, despite them having investigated correspondences from taste to shape.

Velasco, Woods, Petit, Cheok, & Spence, 2016b), in the face of other visual features that are known to influence human information processing (e.g., symmetry, color, complexity, balance, etc.; see Palmer, Schloss, & Sammartino, 2013a; Reber, Schwarz, & Winkielman, 2004).

Affective mediation in crossmodal correspondences

The main theoretical accounts that have been put forward to explain crossmodal correspondences include the statistical, structural, and linguistic accounts (Spence, 2011; see also Parise & Spence, 2013), neither of which has been able to fully and unequivocally capture the formation of the taste–shape correspondence. First, it is difficult to claim a statistical correspondence based on learning environmental regularities, as the shape contour of foodstuffs (not to mention the shape of their packaging), and their taste qualities do not co-occur reliably (though see Spence, 2012). That said, it is possible that such co-occurrences exist but are not obvious (e.g., as in the case of the correspondence between pitch and elevation; Parise, Knorre, & Ernst, 2014), but until a thorough analysis of relevant natural scene statistics is conducted, we are unable to make any definite conclusions. Second, an adequate structurally based theory has, to our knowledge, yet to be proposed for correspondences between metathetic[2] features, as well as between prothetic and metathetic features. Finally, it is unclear whether oft-used gustatory metaphors (e.g., "sharp cheese"; see Marks, 1978) are the *cause* of visual–gustatory associations or *result* from them.

It has also been suggested that modality-specific information may be linked indirectly, through the effect they have on the observer, for example, if they both evoke the same mood, or emotional state (Collier, 1996; Cowles, 1935; Kenneth, 1923; Marks, 1996; Spence, 2011; Spence et al., 2015). In recent years, this viewpoint has resurfaced in the form of the affective mediation hypothesis, by which a common affective property of a shape attribute on one hand, and a taste, on the other hand, will cause the shape and taste to be associated. For example, Salgado-Montejo and his colleagues (2015) demonstrated that, when people were asked to match visual shape stimuli with tastes, round shapes tended to be judged as pleasant and preferentially matched to sweet taste, whereas angular shapes tended to be judged as unpleasant and preferentially matched to sour taste. However, participants could only choose between sweet and sour taste, and pleasant and unpleasant appraisal, as two extremes on a continuum, restricting and potentially biasing responses. Similarly, Velasco and his colleagues (2015; Velasco, Woods, Liu, & Spence, 2016c) have demonstrated that the more a taste was liked, the more likely it was to be matched with a round rather than an angular shape. In this study, liking was only assessed for tastes, which, as will be discussed below, is well documented, whereas liking for shapes was not. In the present study, we investigated whether affective mediation is a contributor to the correspondence between shape and taste, while allowing a broader range of shape–taste matching and assessing the appraisal of shapes based on their component features.

Despite the interchangeable use of pleasantness and liking in investigating the affective mediation hypothesis (as seen from the studies above), measuring emotional valence through pleasantness levels may be a more direct approach than through measuring liking. The affective literature is one that is saturated with redundant jargon, and, as Barrett (2006) observed, valence has been referred to as hedonic tone, utility, appetitive/aversive, positive/negative, and many more. To clarify, valence, or intrinsic pleasantness/unpleasantness, is a characteristic of the stimulus that precedes and determines the subjective response of the observer, which may be liking or disliking (see Ellsworth & Scherer, 2003, for a review). Appraisals are constant and automatic evaluations of the stimuli in our environment (Barrett & Bar, 2009; Ellsworth & Scherer, 2003) that, according to appraisal theorists, underlie discrete emotions (e.g., Scherer, Shorr, & Johnstone, 2001; though see Ellsworth & Scherer, 2003). The valence appraisal (i.e., the appraisal of pleasantness/unpleasantness) is a fundamental factor in human emotional processing (Barrett, 2006). Certain stimulus features may innately be appraised as pleasant, including roundness (in humans: Gómez-Puerto, Munar, & Nadal, 2016; across cultures: Gómez-Puerto, Munar, Acedo, & Gomila, 2013; in great apes: Munar, Gómez-Puerto, Call, & Nadal, 2015), and sweetness (Birch, 1999; Breslin, 2013; in humans, primates, and other animals: Steiner, Glaser, Hawilo, & Berridge, 2001). These results suggest that valence (perceived pleasantness/unpleasantness) may serve as a link between round contour and sweet taste.

Perceived threat is another potential appraisal factor that may be involved in how humans match shapes to tastes. Apart from valence, the primary appraisal that establishes the relevance of a stimulus to the organism also includes whether or not a given stimulus is threatening (Lazarus, 1991). According to many dimensional theories of affective perception, threat has more or less explicitly been subsumed under the opposite of positive valence or pleasantness (e.g., Barrett & Russell, 1999; Larsen & Diener, 1992; Watson & Tellegen, 1985; see also Barrett & Bliss-Moreau, 2009). However, since a stimulus that is unpleasant without also

[2] *Metathetic* features are arranged on a qualitative, "what kind" or "where" continuum, whereas *prothetic* features are arranged on a quantitative, "more than"–"less than" continuum (see Smith & Sera, 1992; Stevens, 1957). The structural account has, so far, been far more successful at explaining correspondences between the latter (Spence, 2011). Since both shape and taste belong to the former category, the structural account may not be an adequate explanation for shape-taste correspondences.

being threatening (e.g., the sight of a dead animal bleeding) is differentially processed both on the behavioral and neural level (Kveraga & Bar, 2014; Kveraga et al., 2015), valence and threat are likely to be distinctly functioning appraisal factors rather than opposites on a single continuum.

There is substantial evidence that people perceive both angular contours and bitter tastes as threatening. In terms of contour, the downward-pointing triangle or "V" has, in the context of abstract shapes, been suggested to be associated with weapons, and, in relation to facial features, with anger (Aronoff, 2006; Aronoff, Barclay, & Stevenson, 1988; Aronoff, Woike, & Hyman, 1992; Larson, Aronoff, & Stearns, 2007; Lundqvist, Esteves, & Öhman, 2004; for neural correlates, see Larson, Aronoff, Sarinopoulos, & Zhu, 2009). In terms of taste, humans and animals tend to react to bitter tastes with a host of rejection behaviors, such as nausea, tongue retraction, and delayed swallowing (Brining, Belecky, & Smith, 1991; Peyrot Des Gachons, Beauchamp, Stern, Koch, & Breslin, 2011; Travers & Norgren, 1986; see also Glendinning, 1994). These are widely held to be protective mechanisms against toxic compounds threatening to survival that bitter taste signals for (Behrens & Meyerhof, 2006; Breslin, 2013; Chaudhari & Roper, 2010; Frank & Hettinger, 2005; Glendinning, Tarre, & Asaoka, 1999; Wu et al., 2002; Zhang et al., 2003). Moreover, people with a heightened sensitivity to bitter taste (supertasters) also showed increased sensitivity to other potentially threatening stimuli (Herbert, Platte, Wiemer, Macht, & Blumenthal, 2014; for a study in rats). To our knowledge, no previous research has investigated threat as a factor underlying crossmodal matching.

