Tasting Transformations:

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

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

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

[2] BI Norwegian Business School, Oslo, Norway

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

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CORRESPONDENCE: Charles Spence, 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

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 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 three 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 the sour or bitter taste. 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 Eastern and Western countries. 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 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 from 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 a plethora of visual features that are known to influence human information processing (e.g., Reber, Shwartz, & Winklemann, 2004).

[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 as an explanation of crossmodal correspondences

Theoretical accounts that have been put forward in order to explain crossmodal correspondences include the statistical, structural, and semantic/linguistic accounts (Spence, 2011, see also Parise & Spence, 2013). However, none of them adequately explain the shape-taste correspondence: 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, making it difficult to claim a statistical correspondence based on learning environmental regularities (though see Spence, 2012). An adequate structurally based theory for correspondences between metathetic[2] features has, to our knowledge, yet to be proposed. Finally, it is unclear whether oft-used gustatory metaphors (e.g., 'sharp cheese', see Marks, 1987) are the *cause* of visual-gustatory associations, or their *result*. So far, the most plausible explanation has come from the affective mediation hypothesis, which posits that a common affective property of a shape attribute on one hand, and a taste, on the other, will cause the shape and taste to be associated. Indeed, the linking of modality-specific information via shared indirect factors has long been suggested in the literature (Collier, 1996; Cowles, 1935; Kenneth, 1923; Marks, 1996; Spence, 2011; Spence et al., 2015). Empirical evidence for the affective link between shapes and tastes was recently provided by Salgado-Montejo and his colleagues (2015). They demonstrated that round shapes tend to be judged as pleasant and preferentially matched to sweet taste, while angular shapes tend to be judged as unpleasant and preferentially matched to sour taste. Similarly, Velasco and his colleagues (2015, 2016a)

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[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 Stevens, 1957; Smith & Sera, 1992). 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.

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.

Despite the interchangeable use of pleasantness and liking in investigating the affective mediation hypothesis (see above), measuring emotional valence through pleasantness levels may be a more direct approach than through measuring liking. Indeed, the affective literature is one 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 (possibly due to inconsistencies in people's preference representations, see Dai, Brendl & Ariely, 2010). To clarify, valence, or intrinsic pleasantness/unpleasantness, is a characteristic of the stimulus that determines the subjective response of the observer, which may be liking or disliking (see Ellsworth & Scherer, 2003, for a review). However, before liking or disliking a stimulus, the observer must appraise the stimulus as pleasant or unpleasant. Appraisals are constant and automatic evaluations of the stimuli in our environment (Ellsworth & Scherer, 2003; Barrett & Bar, 2009) 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) has been recognised as a fundamental factor in human emotional processing (Barrett, 2006). According to Lazarus' classic structural model of appraisal, primary appraisal, which determines the significance of the perceived stimulus to the organism and its wellbeing, subsumes an appraisal of pleasantness/unpleasantness (Lazarus, 1991; Smith & Kirby, 2009).

It has been suggested that certain stimulus features are innately 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. Note, however, that the results of both Velasco et al. (2015, 2016a) and Salgado-Montejo et al. (2015) suggest that valence may not be sufficient in-and-of-itself to capture the full affective mechanism behind shape-taste correspondences.

Perceived threat is another potential appraisal factor that may be involved in how humans match shapes to tastes. To refer to Lazarus' theory, 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). In 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, there is evidence to suggest that valence and threat are distinctly functioning appraisal factors rather than opposites on a single continuum, as a stimulus can be unpleasant without also being threatening. For instance, Kveraga and colleagues (2014; see also Kveraga & Bar, 2014) showed that not only did participants evaluate negatively-valenced and threatening stimuli (e.g., the image of a gun pointed at viewer) more quickly than merely negative, not threatening stimuli (e.g., the image of a dead animal bleeding), but the two also evoked differential neural responses.

