Symmetry and its Role in the Crossmodal Correspondence between Shape and Taste

Nora Turoman[1,2], Carlos Velasco[3,1], Yi-Chuan Chen[1,5], Pi-Chun Huang[4], & Charles Spence[1*]

[1] Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, Oxford, OX1 3UD, UK

[2] Departments of Radiology and Clinical Neurosciences, Centre Hospitalier Universitaire Vaudois (CHUV) and University of Lausanne (UniL), Lausanne, Switzerland

[3] Department of Marketing, BI Norwegian Business School, Oslo, Norway

[4] Department of Psychology, National Cheng Kung University, Tainan, Taiwan

[5] Department of Medicine, Mackay Medical College, New Taipei City, Taiwan

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CORRESPONDENCE: ~~Charles Spence~~Nora Turoman, Departments of Radiology and Clinical Neurosciences, Centre Hospitalier Universitaire Vaudois (CHUV) & University of Lausanne (UniL), BH7.081, rue du Bugnon 46, 1011 Lausanne. TEL.: +41 (0) 79 898 17 99~~Department of Experimental Psychology, Crossmodal Research Laboratory, University of~~

~~Oxford, 9 South Parks Road, Oxford, OX1 3UD, UK; TEL.: +44 (0) 1865 271364~~; E-MAIL: ~~charles.spence@psy.ox.ac.uk~~nora.turoman@chuv.ch

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). However, 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 contour of shapes and measured their influences 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 previous results showing that round shapes are associated with sweet taste, while angular shapes are associated with sour and bitter tastes. In addition, we demonstrate a novel effect that the patterns with a greater number of axes of symmetry tend to be associated with sweet rather than with sour or bitter tastes. A significant relationship was observed between the taste scores 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 comparing participants from Taiwanese and Western (UK, US, Canada) cultures. These findings highlight the fact that perceived pleasantness and threat are culturally-common factors involved in at least some crossmodal correspondences.

KEYWORDS: crossmodal correspondences, shape, symmetry, taste, pleasantness, threat

Introduction

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, there has been growing evidence 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, rounded shapes are typically matched with sweet taste, while angular shapes are matched with sour or bitter tastes instead. These results have been replicated using basic taste solutions (e.g., Velasco et al., 2015; 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). Above and beyond broadening the knowledge on correspondences related to the chemical senses (see Spence & Deroy, 2013), research on the shape-taste correspondence may potentially help in elucidating 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, i.e., roundness and angularity, as the key visual shape attribute (Spence & Deroy, 2013; Spence & Ngo, 2012; Velasco et al., 2016b), in the face of other visual features that are known to influence human information processing (e.g., symmetry, colour, complexity, balance, etc.; see Reber, Schwarz, & Winklemann, 2004; Palmer, Schloss, & Sammartino, 2013).

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

Affective mediation in crossmodal correspondences

Theoretical accounts that have been put forward in order 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 the packaging in which they are presented) 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 et al. 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, 1987) 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

[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.

hand, and a taste, on the other, will cause the shape and taste to be associated. For example, Salgado-Montejo and his colleagues (2015) demonstrated that, when asked to match visual shape stimuli with tastes, round shapes tended to be judged as pleasant and preferentially matched to sweet taste, while 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, 2016a) 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, while liking for shapes was not. In the present study, we investigate 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 to the organism (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 being threatening (e.g., the sight of a dead animal bleeding) is differentially processed both on the level of behaviour and of neural responses (Kveraga et al., 2014; Kveraga & Bar, 2014), 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 et al., 2009). In terms of taste, humans and animals tend to react to bitter tastes with a host of rejection behaviours, such as nausea, tongue

retraction, and delayed swallowing (Brining, Belecky, & Smith, 1991; Peyrot Des Gachons et al., 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 et al., 2014; for a study in rats, see Dess & Minor, 1996). 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, as there are a host of visual features (e.g., symmetry, complexity) that influence preference in addition to, and perhaps more than, contour (e.g., Jacobsen, 2010; Palmer, Schloss, & Sammartino, 2013; Reber, Schwarz, & Winkielman, 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 more symmetrical than their angular counterparts, such as, for example, a pair of stimuli comprised of a circular and a rectangular watch face. Since a circle is symmetrical along all possible axes, while 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 et al., 2006; Tinio & Leder, 2009), faces, and bodies (Langlois and Roggman, 1990; Perrett et al., 1999; Rhodes et al., 1998; Rhodes,