How do different visual features influence shape–taste matching?

Contour is not the only visual shape attribute that is worth investigating, since a host of visual features (e.g., symmetry, complexity) influence preferences in addition to, and perhaps more than, contour (e.g., Jacobsen, 2010; Palmer, Schloss, & Sammartino, 2013a; Reber et al., 2004). For instance, Bar and Neta (2006; though see Silvia & Barona, 2009) demonstrated that when presented with images of rounded and angular objects and patterns, people consistently preferred those stimuli that had rounded contours. However, many of the rounded objects were also more symmetrical than their angular counterparts, such as a circular watch face versus a rectangular watch face. Since a circle is symmetrical along all possible axes, whereas a rectangle is symmetrical only along the horizontal and vertical axes, it is possible that the preference for roundness was due to an effect of symmetry.

Symmetry is known to have a powerful influence on human aesthetic preferences, when it comes to shapes (Jacobsen, 2010; Jacobsen, Schubotz, Höfel, & von Cramon, 2006; Tinio & Leder, 2009), faces, and bodies (Langlois & Roggman, 1990; Perrett et al., 1999; Rhodes, 2006; Rhodes, Proffitt, Grady, & Sumich, 1998; across cultures: Little, Apicella, & Marlowe, 2007; Rhodes et al., 2001). The classic explanation of this preference is based in the purported evolutionary significance of symmetry, as a signal of health and genetic fitness (e.g., Gangestad, Thornhill, & Yeo, 1994; Jones et al., 2001; Møller & Thornhill, 1998). Appraising symmetrical visual stimuli as pleasant would be adaptive, as it would lead to higher quality mate and food choices—and both these qualities, and their signals, are more biologically expensive to produce (Watson & Thornhill, 1994). However, Henderson and colleagues have recently revisited these claims and shown that symmetry is only weakly related to perceived health, although it is somewhat linked to objective health (Henderson, Holzleitner, Talamas, & Perrett, 2016). On the other hand, symmetry may be a preferred feature because of its importance for visual processing. Symmetry has been shown to facilitate object recognition (Enquist & Arak, 1994; Vetter, Poggio, & Bülthoff, 1994), and symmetrical patterns tend to be detected more rapidly than asymmetrical ones (see Wagemans, 1995, for a review), from as early as 4 months of age (Bornstein, Ferdinandsen, & Gross, 1981; Fisher, Ferdinandsen, & Bornstein, 1981).

This is not to discredit the widely observed impact of contour on preference, but rather to highlight the importance of taking other features with extensive empirical support into account, and in a systematically controlled manner. When it comes to investigating the visual aspects of food, symmetry may be an important sign of taste qualia, as symmetry has been suggested to signal nutritive value (e.g., Rodríguez, Gumbert, De Ibarra, Kunze, & Giurfa, 2004). In the context of the affective mediation of the shape–taste correspondence, symmetry was shown to be associated with sweet taste on the basis of their shared pleasantness (Salgado-Montejo et al., 2015). However, this study only compared symmetry and asymmetry, which may not tell the full story.

In geometry, a figure is symmetrical if it can be divided into two or more related parts by an organized set of operations—that is, transformations (Lipson & Cochran, 1966; Lockwood & Macmillan, 1978). In the two-dimensional Euclidean plane, these transformations are translations, rotations, and reflections, leading to three basic types of symmetry—translational, rotational, and reflectional—as well as more complex types and combinations thereof (Armstrong, 1988; Wagemans, 1995; Weyl, 1952; see Fig. 1).

When it comes to human perception, the only types that are detectable by the visual system appear to be reflectional and rotational symmetry (Corballis & Roldan, 1974; Wagemans, 1997; Weyl, 1952/2016). Moreover, among reflections, symmetry along the vertical axis (bilateral symmetry) seems to be the preferred type, both when it comes to detection (e.g.,

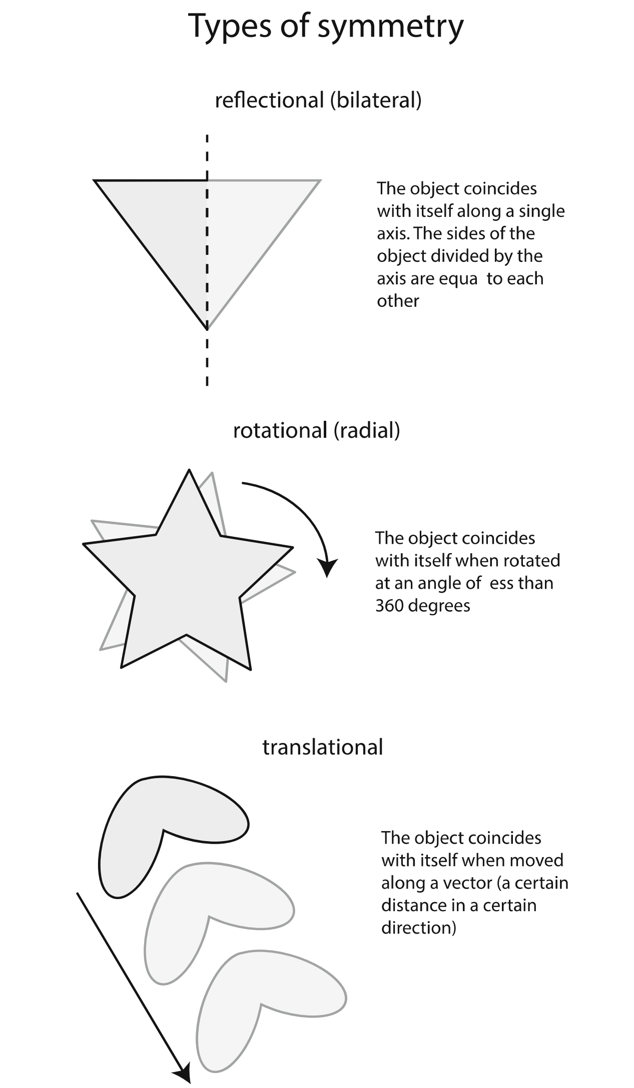

Fig. 1 Graphic examples of the basic types of transformations in the plane, giving reflectional, rotational, and translational symmetries.