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), further underscoring the link between bitterness and threat. To our knowledge, no previous research has investigated threat as a factor underlying crossmodal matching.

The evidence presented thus far supports the view that the common positive (perceived pleasantness) evoked by round contour and sweet taste, and the common perceived threat evoked by angularity and bitterness may facilitate their crossmodal association. What remains to be ascertained is to disentangle how stimulus pleasantness and threat work to mediate shape-taste matching. Some studies on the affective appraisal of shapes have proposed that the innate preference for curvature is actually driven by the perceived threat of angular stimuli (e.g., Bar & Neta, 2006, 2007). By extension, the perceived threat of a shape modulates perceived pleasantness, which, in turn, influences matching to tastes. However, the preference for curvature has been shown to exist as a phenomenon in its own right (Bertamini et al., 2016). Thus, it is more plausible that pleasantness and threat act separately, but as parts of a single affective mediation process, whereby pleasantness mediates the matching of rounded contour to sweet taste, while threat mediates the matching of angular contour to bitter taste.

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., Gangestad, Thornhill, & Yeo, 1994; Møller & Thornhill, 1998; Jones et al., 2001). Thus, appraising symmetrical visual stimuli as pleasant seems to be evolutionarily adaptive, as it leads to higher quality mates and food, and both these qualities, and their signals, are more biologically expensive to produce (Watson & Thornhill, 1994). 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). Everyday experience suggests fruits that are ripe tend to be more symmetrical, and become less so once they begin to spoil. 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.

Here, it is important to note that symmetry is not a singular category, but rather, it comes in different types of Euclidean transformations in the plane, of which the basic types are reflectional, rotational, and translational (see Figure 1). Strangely though, few studies to date have explicitly taken this typology into account. In those studies that have, reflectional symmetry along the vertical axis (left-right) has generally emerged as preferred over other types (e.g., Vetter, Poggio, & Bülthoff, 1994, Wagemans, 1995; Makin, Pecchinenda, & Bertamini, 2012). This may be because of the implied evolutionary significance of left-right reflectional symmetry for humans, since faces and bodies are symmetrical in this regard. Moreover, it is preferred over up-down reflectional symmetry (Corballis & Roldan, 1974; Julesz, 1971; Palmer & Hemenway, 1978; Royer, 1981), its mathematical equivalent, but which is not thought to have any evolutional implications. Alternatively, the preference for left-right symmetry has been proposed to result from the structural left-right symmetry of the human nervous system (see Corballis & Roldan, 1974), as well as from sensitisation to the commonality of this type of symmetry in the environment (Rock & Leaman, 1963). Curiously, translational symmetry has not been shown to be relevant, or perhaps even detectable as a type of symmetry (Corballis & Roldan, 1974; Bertamini, Friedenberg, & Argyle, 2002; Makin et al., 2012). Based on the evidence discussed thus far, it may be of interest to compare different types of symmetry on how they affect perceived pleasantness, alongside contour, and whether symmetry and contour in any way modulate each other.

INSERT FIGURE 1 ABOUT HERE

Apart from the type of symmetry, the number of axes of symmetry in a shape may also play a part in the shape-taste correspondence. For instance, Tinio and Leder (2009) have shown that multiple axes of symmetry provide advantages for information processing. Namely, with the increase of axes of symmetry from single to quadruple, the speed of symmetry detection increases as well (see Palmer & Hemenway, 1978; Royer, 1981). In terms of preference, current results suggest that aesthetic preference is a function of the ease of processing of a stimulus (Reber, Schwartz, & Winkielman, 2004). Thus shapes with four axes of symmetry (quadruple symmetrical shapes) may be more pleasant than shapes with fewer axes of symmetry, because the former are processed more fluently.