2006; across cultures: Little et al., 2007; Rhodes et al., 2001). The classic explanation of this preference is based in the purported evolutionary significance of symmetry. Namely, symmetry has long been recognised as a signal of health and genetic fitness (e.g., Jones et al., 2001; Gangestad, Thornhill, & Yeo, 1994; Møller & Thornhill, 1998). Thus, appraising symmetrical visual stimuli as pleasant would be evolutionarily adaptive, as it would lead to higher quality mates and food – 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. For instance, bumblebees tend to judge symmetrical flowers as richer in nectar (Rodríguez et al., 2004). In the context of the affective mediation of the shape-taste correspondence, symmetry was shown to be associated with sweet taste based on 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 organised set of operations, i.e., transformations (Lipson & Cochran, 1966; Lockwood, & Macmillan, 1978). In the 2-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 Figure 1).

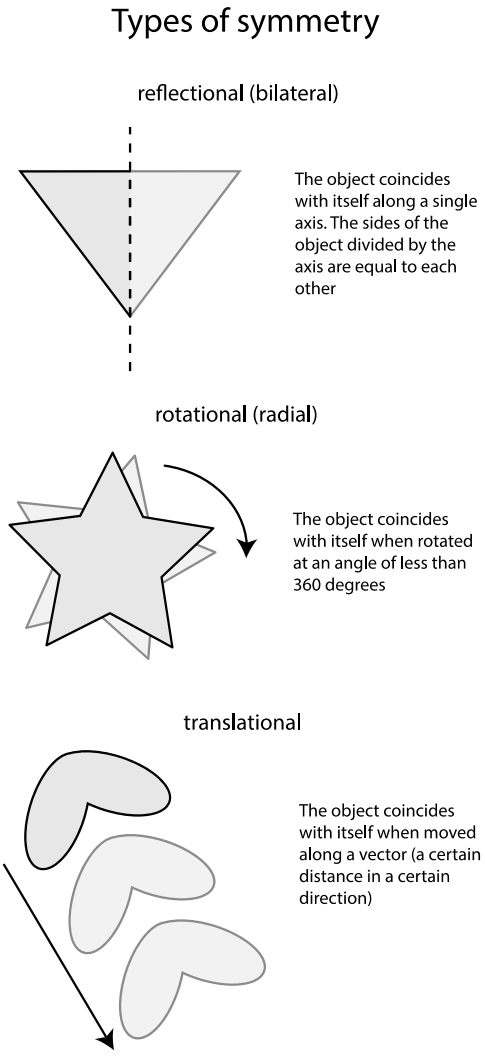


Figure 1. A graphic example of the basic types of transformations in the plane, giving reflectional, rotational, and translational symmetry.

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). Moreover, among reflections, bilateral, or reflectional symmetry along the vertical axis (left-right) seems to be the preferred type of symmetry, both when it comes to detection (e.g., 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 sensitisation 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 5^{th} order is actually more easily detectable than reflectional symmetry.

From a mathematical standpoint, these two types belong to two different symmetry groups, where 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, there exist many other types of symmetry, 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, Schwarz, & Winkielman, 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, there was interest 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, odours, 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 (United Kingdom, United States and Canada), while 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, compared to 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 non-arbitrary link between the perceived taste and appraisal of shapes. Since the links between tastes and their appraisals are known (e.g., Steiner, Glaser, Hawilo, & Berridge, 2001), the correlations above could provide evidence as to common affective appraisal (pleasantness or threat) underlying visual shape features and taste.

Experiment 1

Participants

90 participants (37 females, age range: 18 – 50 years, *M* = 29.28, *SD* = 7.67) took part in the experiment through the Qualtrics Online Survey platform. The 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 (Figure 2) were created using a formula for radial frequency (RF) patterns based on Wilkinson, Wilson, & Habak (1998), i.e., 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):

$$r(\theta) = r_{mean}(1 + A\,sin(\omega\theta + \varphi))$$

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 for two shapes, 7 and 8 cycles/circle for one shape, and 1.5 and 8 for the other shape. Angular versions of each shape were created by adding four additional harmonics of 8 cycles/circle RF patterns on top of each sinusoidal modulation.