Corballis & Roldan, 1974; Julesz, 1971; Locher & Nodine, 1989; Palmer & Hemenway, 1978; Royer, 1981), and evaluation (e.g., Bertamini, Friedenberg, & Argyle, 2002; Makin, Pecchinenda, & Bertamini, 2012). Possible explanations for the preference for bilateral symmetry include implied evolutionary significance (since faces and bodies are symmetrical in this regard), the structural left–right symmetry of the human nervous system (see Corballis & Roldan, 1974), and sensitization to the commonality of this type of symmetry in the environment (Rock & Leaman, 1963). However, a new study by Jennings and Kingdom (2017) has demonstrated, albeit on a small sample, that rotational symmetry above the fifth-order is actually more easily detectable than reflectional symmetry.

From a mathematical standpoint, these two types belong to two different symmetry groups, in which rotational symmetry belongs to the cyclic groups, and bilateral symmetry corresponds to D_1 of the dihedral groups in the two-dimensional plane. However, under the dihedral groups, which involve both rotational and reflectional transformations, many other types of symmetry exist, which may be worth investigating in the context of affective appraisals, and by extension, shape–taste correspondences. A recent study has implied that shapes with more than one axis of reflectional symmetry offer advantages for information processing (Tinio & Leder, 2009; see also Palmer & Hemenway, 1978; Royer, 1981). Similarly, in a pilot study preceding the present work, we have shown that shapes with more than one symmetry axis were rated as the most pleasant and least threatening, as well as the most sweet and least bitter, as compared to shapes with one axis of symmetry. However, these shapes were both rotationally symmetrical, and reflectionally symmetrical along four axes, making up D_8 of the dihedral groups (same as in Tinio & Leder, 2009). Indeed, if the aesthetic preference of a visual stimulus resulted from its ease of processing (Reber et al., 2004), then D_8 shapes would be preferred over D_1 shapes, and perhaps, as a result, sweeter. Thus we now ask: how do different types of dihedral groups compare on how they affect perceived pleasantness, alongside contour, and whether symmetry and contour in any way modulate each other.

Overview of the study

The main interest of the present study was to investigate the role of visual symmetry, alongside contour, in the shape–taste correspondence. Apart from exploring whether and how symmetry influences the established correspondence between shape contour and taste, we were interested in investigating the robustness of the effect of symmetry and contour across different populations. Since the feature of shape carries many crossmodal associations (e.g., to speech sounds, odors, textures), it is to be expected that shape will trigger taste associations in contexts that are related to gustation, that is, when people are asked to think about taste. For this reason we explicitly asked people to evaluate the taste of the visual stimuli they saw. A secondary interest was to investigate whether a common affect associated with stimuli properties contributes to the emergence of the shape–taste correspondence. These aims were explored over two online experiments, designed as replications with slightly modified conditions. Experiment 1 was conducted with a Western sample (participants from the United Kingdom, the United States, and Canada), whereas Experiment 2 was conducted with participants from Taiwan. Both experiments were approved by the Central University Research Ethics Committee at the University of Oxford (reference number: MS-IDREC-C1-2015-215).

We predicted that rounded shapes, as compared to angular shapes, would be rated as sweeter and less bitter, and also as more pleasant and less threatening, replicating the research on shape–taste correspondences reviewed above. Furthermore, following the results of a pilot study, we hypothesized that shapes from D_8 of the dihedral groups would be rated the sweetest, least bitter, most pleasant, and least threatening, as compared to the D_1 and asymmetric shapes. These assumptions would presumably be facilitated by the shared pleasantness and threat appraisals of the visual features of the shapes on one hand, and the taste words on the other. We tested affective mediation through correlational analyses. If a shape were rated as sweet (or bitter) and also as pleasant (or threatening), and if these ratings were significantly correlated, it would suggest a nonarbitrary link between the perceived taste and appraisal of shapes. Since the links between tastes and their appraisals are known (e.g., Steiner et al., 2001), the correlations above could provide evidence as to common affective appraisal (pleasantness or threat) underlying visual shape features and taste.

Experiment 1

Method

Participants A total of 90 participants (53 males, 37 females; age range: 18–50 years, $M = 29.28$, $SD = 7.67$) took part in the experiment through the Qualtrics Online Survey platform. Participants were recruited using the online recruitment platform Prolific Academic in exchange for a payment of £1.50, and were based in the following countries: United States (58.9%), United Kingdom (35.6%), and Canada (5.6%). Before taking part in the study, participants were directed to an information sheet and asked to give consent by clicking the appropriate button at the end of a standard consent form. All of the participants had reported normal or corrected-to-normal senses of vision, taste, smell, hearing, and touch.

Materials Visual stimuli (see Fig. 2) were created using a formula for radial frequency (RF) patterns based on work by Wilkinson, Wilson, and Habak (1998)—that is, closed contours with sinusoidal modulations along the circumference of a circle (Schmidtmann, Jennings, & Kingdom, 2015). This formula can be defined as a function of polar angle (θ):

$r(\theta) = r_{\text{mean}}[1 + A\sin(\omega\theta + \varphi)]$,where r_{mean} is the radius of the base circle, A is the amplitude of the sinusoidal modulation, ω is the frequency, and ϕ is the phase of the sinusoids (Chen, Huang, Woods, & Spence, 2016). To generate different symmetry conditions, we manipulated the frequency of the RF patterns and the relative phase between them. Four rounded D_1 shapes were created by adding two RF patterns with radial frequencies of 3 and 8 cycles/circle for two shapes, and 5 and 8 cycles/circle for the other two shapes, and by varying the relative angular phase (position expressed in radians) between the two RF patterns. Four rounded D_8 shapes were created by adding two RF patterns with 4 and 8 cycles/circle for two shapes, and 8 and 8 cycles/circle for the other two shapes. Four asymmetrical shapes were created by adding two RF patterns with radial frequencies of either 5 and 8 cycles/circle for two shapes, 7 and 8 cycles/circle for one shape, and 1.5 and 8 cycles/circle for the other shape. Angular versions of each shape were created by adding four additional harmonics of 8-cycle/circle RF patterns on top of each sinusoidal modulation. All of the patterns contained 8-cycle/circle RF patterns with an amplitude of 0.3, conserving the number of elements and the protrusion of "lobes" across shapes. Because only eight quadruple symmetrical shapes (four round and four angular) could be created while keeping the number of elements in a shape constant, this number was generalized to all symmetry conditions, amounting to a total of 24 shapes. The full list of parameters used to create the visual stimuli, the stimuli themselves, and the code based on the above formula that generated the stimuli are available in the Open Science Framework (OSF) repository for this project (https://osf.io/qn593/).