Overview of the present 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. A secondary interest was to investigate the affective matching hypothesis in the context of the shape-taste correspondences, in order to hopefully shed light on the origins of crossmodal correspondences. These aims were explored over three consecutive experiments, designed as replications with slightly modified conditions. Experiment 1 compared different types of symmetry, using taste words, in a face-to-face setting, with a Western European sample. Experiment 2 differed in that different numbers of axes of symmetry were compared. Experiments 2 and 3 were conducted online. Experiment 3 was conducted with East Asian participants.

For contour, it was predicted that the results would replicate the research on shape-taste correspondences reviewed above. That is, rounded shapes, as compared to angular shapes, would be rated as sweeter and less bitter, and also as more pleasant and less threatening. This would be because of the shared pleasantness of rounded contours and sweet taste, and the shared perceived threat of angular contours and bitter taste. In line with Palmer, Schloss, Xu, and Prado-León (2013; see also Palmer, Langlois, & Schloss, 2016), affective mediation was investigated through correlational analyses.

For symmetry, in Experiment 1 it was hypothesized that the shape with left-right reflectional symmetry would be rated the sweetest, least bitter, most pleasant and least threatening. This would be due to the shared positive pleasantness of left-right symmetry and sweet taste, since left-right symmetry is widely held to be the type of symmetry that is perceived as the most pleasant. In Experiments 2 and 3, it was quadruple symmetry (four axes of symmetry) that was expected to show the aforementioned pattern of results. This was because multiple axes of symmetry have been suggested, in the literature above, to be perceived as more pleasant than one or none.

Experiment 1

Participants

Ninety-two participants (24 male, age range: 19 – 69 years, *M* = 36.18, *SD* = 11.5) were recruited at the Food Matters Live 2015 Event, taking place at ExCeL, London 17-19th November 2015. The present experiment was one of several exhibitions running simultaneously as part of the Food Sensorium Attraction at the event. Upon entering the exhibition space, the participants were given a general debriefing on the purpose of the Attraction and were asked to sign an informed consent form for participation in all of the constituent experiments, as determined by the organisers. All of the participants had reported normal or corrected-to-normal senses of vision, taste, smell, hearing, and touch. The present experiment, as well as all subsequent experiments in this study, was approved by the Central University Research Ethics Committee at the University of Oxford (reference number: MS-IDREC-C1-2015- 215).

Materials

Visual stimuli were six patterns created by linearly summing up 2 to 5 radial frequency (RF) patterns (see Figure 2), i.e., closed contours with sinusoidal modulations along the circumference of a circle (Wilkinson, Wilson, & Habak , 1998; Schmidtmann, Jennings, & Kingdom, 2015). This allowed us to systematically manipulate the visual features of the stimuli. Two rounded reflectionally-symmetrical shapes were created by adding two RF patterns with radial frequency of 3 and 8 cycles/circle and by varying the relative angular phase (position expressed in radians) between the two RF patterns. One rounded rotationally symmetrical shape was created by adding two RF patterns with 4 and 8 cycles/circle, while keeping the amplitude of the shape constant. Angular versions of each shape were created by adding harmonic frequency of 8 cycles/circle.

INSERT FIGURE 2 ABOUT HERE

Taste matching was assessed via three visual analogue scales (VAS) representing the taste words ‘sweet’, ‘sour’, and ‘bitter’, 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 used categorical scales such as Likert, as they allow for more options in terms of the statistical analysis. ‘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.

Procedure

Participants were presented with a set of flashcards, each depicting a shape on one side and a three-digit numerical code on the inverse side, and two sets of paper forms (taste condition and appraisal condition). Paper testing sheet order was counterbalanced, to control for any order effects. Depending on which condition was allocated first, the participants had to rate each of the six shapes either on how well they ‘go with’ the words ‘sweet’, ‘sour’, and ‘bitter’ (taste condition), or how pleasant or threatening they felt each shape to be (appraisal condition). The participants had to complete one testing sheet before moving onto the next, and to write the code of the shape being rated into a blank box above each set of scales. The participants also had to choose shapes in a random order and not repeat any of the shapes. Each experiment lasted approximately five to seven minutes, and no more than ten.