The full list of parameters used to create the visual stimuli, as well as the stimuli themselves, are available in the Open Science Framework (OSF) repository for this project (https://osf.io/qn593/?view_only=556b851781a548f3abaff74390ed1ade). All of the patterns contained 8 cycles/circle RF patterns with amplitude of 0.3, conserving the number of elements and protrusion of 'lobes' across shapes. Because only eight quadruple symmetrical shapes (four round and four angular) could be created keeping the number of elements in a shape constant, this number was generalised to all symmetry conditions, amounting to a total of 24 shapes.

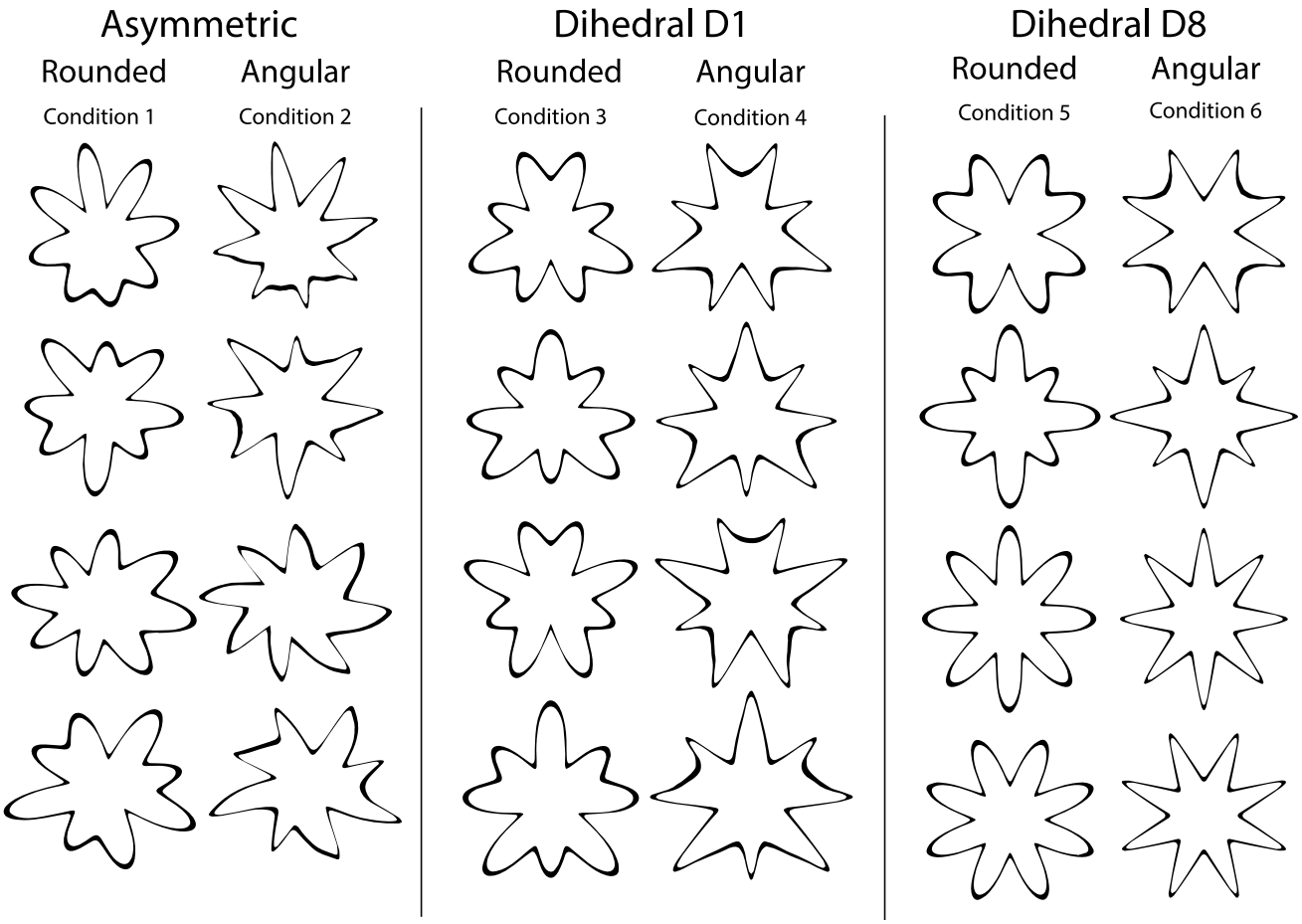


Figure 2. Shapes used as visual stimuli in both experiments. All shapes were presented in black against a white background and had the same line thickness and number of elements.

Taste matching was assessed via three visual analogue 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 labelled 'pleasant' and 'threatening'. The continuous VAS scales were chosen over more frequently

[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.

used categorical scales such as Likert, as they allow 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 for approximately 15 minutes, and no more than 25 minutes.

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).

Taste (sweet, sour, and bitter). First, we conducted Pearson correlations between the dependent variables (taste ratings) to assess the appropriateness of a 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, η_p^2 = .428) and of contour (Pillai's Trace = .609, F (3, 87) = 45.24, p < .001, η_p^2 = .609), as well as a significant interaction (Pillai's Trace = .215, F (6, 84) = 3.83, p < .001, η_p^2 = .215). In order to compare symmetry conditions at each level of contour, the dataset was split by contour and MANOVAs were performed on round and angular shapes separately. The multivariate effect of symmetry was significant both for round shapes (Pillai's Trace = .428, F (6, 84) = 10.48, p < .001, η_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 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, $p < .001$, $\eta_p^2 = .138$), compared to D_1 and asymmetric shapes. For angular shapes, 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 there were no significant differences for sourness (F (1.78, 158.66) = .29, $p = .706$, $\eta_p^2 = .003$). This supported our hypothesis on 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, $p < .001$, $\eta_p^2 = .596$), while 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 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, η_p^2 = .219). For angular shapes, D_8 shapes were rated as significantly more pleasant than D_1 and asymmetric shapes (F (1.70, 150.78) = 74.84, p < .001, η_p^2 = .457), and significantly less threatening than D_1 and asymmetric shapes (F (1.69, 151.24) = 41.50, p < .001, η_p^2 = .318). Univariate testing on the two types of contour confirmed that pleasantness ratings for round shapes were significantly higher than those for angular shapes (F (1, 89) = 154.76, p < .001, η_p^2 = .635), while threat ratings were significantly higher than for round shapes (F (1, 89) = 208.47, p < .001, η_p^2 = .701). Our hypothesis on symmetry was supported, as quadruple symmetry was rated as 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 and 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/?view_only=556b851781a548f3abaff74390ed1ade).