Taste matching was assessed via three visual analog scales (VAS)—that is, continuous line-mark rating scales—representing the taste words "sweet," "sour," and "bitter,"[3] each ranging from 0 (*not at all*) to 100 (*very well*), after the question "How well does this shape 'go with' the taste words below?" Pleasantness and perceived threat were also assessed by means of VAS scales, ranging from 0 (*not at all*) to 100 (*very*) on scales labeled *pleasant* and *threatening*. Continuous VAS scales were chosen over the more frequently used categorical scales, such as Likert, because they allowed for more options in terms of the statistical analysis.

Procedure After giving their informed consent, the participants were directed to either the taste condition followed by the appraisal condition, or vice versa, in a counterbalanced order. In both conditions, a single shape was presented on the screen at a time, which participants could rate by means of different 100-point VAS sliders, corresponding to "sweet," "sour," and "bitter" in the taste condition, or "pleasant" and "threatening" in the appraisal condition. Each experiment lasted approximately 15 min, and none lasted more than 25 min.

Results and discussion

The results of the four shapes in each symmetry-by-contour condition were collapsed to form one composite measure, representing all shapes within a condition (see Velasco et al., 2015).

[3] "Salty" taste was not included because its appraisal depends heavily on internal biological needs, such as electrolyte balance (Frank & Hettinger, 2005; Yarmolinsky, Zuker, & Ryba, 2009), potentially biasing any observed crossmodal associations.

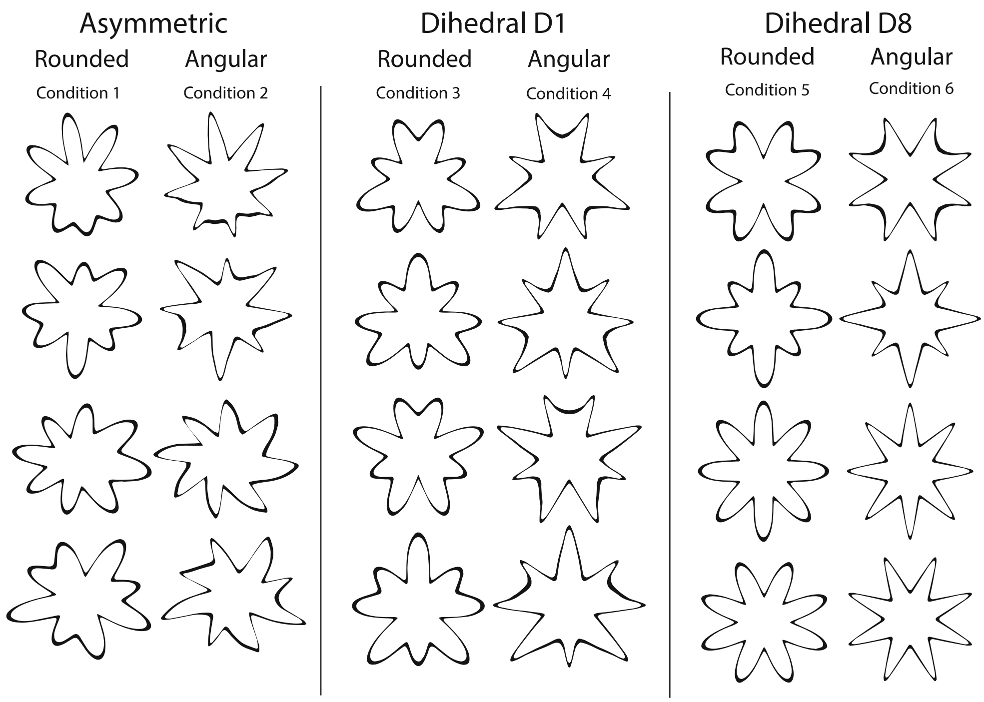

Fig. 2 Shapes used as visual stimuli in both experiments. All shapes were presented in black against a white background and had the same line thickness and number of elements.

Taste (sweet, sour, and bitter) First, Pearson correlations were conducted between the dependent variables (taste ratings) to assess the appropriateness of a multivariate analysis of variance (MANOVA; Meyers, Gamst, and Guarino, 2006). Next we conducted a repeated measures MANOVA, which revealed significant main effects of symmetry [Pillai's trace = .428, $F(6, 84) = 10.46$, $p < .001$, $\eta_p^2 = .428$] and of contour [Pillai's trace = .609, $F(3, 87) = 45.24$, $p < .001$, $\eta_p^2 = .609$], as well as a significant interaction [Pillai's trace = .215, $F(6, 84) = 3.83$, $p < .001$, $\eta_p^2 = .215$]. To compare symmetry conditions at each level of contour, the dataset was split by contour. The multivariate effect of symmetry was significant both for round shapes [Pillai's trace = .428, $F(6, 84) = 10.48$, $p < .001$, $\eta_p^2 = .428$] and angular shapes [Pillai's trace = .323, $F(6, 84) = 7.17$, $p < .001$, $\eta_p^2 = .339$]. For round shapes, follow-up univariate testing revealed that the D_8 shapes were rated the sweetest [$F(1.86, 165.37) = 35.19$, $p < .001$, $\eta_p^2 = .283$], least sour [$F(2, 178) = 11.91$, $p < .001$, $\eta_p^2 = .118$], and least bitter [$F(2, 178) = 14.24$, $p < .001$, $\eta_p^2 = .138$], as compared to the D_1 and asymmetric shapes. For angular shapes, the D_8 shapes were also rated the sweetest [$F(1.69, 150.63) = 17.25$, $p < .001$, $\eta_p^2 = .162$], and least bitter [$F(1.68, 150.34) = 19.31$, $p < .001$, $\eta_p^2 = .178$], but no significant differences emerged for sourness [$F(1.78, 158.66) = 0.29$, $p = .706$, $\eta_p^2 = .003$]. This supported our hypothesis regarding symmetry. Moreover, the differential result for sourness showed that contour modulates the effect of symmetry on taste ratings. Univariate testing on the two types of contour confirmed that sweetness ratings were significantly higher for round shapes [$F(1, 89) = 131.50$, $p < .001$, $\eta_p^2 = .596$], whereas the sourness and bitterness ratings were significantly higher for angular shapes [sour: $F(1, 89) = 86.46$, $p < .001$, $\eta_p^2 = .493$; bitter: $F(1, 89) = 109.77$, $p < .001$, $\eta_p^2 = .552$]. This supported our expectations regarding contour and also replicated previous research (e.g., Salgado-Montejo et al., 2015; Velasco et al., 2015, 2016a).