Results and discussion

Taste (sweet, sour, and bitter). To test the appropriateness of multivariate analysis of variance (MANOVA), Pearson correlations were conducted between the dependent variables (taste ratings). In accordance with Meyers, Gamst, and Guarino (2006), the taste ratings were moderately correlated (r = .20 – .60), confirming the appropriateness of a MANOVA. A repeated-measures MANOVA revealed significant main effects of symmetry (Pillai's Trace = .186, F (6, 84) = 3.19, p = .007, η_p^2 = .186) and of contour (Pillai's Trace = .766, F (3, 87) = 94.83, p < .001, η_p^2 = .766) on people's ratings of shapes across taste scales. There was no significant interaction (Pillai's Trace = .079, F (6, 84) = 1.19, p = .317, η_p^2 = .079).

Follow-up univariate analyses of variance (ANOVAs) and Bonferroni-corrected pairwise comparisons were conducted to clarify the effect of each level of contour, and of symmetry on shape-taste association for each taste. A Greenhouse–Geisser correction was used in cases where the assumption of sphericity was not met. The analysis revealed that round shapes were rated higher on sweetness than angular shapes (F (1, 89) = 254.80, p <

.001, η_p^2 = .741; M_R[3] – M_A = 5.03, p < .001, see Table 1 for all means and standard errors), while angular shapes were rated higher on sourness (F (1, 89) = 48.29, p < .001, η_p^2 = .352; $M_A – M_R$ = 3.32, p < .001), and bitterness (F (1, 89) = 157.76, p < .001, η_p^2 = .639; $M_A – M_R$ = 4.34, p < .001) than round shapes. As expected, this was in line with previous findings in the field that people preferentially match rounded contours to sweet taste and angular contours to sour or bitter taste (e.g., Ngo et al., 2013; Ngo, Misra, & Spence, 2011; see Velasco et al., 2016b, for a review).

As for symmetry, shapes with rotational symmetry were rated highest on sweetness (F (2, 178) = 7.26, p = .001, η_p^2 = .075; $M_{ROT} – M_{LR}$ = .79, p = .027; $M_{ROT} – M_{UD}$ = 1.13, p = .003) and lowest on bitterness (F (2, 178) = 5.77, p = .004, η_p^2 = .061; $M_{UD} – M_{ROT}$ = 1.05, p = .003). Symmetry had no significant effect on sourness ratings (F (1.463, 130.246) = 2.77, p = .083, η_p^2 = .030). This result was not consistent with our predictions, as it was reflectional symmetry that was expected to be the sweetest and least bitter type of symmetry. Importantly, left-right and up-down symmetry were not significantly different on sweetness ($M_{LR} – M_{UD}$ = 1.35), or bitterness ($M_{UD} – M_{LR}$ = 1.35).

Appraisal (pleasantness and threat). The procedure was repeated with the dependent variables being pleasantness and threat ratings for each shape. Pearson correlations supported the appropriateness of MANOVA. A repeated-measures MANOVA revealed significant main effects of symmetry (Pillai's Trace = .495, F (4, 85) = 20.80, p < .001, η_p^2= .495) and contour (Pillai's Trace = .749, F (2, 87) = 129.78, p < .001, η_p^2 = .749) on appraisal ratings. Interaction effects were not significant (Pillai's Trace = .021, F (4, 85) = .455, p < .769, η_p^2 = .021). Follow-up ANOVAs and post-hoc tests revealed that round shapes were

[3] We used the following labels for the mean ratings in each condition: M_R for round shapes, M_A for angular shapes, M_{LR} for left-right reflectionally-symmetrical shapes, M_{UD} for up-down reflectionally symmetrical shapes, and M_{ROT} for rotationally symmetrical shapes.

more pleasant than angular shapes (F (1, 88) = 221.88, p < .001, η_p^2 = .716; $M_R - M_A$ = 4.29, p < .001, see Table 1 for all means and standard errors), whereas angular shapes were more threatening than round shapes (F (1, 88) = 221.08, p < .001, η_p^2 = .715; $M_A - M_R$ = 4.95, p < .001). This replicated previous findings that rounded contours are preferred over angular contours (e.g., Salgado-Montejo et al., 2015; Velasco, 2015, 2016a).