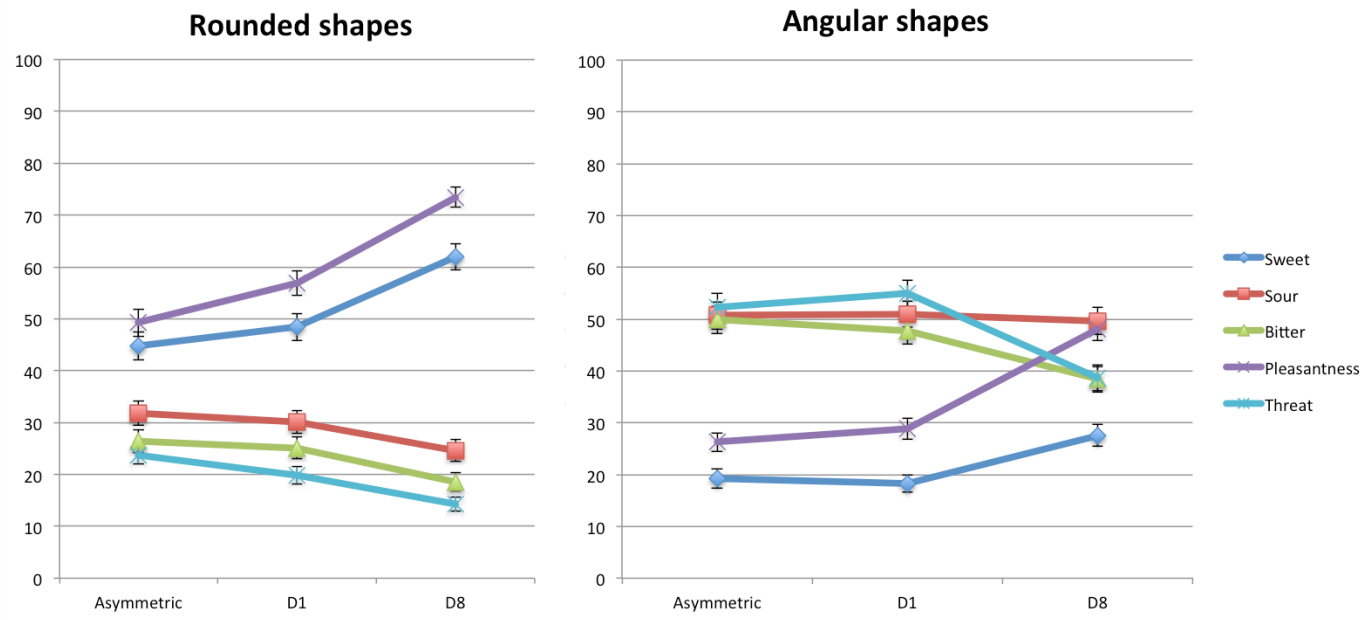


Figure 3. Line graphs showing the mean taste and appraisal ratings for rounded and angular shapes at each level of symmetry in Experiment 1.

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 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 pleasant and sweet ratings were lower than sour, bitter, and threat ratings.

Bonferroni-corrected Pearson correlations with one-tailed significance tests were conducted between taste and appraisal ratings for the 6 symmetry-by-contour stimulus conditions [4]. 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. Thus, 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. That is, round shapes, like sweetness, are perceived as highly pleasant, and round shapes are also associated with sweetness. Therefore, the correlation informs that affective factors of pleasantness and threat may relate to the way in which people match shapes and tastes.

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*

[4] Correlation results for all 24 individual shapes can be found in the OSF repository for this project (https://osf.io/qn593/?view_only=556b851781a548f3abaff74390ed1ade)

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 10 comparisons)

Experiment 1 showed that not only do contour and symmetry influence the appraisal and taste-association of shapes, but the former modulates the latter. Namely, for rounded shapes, symmetry group differentially affected association for all tastes, while for angular shapes, symmetry group affected only association with sweet and bitter taste. Round shapes from all symmetry groups were significantly different on pleasantness and threat ratings. By contrast, for angular shapes, D_8 shapes were significantly different from D_1 and asymmetric shapes, while the latter two did not differ significantly on pleasantness or threat. Over-and-above the interaction between symmetry and contour, there were larger differences in the overall levels of the taste and appraisal ratings: 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. Further, Experiment 1 clarified the contribution of symmetry to the shape-taste correspondence: higher symmetry amount was linked to higher perceived sweetness and pleasantness of shapes regardless of contour. Conversely, lower symmetry amount was linked to higher perceived sourness, bitterness and threat of round shapes, and perceived bitterness and threat of angular shapes.

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 towards certain shape-taste associations (e.g., round-sweet; see Intoduction, p. 6),

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., 2013, 2016). 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). In Taiwanese culture, a similar pattern is observed, 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 taste-word speech sounds, 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 compared 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, Huang, Woods & Spence, 2016; Doherty, Tsuji, & Phillips, 2008; Gutchess et al., 2006; McKone et al., 2010; Nisbett & Miyamoto, 2005), further motivating the comparison between Western and Taiwanese cultures.

Participants

127 students of the National Cheng Kung University in Tainan, Taiwan took part in the experiment (55 males, 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 in the OSF repository for this project (https://osf.io/qn593/?view_only=556b851781a548f3abaff74390ed1ade), together with the results from Experiment 1.