Appraisal (pleasantness and threat) Significant main effects of symmetry [Pillai's trace = .600, $F(4, 86) = 32.24$, $p < .001$, $\eta_p^2 = .600$] and of contour [Pillai's trace = .701, $F(2, 88) = 103.06$, $p < .001$, $\eta_p^2 = .701$] were observed for people's pleasantness and threat ratings. There was also a significant interaction between symmetry and contour [Pillai's trace = .313, $F(4, 86) = 9.78$, $p < .001$, $\eta_p^2 = .313$]. After splitting by contour, multivariate analysis revealed a significant effect of symmetry both for round shapes [Pillai's trace = .519, $F(4, 86) = 22.27$, $p < .001$, $\eta_p^2 = .509$] and for angular shapes [Pillai's trace = .571, $F(4, 86) = 28.66$, $p < .001$, $\eta_p^2 = .571$]. Follow-up univariate testing revealed that, for round shapes, D_8 shapes were rated the most pleasant, followed by D_1 shapes, and finally asymmetric shapes [$F(1.56, 138.66) = 68.42$, $p < .001$, $\eta_p^2 = .435$]. D_8 shapes were also the least threatening, followed by D_1 shapes, and asymmetric shapes, which were the most threatening [$F(1.72, 152.83) = 24.99$, $p < .001$, $\eta_p^2 = .219$]. For angular shapes, the D_8 shapes were rated as significantly more pleasant than the D_1 and asymmetric shapes [$F(1.70, 150.78) = 74.84$, $p < .001$, $\eta_p^2 = .457$], and significantly less threatening than those same shapes [$F(1.69, 151.24) = 41.50$, $p < .001$, $\eta_p^2 = .318$]. Univariate

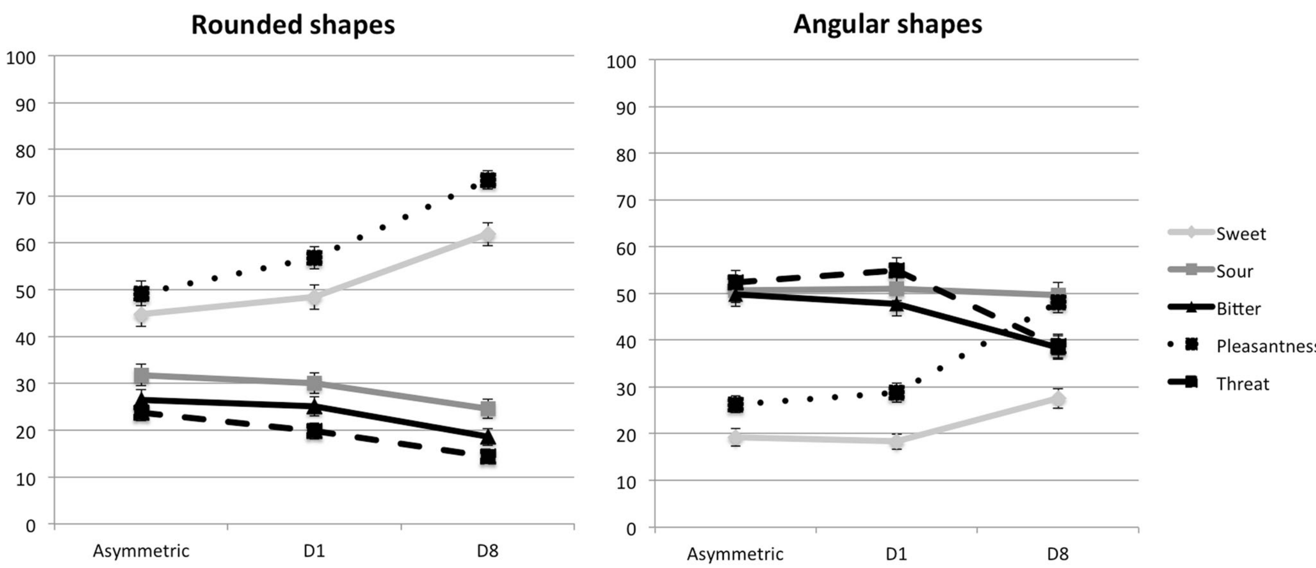

Fig. 3 Line graphs showing the mean taste and appraisal ratings for rounded and angular shapes at each level of symmetry in Experiment 1.

testing on the two types of contour confirmed that pleasantness ratings were significantly higher for round than for angular shapes [$F(1, 89) = 154.76, p < .001, \eta_p^2 = .635$], whereas threat ratings were significantly higher for angular than for round shapes [$F(1, 89) = 208.47, p < .001, \eta_p^2 = .701$]. Our hypothesis regarding symmetry was supported, in that quadruple symmetry was rated as being the most pleasant and least threatening. Once again, contour modulated the effect of symmetry, such that the difference in the appraisal of bilaterally symmetrical and asymmetric shapes was only observed when they were rounded but not when they were angular. More detailed results, such as group means, standard errors, and pairwise comparisons, as well as the original datasets can be found in the OSF repository for this project (https://osf.io/qn593/).

Figure 3 shows that the taste and appraisal ratings of the rounded shapes fell into two clear patterns: increasing for sweet and pleasant, and decreasing for sour, bitter, and threat, from asymmetric to D_8 shapes. The main effects are clearly visible, with pleasant and sweet ratings being higher overall than sour, bitter, and threat ratings. Angular shapes showed a similar trend, with increasing ratings for pleasant and sweet, and decreasing for bitter, and threat, but opposite main effects, in that the pleasant and sweet ratings were lower than the sour, bitter, and threat ratings.

Bonferroni-corrected Pearson correlations with one-tailed significance tests were conducted between taste and appraisal ratings for the six symmetry-by-contour stimulus conditions.[4]

[4] Correlation results for all 24 individual shapes can be found in the OSF repository for this project (https://osf.io/qn593/).

Table 1 shows strong significant correlations between sweetness and pleasantness ratings, and sourness and bitterness and threat ratings. Conversely, sweetness and threat are highly inversely correlated, as are sourness and bitterness and pleasantness.