Symmetry also had a significant effect on appraisal, such that shapes with rotational symmetry were rated as more pleasant (F (2, 176) = 37.43, p < .001, η_p^2 = .298; $M_{ROT} - M_{LR}$ = 1.82, $M_{ROT} - M_{UD}$ = 2.32, both ps < .001) and less threatening (F (2, 176) = 25.48, p < .001, η_p^2 = .224; $M_{LR} - M_{ROT}$ = 1.35, $M_{UD} - M_{ROT}$ = 1.73, both ps < .001) than shapes with left-right and up-down symmetry. Once again, this result was not consistent with our predictions, as it was reflectional symmetry that was expected to be the most pleasant and least threatening type of symmetry. Interestingly, left-right and up-down reflectional symmetry were not significantly different on pleasantness ($M_{LR} - M_{UD}$ = .33) or threat ratings ($M_{UD} - M_{LR}$ = .76).

INSERT TABLE 1 ABOUT HERE

Lastly, in order to investigate the relationship between the pleasantness and threat of shapes and their matching to tastes, Pearson correlations with one-tail significance tests were conducted between all taste and appraisal ratings per shape. Positive correlations were expected between pleasantness and sweetness ratings, threat and bitterness ratings, and between threat and sourness ratings. Conversely, negative correlations were predicted between pleasantness and sourness ratings, and pleasantness and bitterness ratings, and threat and sweetness ratings. Bonferroni corrections were used to control for potential inflation of type-I error due to the high number of correlations, resulting in a more stringent significance criterion. Shapes that were rated highest on sweetness were also rated highest on pleasantness, and likewise for sourness and bitterness and threat. This indicated a relation between taste ratings and appraisal ratings of shapes, providing indirect support for potential affective mediation (see also Salgado-Montejo, 2015). However, the correlations between taste and appraisal ratings were not significant (see Table 2). It may have been that the affective mediation model including pleasantness and threat was incomplete, or, the symmetry framework may have been inadequate.

INSERT TABLE 2 AND FIGURE 3 ABOUT HERE

The results of Experiment 1 demonstrated that both contour and symmetry influence shape-taste associations, as well as the perceived pleasantness and threat of the shapes that were presented. The rotationally-symmetrical shape was perceived as the most pleasant and sweet, perhaps because it contained a greater number of axes of symmetry (see Silvia & Barona, 2009) than the other two types. Indeed, these shapes were rotationally-symmetrical at 90^{o}, as well as reflectionally-symmetrical across the vertical, horizontal, and diagonal axes. Moreover, left-right and up-down symmetry were not significantly different on taste or appraisal ratings, as they both had the same number of axes of symmetry. Thus, subsequent experiments focused on the amount, over the type, of symmetry, that is, the number of axes of symmetry in a shape, over the type of Euclidean transformation involved.

Experiment 2

Participants

119 participants (44 females, age range: 18 – 50 years, *M* = 28.45, *SD* = 7.72) 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 (44.5%), United Kingdom (26.9%),

Canada, Serbia, Brazil, and India (all 4.2%), Lithuania, Germany, Romania, Poland and the Philippines (3.4% and below). 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.