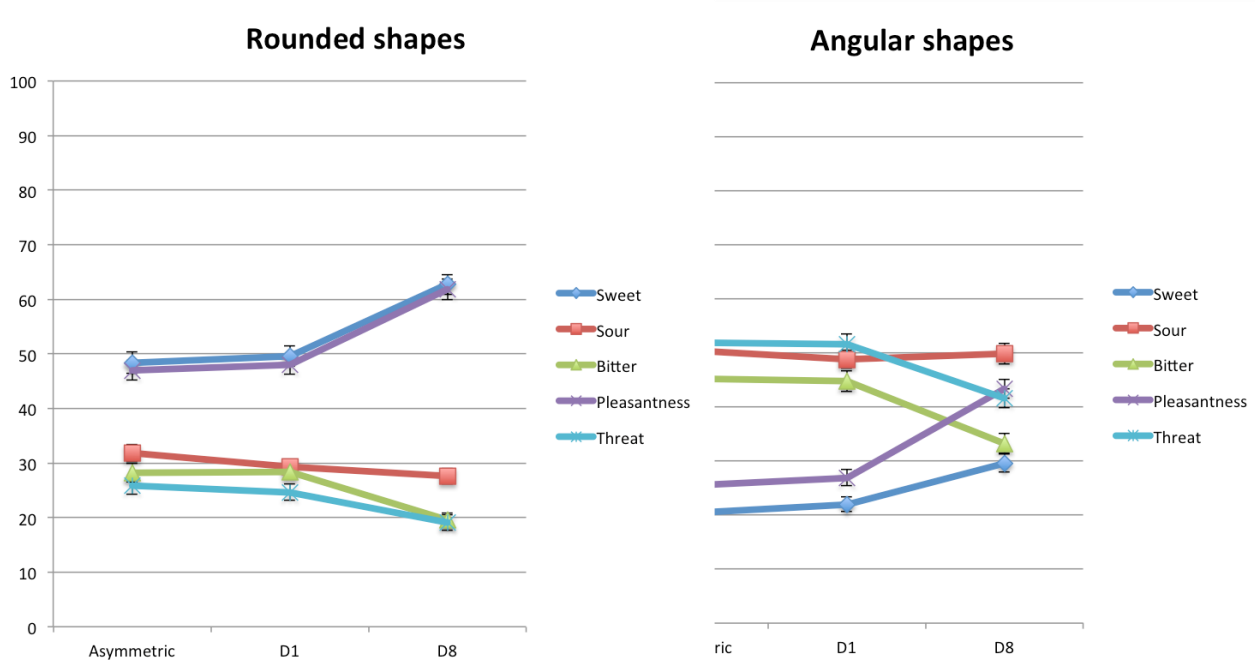


Figure 4. Line graphs showing the mean taste and appraisal ratings for rounded and angular shapes at each level of symmetry in Experiment 2.

Figure 4 shows the key results of this analysis. Like 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: 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 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, η_p^2 = .0.41). This is in line with the results of the parallel analyses of each sample, as, similarly to the Western sample in Experiment 1, D_8 shapes were rated the sweetest (F (2, 252) = 47.82, p < .001, η_p^2 = .275), and least bitter (F (2,252) = 26.41, p < .001, η_p^2 = .173) compared to the other two symmetry categories, and less sour than asymmetric shapes (F (2, 252) = 4.81, p < .001, η_p^2 = .037). For angular shapes, again, D_8 shapes were rated the sweetest (F (1.858, 234.046) = 20.29, p < .001, η_p^2 = .139) and least bitter (F (1.883, 237.232) = 34.42, p < .001, η_p^2 = .215) compared to D_1 and asymmetric shapes. Sourness ratings were not significantly affected (F (1.810, 228.032) = .61, p = .530, η_p^2 = .005).

Appraisal (pleasantness and threat). There was a significant main effect of culture (Pillai's Trace = .133, F (2, 88) = 6.77, p = .002, η_p^2 = .133), but no significant interactions with symmetry (Pillai's Trace = .102, F (4, 86) = 2.44, p = .053, η_p^2 = .102), or contour (Pillai's Trace = .030, F (2, 88) = 1.38, p = .257, η_p^2 = .030). The three-way interaction between these factors was also not significant (Pillai's Trace = .077, F (4, 86) = 1.80, p = .136, η_p^2 = .077). Further univariate testing and simple effects tests on culture showed that

Westerners rated the shapes as more pleasant overall, compared to 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), as similar significant relationships were found between taste ratings and appraisal ratings. Those shapes that were rated highest on sweetness were also rated highest on pleasantness, and likewise for sourness and bitterness and threat. The significant correlations between taste and appraisal ratings supported that pleasantness and threat may underlie shape-taste associations.