Experiment 1 showed that not only do contour and symmetry influence the appraisal and taste associations of shapes, but the former modulates the latter factor. Namely, for rounded shapes, symmetry group differentially affected the associations for all tastes, whereas for angular shapes, symmetry group affected only the associations with sweet and bitter taste. Round shapes from all symmetry groups were significantly different in terms of pleasantness and threat ratings. By contrast, for angular shapes, D_8 shapes were significantly different from both D_1 and asymmetric shapes, whereas the latter two did not differ significantly on either pleasantness or threat. Over and above the interaction between symmetry and contour, we observed larger differences in the overall levels of the taste and appraisal ratings, with pleasant and sweet ratings being higher than sour, bitter, and threat ratings for rounded shapes, but pleasant and sweet ratings being lower than sour, bitter, and threat ratings for angular shapes. Furthermore, Experiment 1 clarified the contribution of symmetry to the shape–taste correspondence: A higher number of reflection/rotation axes was linked to higher perceived sweetness and pleasantness of the shapes, regardless of contour. Conversely, a lower number of reflection/rotation axes was linked to higher perceived sourness, bitterness, and threat of round shapes, and to higher perceived bitterness and threat of angular shapes.

Table 1 Correlations between taste and appraisal ratings per shape condition in Experiment 1

	Sweet	Sour	Bitter	Pleasantness	Threat
Sweet	1.000	– .979*	– .985*	.951*	– .977*
Sour	– .979*	1.000	.966*	– .874	.960*
Bitter	– .985*	.966*	1.000	– .951*	.993*
Pleasantness	.951*	– .874	– .951*	1.000	– .940*
Threat	– .977*	.960*	.993*	– .940*	1.000

* $p < .005$ (Bonferroni corrected for ten comparisons).

Experiment 2

In Experiment 2 we tested the universality of symmetry (and contour) in shape–taste associations in Taiwan, an East Asian population. Despite the evidence supporting universal tendencies toward certain shape–taste associations (e.g., round–sweet; see the introduction), some studies have found differences across cultures. For example, Bremner et al. (2013) found that tribal Namibians matched the comparatively sweetest milk chocolate to angular shapes, instead of round shapes, as observed in Western populations (though see also Liang et al., 2016; Liang, Roy, Chen, & Zhang, 2013). This effect was attributed to linguistic factors, whereby the Namibian word for bitter/sour contains more speech sounds that are normally associated with round shapes, going against traditionally observed sound symbolic matching (Bremner et al., 2013, p. 171). A similar pattern is observed in Taiwanese culture, where the word for sweet [tián] contains more speech sounds normally associated with angular rather than round shapes. Because of the similarity of sound symbolism patterns of speech sounds in taste words, the influence of linguistic over affective factors on the shape–taste correspondence could, then, be readily investigated on Taiwanese participants. If linguistic, rather than affective factors, mediated the taste–shape correspondence, then we would expect differences in how the Taiwanese participants rate shapes relative to the Western cohort from Experiment 1 (comprising participants from the United Kingdom, the United States, and Canada). In terms of food culture, Taiwan and the aforementioned Western cultures are quite different, though presumably less so than the tribal Himba culture. Crucially, though, there is growing empirical evidence of perceptual differences between East Asian and Western cultures (e.g., Chen et al., 2016; Doherty, Tsuji, & Phillips, 2008; Gutchess, Welsh, Boduroglu, & Park, 2006; McKone et al., 2010; Nisbett & Miyamoto, 2005), further motivating the comparison between Western and Taiwanese cultures.

Method

Participants A total of 127 students of the National Cheng Kung University in Tainan, Taiwan took part in the experiment (55 males, 72 females; age range: 18–25 years, M = 20.53, SD = 1.36) through the Qualtrics Online Survey platform. Participants gave their informed consent at the time of recruitment at the university, and the informed consent was approved by the Department of Psychology, National Cheng Kung University. Participants received course credit as compensation.

Materials and procedure The materials used in Experiment 2 were translated into Mandarin Chinese by two native speakers for the purpose of this experiment. The procedure was the same as in Experiment 1.

Results and discussion

The data analysis procedure from Experiment 1 was repeated. However, for the sake of brevity, we will not report these parallel results here, but rather they can be found in the OSF repository for this project (https://osf.io/qn593/), together with the results from Experiment 1.

Figure 4 shows the key results of this analysis. As in the Western sample, pleasant and sweet ratings were overall higher than sour, bitter, and threat ratings for rounded shapes, but the opposite trend was observed for angular shapes: That is, pleasant and sweet ratings were lower than sour, bitter, and threat ratings. Below we will present and discuss the results of an overall MANOVA comparing the two datasets (factors: culture, symmetry, and contour), in an attempt to better grasp any differences driven by culture.

Taste (sweet, sour, and bitter) The overall analysis showed no significant main effect of culture [Pillai's trace = .041, $F(3, 87) = 1.236$, $p = .301$, $\eta_p^2 = .041$]. This is in line with the results of the parallel analyses of each sample, because, similar to the results from the Western sample in Experiment 1, the D_8 shapes were rated the sweetest [$F(2, 252) = 47.82$, $p < .001$, $\eta_p^2 = .275$] and least bitter [$F(2, 252) = 26.41$, $p < .001$, $\eta_p^2 = .173$], as compared to the other two symmetry categories, and less sour than the asymmetric shapes [$F(2, 252) = 4.81$, $p < .001$, $\eta_p^2 = .037$]. For angular shapes, again the D_8 shapes were rated the sweetest [$F(1.858, 234.046) = 20.29$, $p < .001$, $\eta_p^2 = .139$] and least bitter [$F(1.883, 237.232) = 34.42$, $p < .001$, $\eta_p^2 = .215$], as compared to the D_1 and asymmetric shapes. Sourness ratings were not significantly affected [$F(1.810, 228.032) = 0.61$, $p = .530$, $\eta_p^2 = .005$].