Materials

The shapes were generated using the program from Experiment 1. Shape number in each condition was increased from 1 to 4 in order to ascertain whether the results were genuine or biased by participants' past experience. For example, the rotationally-symmetrical shapes (see Figure 2) closely resembled a star or a four-leaf clover – both familiar symbols in Western culture. This perceptual familiarity could have driven taste and appraisal effects rather than the type of symmetry and/or contour of the shape, as familiarity is typically thought to increase preference (Zajonc, 1968, 2001; Reber, Schwarz, & Winkielman, 2004; though see Berlyne, 1970; Biederman & Vessel, 2006; Weierich et al., 2010; Whittlesea, 1993).

Since Experiment 1 showed no significant difference between left-right and up-down symmetry, in the present experiment, shapes were categorized into: asymmetric (no axes), bilateral (1 axis), and quadruple symmetrical (four axes; see Figure 4). All of the patterns contained 8 cycles/circle RF patterns with an amplitude of 0.3. The degrees of symmetry were controlled by the frequency of the other RF patterns and the relative phase between them. The angular patterns were created by adding four harmonics of 8 cycles/circle RF patterns. 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 types, amounting to a total of 24 shapes.

INSERT FIGURE 4 ABOUT HERE

Procedure

The procedure from Experiment 1 was adapted for use online. 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 0-100 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). Pearson correlations supported the appropriateness of MANOVA. A repeated-measures MANOVA revealed significant main effects of symmetry (Pillai’s Trace = .389, F (6, 113) = 12.01, p < .001, η_p^2 = .389) and of contour (Pillai’s Trace = .592, F (3, 116) = 56.07, p < .001, η_p^2 = .592). There was also a significant interaction between symmetry and contour (Pillai’s Trace = .199, F (6, 113) = 4.69, p < .001, η_p^2 = .199). 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 = .399, F (6, 113) = 12.52, p < .001, η_p^2 = .399) and angular shapes (Pillai’s Trace = .323, F (6,

113) = 8.97, p < .001, η_p^2 = .323). For round shapes, follow-up univariate testing revealed that quadruple symmetrical shapes were rated the sweetest (F (1.864, 219.9) = 42.02, p < .001, η_p^2 = .263; M_{QU}[4] – M_{BI} = 12.57, M_{QU} – M_{AS} = 16.85, both ps < .001, see Table 3 for all means and standard errors), least sour (F (2, 236) = 17.91, p < .001, η_p^2 = .132; M_{BI} – M_{QU} = 5.39, M_{AS} – M_{QU} = 7.78, both ps < .001), and least bitter (F (1.902, 224.46) = 15.70, p < .001, η_p^2 = .117; M_{BI} – M_{QU} = 5.49, M_{AS} – M_{QU} = 7.41, both ps < .001), compared to bilateral and asymmetrical shapes. For angular shapes, those shapes with quadruple symmetry were also rated the sweetest (F (1.764, 208.098) = 21.08, p < .001, η_p^2 = .152; M_{QU} – M_{BI} = 9.03, M_{QU} – M_{AS} = 9.12, both ps < .001), and least bitter (F (1.852, 218.584) = 23.58, p < .001, η_p^2 = .167; M_{BI} – M_{QU} = 8.43, M_{AS} – M_{QU} = 11.07, both ps < .001). There were no significant differences for sourness (F (1.900, 224.212) = 1.592, p = .207, η_p^2 = .013). Our hypothesis on symmetry was supported, as quadruple symmetry was rated as the most sweet and least bitter. 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, 118) = 162.76, p < .001, η_p^2 = .580), while sourness and bitterness ratings were significantly higher for angular shapes (sour: F (1, 118) = 123.32, p < .001, η_p^2 = .511; bitter: F (1, 118) = 104.056, p < .001, η_p^2 = .469). This supported our expectations regarding contour, and replicated previous research.

Appraisal (pleasantness and threat). Significant main effects of symmetry (Pillai's Trace = .609, F (4, 115) = 44.76, p < .001, η_p^2 = .609) and of contour (Pillai's Trace = .672, F

[4] We used the following labels for the mean ratings in each condition: M_R for round shapes, M_A for angular shapes, M_{BI} for bilaterally symmetrical shapes (1 axis of symmetry), M_{QU} for quadruple symmetrical shapes (4 axes of symmetry), and M_{AS} for asymmetric shapes (0 axes of symmetry).