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 10 comparisons)

Experiment 2 demonstrated that the observed influences of contour and symmetry on shape-taste associations replicate across cultures, as both contour and symmetry were shown to contribute, in interaction, to shape-taste associations, as in Experiment 1. This experiment provided balance to 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., 2013; 2016; Wan et al., 2014 for relevant exceptions). Moreover, this experiment supported the robustness of visually presented symmetry, as its 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 more pleasant overall. Nevertheless, 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.

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 evolutionary accounts, 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 signalling mate quality (e.g., Jones et al., 2001), and the latter in signalling 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 generalise 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, Schwarz & Wienkielman, 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, as introducing rotations of 0, 90, 180, and 270 degrees 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, i.e., shapes from the cyclic group, would help disentangle this issue.

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 round and angular shapes, respectively. 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 et al., 2016a). 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 where food consumption is imminent, for example. More research would be needed to clarify the extent to which taste associations are activated in non-gustatory contexts, and conversely, the extent to which other associations are activated in gustatory contexts. While 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 one of many crossmodal correspondences, it stands to reason that affective mediation may 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 (odour-colour, Schifferstein & Tanudjaja, 2004; odour-shape, Hanson-Vaux, Crisinel, & Spence, 2013; odour-pitch, Crisinel & Spence, 2012; for a review of olfactory correspondences see Deroy, Crisinel & Spence, 2013), and in music-colour associations (e.g., Barbiere, Vidal & Zellner, 2007; Palmer, Schloss, Xu, & Prado-León, 2013, Palmer, Langlois & Schloss, 2016) 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 which are better explained by other factors. Given that tastes, odours, colours, 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 footnote 2), it may be that metathetic features are more likely to be affectively mediated.

In terms of cross-cultural results, Westerners perceived all the shapes as more pleasant than did the Taiwanese. Differences were indeed expected, given the known influence of culture on aesthetic judgements (e.g., Jacobsen, 2006, 2010, Mühlenbeck, Liebal, Pritsch, & Jacobsen, 2016; Tomasello, 2000). But, under this premise, how were there no greater differences between samples in shape-taste associations? It may have been the case that the differences were not great enough to dive differential taste matching. After all, 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, and likewise the sweetest and least bitter. It would make sense that overall higher perceived pleasantness in Westerners would result in their rating shapes as more sweet than would the Taiwanese, but nothing drastically different 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, connotative meaning of shapes and taste words that was similar across cultures (Martino & Marks, 1999; 2001; Adams & Osgood, 1973; Osgood, 1960; see also Osgood, Suci & Tannenbaum, 1957). Indeed, taste words such as ‘sweet’, ‘sour’, and ’bitter’ represent broader semantic spaces, which, beside gustatory sweetness, sourness, and bitterness, include a variety of dimensions of connotative meaning, such as pleasantness and threat (Velasco et al., 2016c). This broader connotative meaning is 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 痛苦). Shapes, and other non-word stimuli, also have semantic spaces of connotative meaning (see Walker, 2012; Walker & Walker, 2016). For round shapes, this may include mildness, goodness, and pleasantness, while for angular shapes, it may be harshness, badness, and dangerousness (e.g., Poffenberger & Barrows, 1924; Lyman, 1979; Velasco et al., 2016c). Thus, it may be that the shared connotative meaning between shapes and taste words, which includes pleasantness and threat, was consistent across cultures, allowing the shape-taste correspondence to replicate. What is more certain is that pure 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 are between the Western and Taiwanese group.

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Author Contributions

Conceived and designed the experiments: NT, CV, CS. Provided materials for the experiments: YCC, PCH. Performed the experiments and analysed the data: NT. Wrote the paper: NT, CV, YCC, PCH, CS.

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