Appraisal (pleasantness and threat) We found a significant main effect of culture [Pillai's trace = .133, $F(2, 88) = 6.77$, $p = .002$, $\eta_p^2 = .133$], but no significant interactions with either

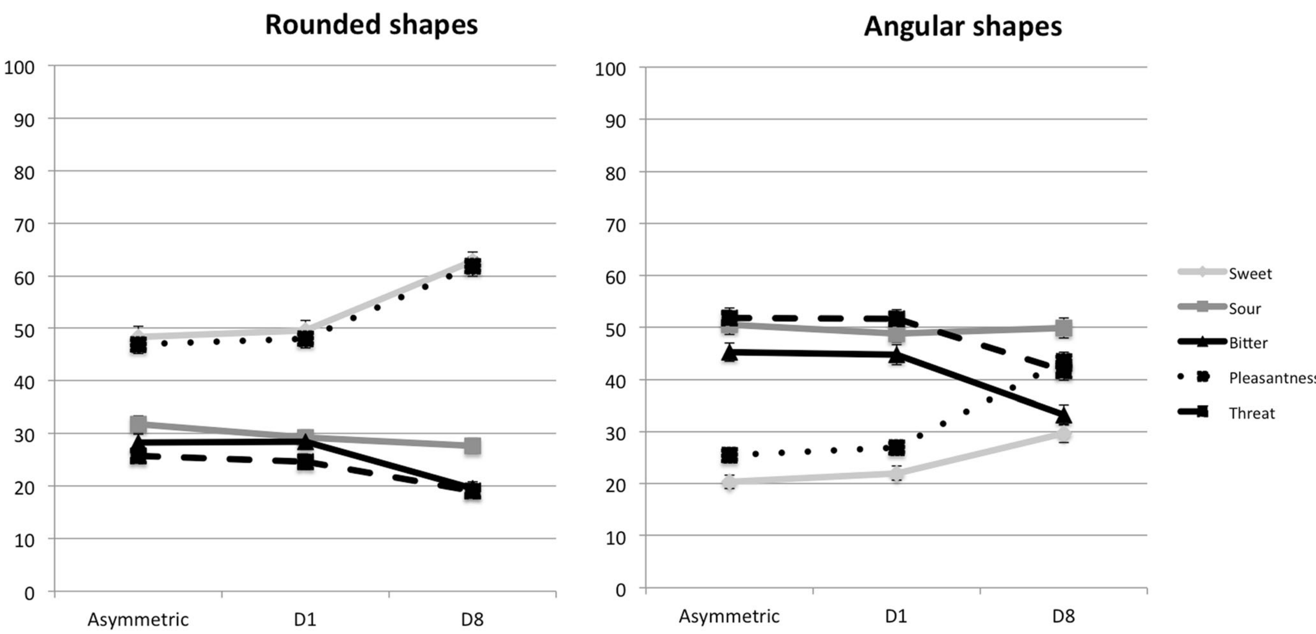

Fig. 4 Line graphs showing the mean taste and appraisal ratings for rounded and angular shapes at each level of symmetry in Experiment 2.

symmetry [Pillai's trace = .102, $F(4, 86) = 2.44$, $p = .053$, $\eta_p^2 = .102$], or contour [Pillai's trace = .030, $F(2, 88) = 1.38$, $p = .257$, $\eta_p^2 = .030$]. The three-way interaction between the factors was also not significant [Pillai's trace = .077, $F(4, 86) = 1.80$, $p = .136$, $\eta_p^2 = .077$]. Further univariate testing and simple effects tests on culture showed that Westerners rated the shapes as more pleasant overall than did the Taiwanese sample [$F(1, 126) = 162.75$, $p < .001$, $\eta_p^2 = .564$; $M_W - M_E = 5.65$, $p = .009$].

Finally, the correlation results of Experiment 1 were replicated (see Table 2), in that similar significant relationships were found between the taste and appraisal ratings.

Experiment 2 demonstrated that the observed influences of contour and symmetry on shape–taste associations replicate across cultures, since both contour and symmetry were shown to contribute, in interaction, to shape–taste associations, as in Experiment 1. This experiment provides some balance for the homogeneous Western, educated, industrialized, rich, and democratic (WEIRD; Henrich, Heine, & Norenzayan, 2010) samples that continue to dominate much of psychological research (though see Bremner et al., 2013; Liang et al., 2016; Liang et al., 2013; Wan et al., 2014, for relevant exceptions). Moreover, this experiment supports the robustness of visually presented symmetry, whose influence on shape–taste associations was consistent across the culturally distinct samples. Cultural differences were observed only in shape appraisal: Specifically, Westerners perceived the shapes as being more pleasant overall. Nevertheless, the general trends that D_8 shapes were the most pleasant and least threatening, and that round shapes were more pleasant and less threatening than angular shapes, were consistently observed in both cultures.

Table 2 Correlations between taste and appraisal ratings per shape condition in Experiment 2

	Sweet	Sour	Bitter	Pleasantness	Threat
Sweet	1.000	– .960*	– .965*	.949*	– .988*
Sour	– .960*	1.000	.867	– .833	.959*
Bitter	– .965*	.867	1.000	– .997*	.967*
Pleasantness	.949*	– .833	– .997*	1.000	– .946*
Threat	– .988*	.959*	.967*	– .946*	1.000

* $p < .005$ (Bonferroni corrected for ten comparisons).

General discussion

The present study provided new insights into the shape–taste correspondence by replicating existing knowledge on the role of shape contour, and expanding it through a delineation of the role of shape symmetry—a previously unexplored dimension in the field. The symmetry group of a shape crucially influenced how shapes were associated with tastes. The influence of symmetry was modulated by contour, such that, for rounded shapes, symmetry affected all taste ratings, but for angular shapes, symmetry did not affect sourness ratings. These results were consistent across our two culturally distinct samples.

In the comparison of symmetry groups, the dihedral group D_8, with both reflectional and rotational symmetry, was rated as the most pleasant and most associated with sweet taste. Following the evolutionary account, the D_1 group, with its bilateral symmetry across the vertical axis, should have shown this pattern of results, as both preference for this type of symmetry, and preference for sweet taste are thought to have evolutionarily significant roles—the former in signaling mate quality (e.g., Jones et al., 2001), and the latter in signaling the nutritive value of food (e.g., carbohydrates, ripeness; Breslin, 2013). However, some studies suggest that the preference for left–right symmetry is domain-specific to biological images (animals: Evans, Wenderoth, & Cheng, 2000; human faces: Young, Sacco, & Hugenberg, 2011; human but not animal faces: Little, 2014), and that it does not generalize to other kinds of stimuli. Moreover, it is known that symmetry introduces redundancy in visual displays, making them less resource-intensive to process (e.g., Apthorp & Bell, 2015), which, in turn, may result in higher perceived pleasantness (Reber et al., 2004; Reber, Wienkielman, & Schwarz, 1998). Thus, our finding that shapes with the most symmetry were perceived as the sweetest, least bitter, most pleasant, and least threatening supports the processing fluency account of aesthetic preference, over the evolutionary account. However, it is unknown whether rotation or reflection was driving the effect, because introducing rotations of 0, 90, 180, and 270 deg inevitably comes with reflectional symmetries about two orthogonal axes, as a result of the group-theoretical structure of the shapes. Introducing a control condition with rotationally symmetrical shapes without reflection—that is, shapes from the cyclic group—would help disentangle these transformations.