(2, 117) = 119.73, p < .001, η_p^2 = .672) were observed for people's pleasantness and threat ratings. There was also a significant interaction between symmetry and contour (Pillai's Trace = .252, F (4, 115) = 9.70, p < .001, η_p^2 = .252). The file was split by contour, as in the analysis of taste ratings, and MANOVAs were performed for round and angular shapes separately. The multivariate effect of symmetry was significant both for round shapes (Pillai's Trace = .519, F (4, 115) = 31.08, p < .001, η_p^2 = .519) and for angular shapes (Pillai's Trace = .571, F (4, 115) = 38.27, p < .001, η_p^2 = .571). For round shapes, univariate effects of symmetry were significant for pleasantness (F (1.741, 205.454) = 86.35, p < .001, η_p^2 = .423). Shapes with quadruple symmetry were rated as the most pleasant, followed by bilaterally-symmetrical shapes, and asymmetric shapes, which were the least pleasant ($M_{QU} – M_{BI}$ = 16.92, $M_{QU} – M_{AS}$ = 24.25, $M_{BI} – M_{AS}$ = 7.33, all ps < .001, see Table 3 for all means and standard errors). Effects of symmetry were also significant for threat (F (1.873, 220.997) = 31.25, p < .001, η_p^2 = .209). Quadruple symmetrical shapes were rated as the least threatening followed by bilaterally symmetrical shapes, and asymmetric shapes, which were the most threatening ($M_{BI} – M_{QU}$ = 5.92, $M_{AS} – M_{QU}$ = 9.78, $M_{AS} – M_{BI}$ = 3.85, all ps < .001).

For angular shapes, effects of symmetry were significant for pleasantness (F (1.613, 190.347) = 105.69, p < .001, η_p^2 = .472), such that shapes with quadruple symmetry were rated as significantly more pleasant than bilaterally symmetrical and asymmetric shapes ($M_{QU} – M_{BI}$ = 20.47, $M_{QU} – M_{AS}$ = 22.48, both ps < .001). Effects of symmetry were also significant for threat (F (1.701, 200.700) = 51.73, p < .001, η_p^2 = .305), such that quadruple symmetrical shapes were rated as significantly less threatening than bilaterally symmetrical and asymmetric shapes ($M_{BI} – M_{QU}$ = 15.99, $M_{AS} – M_{QU}$ = 14.14, both ps < .001).

Taken together, 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.

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, 118) = 165.810, p < .001, η_p^2 = .584), while threat ratings were significantly higher than for round shapes (F (1, 118) = 241.239, p < .001, η_p^2 = .672).

INSERT TABLE 3 ABOUT HERE

Bonferroni-corrected Pearson correlations with one-tailed significance tests were conducted between taste and appraisal ratings. Similar correlation patterns were observed as in Experiment 1 but they reached the level of significance in this experiment: Shapes that were rated highest on sweetness were also rated highest on pleasantness, and likewise for sourness and threat, and bitterness and threat. Crucially, there was a significant correlation between these scores. 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.

INSERT TABLE 4 AND FIGURE 5 ABOUT HERE

Experiment 2 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, the amount of symmetry differentially affected association for all tastes, while for angular shapes, the amount of symmetry affected only association with sweet and bitter taste. When it comes to appraisal, for round shapes, all symmetry levels were significantly different on pleasantness and threat ratings. By contrast, for angular shapes, quadruple symmetry was significantly different from bilateral symmetry and asymmetric shapes, while the latter two did not differ significantly on pleasantness or threat. Further, Experiment 2 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.