The study also suggested affective mediation as a possible contributor to the shape–taste correspondence. Significant correlations were obtained between sweetness and pleasantness ratings, and bitterness and threat ratings of shapes, meaning that shapes that were rated highest on sweetness were also rated highest on pleasantness, and likewise for sourness and threat, and bitterness and threat. This correlation shows that shapes share the same affective appraisal as the tastes that they are associated with, indicating that this appraisal may relate to the way in which people match shapes and tastes. However, this finding cannot unequivocally demonstrate that people's taste ratings of shapes are mediated exclusively by affective information, as correlational analyses cannot guarantee a causal link between shape appraisal and their association to tastes. Indeed, both Velasco et al. (2015) and Salgado-Montejo et al. (2015) have already noted that the affective mediation hypothesis may only partially explain the association between shape and taste. Other factors could be explored alongside affective appraisal in further studies (e.g., intensity in Velasco, Woods, Liu, & Spence, 2016b). With this, it cannot be said that the taste–shape correspondence is a purely affectively mediated correspondence, although, we can predict that those features that share a common affect might be more likely to be associated. That said, affective factors are not the only thing that varies with sensory features in the real world, and different types of correspondences need not be mutually exclusive (e.g., Parise & Spence, 2012, 2013), so an exclusively affective correspondence may not be feasible at all.

Any given sensory feature carries a multitude of associations to other sensory features, but it is difficult to estimate which of these associations will be activated in a given context. One limitation of the present study, as many other similar studies in the field, is that participants were "primed" for a specific context (in this case gustation), in order to investigate one particular correspondence (in this case the shape–taste correspondence). In the real world, such priming may exist, but may be restricted to situations in which food consumption is imminent, for example. More research would be needed to clarify the extent to which taste associations are activated in nongustatory contexts, and conversely, the extent to which other associations are activated in gustatory contexts. Although shape features might not necessarily make people think about taste, when they *are* thinking about taste, shape features that affectively correspond to the tastes might help disambiguate food/drink objects in environment.

Since the shape–taste correspondence is only one of many crossmodal correspondences, it stands to reason that affective mediation might be involved in other correspondences, as well. Related research so far suggests that affective factors play a role in other taste-related correspondences (e.g., taste–music, Crisinel & Spence, 2010; for a review, see Knöferle & Spence, 2012), as well as correspondences related to smell (odor–color: Schifferstein & Tanudjaja, 2004; odor–shape: Hanson-Vaux, Crisinel, & Spence, 2013; odor–pitch: Crisinel & Spence, 2012; for a review of olfactory correspondences, see Deroy et al., 2013), and in music–color associations (e.g., Barbiere, Vidal, & Zellner, 2007; Palmer, Langlois, & Schloss, 2016; Palmer, Schloss, Xu, & Prado-León, 2013b) alike. Thus, it cannot be said that the shape–taste correspondence is the only correspondence under the influence of affective factors. However, it is curious to ask whether affectively mediated correspondences are similar in some way, and thus, different from other correspondences that are better explained by other factors. Given that tastes, odors, colors, and musical stimuli (that vary in pitch, timbre and tempo, not pure tones) are metathetic features (features arranged on a qualitative as opposed to a magnitude-based continuum; see note 2), it may be that metathetic features are more likely to be affectively mediated.

In terms of cross-cultural results, Westerners perceived all of the shapes as more pleasant than did the Taiwanese. Differences were indeed expected, given the known influence of culture on aesthetic judgments (e.g., Jacobsen, 2010; Jacobsen et al., 2006; Mühlenbeck, Liebal, Pritsch, & Jacobsen, 2016; Tomasello, 2000). But, under this premise, why were there not greater differences between the samples in shape–taste associations? It may have been the case that the differences were not great enough to drive differential taste matching. After all, the general patterns of perceived pleasantness and threat were the same across cultures: Round shapes were more pleasant and less threatening than angular shapes, and likewise sweeter and less bitter, and D_8 shapes were the most pleasant and least threatening of all, as well as the sweetest and least bitter. It would make sense that an overall higher perceived pleasantness among Westerners would result in their rating the shapes as more sweet than would the Taiwanese, but produce no drastic differences otherwise. However, such a difference was not observed in the overall cultural comparison. Alternatively, it is possible that other, conflicting factors were at play—for example, the connotative meanings of shape and taste words that were similar across cultures (Adams & Osgood, 1973; Martino & Marks, 1999, 2001; Osgood, 1960; see also Osgood, Suci, & Tannenbaum, 1957). Indeed, taste words such as "sweet," "sour," and "bitter" represent broader semantic spaces, which, besides gustatory sweetness, sourness, and bitterness, include a variety of dimensions of connotative meaning, such as pleasantness and threat (Velasco et al., 2016c). These broader connotative meanings are seen to surface in both the English language (e.g., in gustatory metaphors such as "bitter person," "bitter end," "bitter argument," etc.; see Marks, 1978) and in Mandarin Chinese (in 苦味, the word for "bitter taste," the first character, 苦, can also mean "pain" and "suffering," such as in 痛苦). Shapes and other nonword stimuli also have semantic spaces of connotative meaning (see L. Walker & Walker, 2016; P. Walker, 2012). For round shapes, this may include mildness, goodness, and pleasantness, in contrast to harshness, badness, and dangerousness for angular shapes (e.g., Lyman, 1979; Poffenberger & Barrows, 1924; Velasco, Woods, Marks, Cheok, & Spence, 2016b). Thus, it may be that the shared connotative meanings between shape and taste words, which include pleasantness and threat, are consistent across cultures, allowing the shape–taste correspondence to replicate. What is more certain is that purely linguistic factors, such as the speech sounds making up particular taste words, were not likely drivers of the shape–taste matching pattern, given how similar these patterns were between the Western and Taiwanese groups.

Author note Y.C.C. and C.S. acknowledge the support of the AHRC, through a Rethinking the Senses grant (AH/L007053/1). The authors thank the anonymous reviewers for their valuable comments and suggestions to improve the manuscript, and declare that they have no conflicts of interest. N.T., C.V., and C.S. conceived and designed the experiments. Y.C.C. and P.C.H. provided materials for the experiments. N.T. performed the experiments and analyzed the data. N.T., C.V., Y.C.C., P.C.H., and C.S. wrote the article.

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