In the literature to date, and especially the evolutionary literature, the importance of symmetry for information processing has been considered universal to all human populations (though see Mühlenbeck, Liebal, Pritsch, & Jacobsen, 2016). However, there has been growing evidence of perceptual differences between Eastern and Western cultures (e.g., Doherty, Tsuji, & Phillips, 2008; Gutchess et al., 2006; McKone et al., 2010; Nisbett & Miyamoto, 2005), and, to our knowledge, no study has explored differences in symmetry perception. Moreover, in the context of shape-taste correspondences, some studies have suggested differences in the supposedly universal association of roundness to sweetness. Namely, Bremner and his colleagues (2013) found that tribal Namibians matched the comparatively sweetest milk chocolate to angular shapes, instead of round shapes, as observed in Western Anglo-Saxon populations (though see Liang et al., 2013; 2016). In order to test the universality of symmetry (and contour) in shape-taste associations, Experiment 3 was conducted in Taiwan, with East Asian participants.

Experiment 3

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 2.

Results and discussion

Taste (sweet, sour, and bitter). The data analysis procedure from Experiment 2 was repeated. Both symmetry (Pillai's Trace = .501, F (6, 121) = 20.22, p < .001, η_p^2 = .501) and contour (Pillai's Trace = .708, F (3, 124) = 100.35, p < .001, η_p^2 = .708) had significant multivariate effects on taste ratings, and there was also a significant interaction between symmetry and contour (Pillai's Trace = .150, F (6, 121) = 3.55, p = .003, η_p^2 = .150). The dataset was split by contour. Separate MANOVAs showed significant effects of symmetry for both round (Pillai's Trace = .461, F (6, 121) = 17.216, p < .001, η_p^2 = .461) and angular shapes (Pillai's Trace = .337, F (6, 121) = 12.19, p < .001, η_p^2 = .337). For round shapes, quadruple symmetrical shapes were rated the sweetest (F (2, 252) = 47.82, p < .001, η_p^2 = .275; $M_{QU} - M_{BI}$ = 13.13, $M_{QU} - M_{AS}$ = 14.38, both ps < .001, see Table 6 for all means and standard errors), and least bitter (F (2,252) = 26.41, p < .001, η_p^2 = .173; $M_{BI} - M_{QU}$ = 8.86, $M_{AS} - M_{QU}$ = 8.70, both ps < .001) compared to the other two symmetry categories, and less sour than asymmetric shapes (F (2, 252) = 4.81, p < .001, η_p^2 = .037; $M_{AS} - M_{QU}$ = 4.16, p < .001). For angular shapes, again, quadruple symmetrical shapes were rated the sweetest (F (1.858, 234.046) = 20.29, p < .001, η_p^2 = .139; $M_{QU} - M_{BI}$ = 7.59, $M_{QU} - M_{AS}$ = 9.28, both ps < .001), and least bitter (F (1.883, 237.232) = 34.42, p < .001, η_p^2 = .215; $M_{BI} - M_{QU}$ = 11.84, $M_{AS} - M_{QU}$ = 12.01, both ps < .001) compared to bilateral and asymmetric shapes. Sourness ratings were not significantly affected (F (1.810, 228.032) = .61, p = .530, η_p^2 = .005). The symmetry hypothesis was supported, as quadruple symmetry was rated the most sweet and least bitter. As in Experiment 2, angular shapes were differentially associated with sourness, as a result of contour modulating the effects of symmetry.

Univariate testing on the two types of contour confirmed that sweetness ratings were significantly higher for round shapes (F (1, 126) = 277.03, p < .001, η_p^2 = .687), while sourness and bitterness ratings were significantly higher for angular shapes (sour: F (1, 126) = 170.33, p < .001, η_p^2 = .575; and bitter F (1, 126) = 123.06, p < .001, η_p^2 = .494; see Table 5 for means and standard errors). The results in Experiment 2 were replicated.

INSERT TABLE 5 AROUND HERE

Appraisal (pleasantness and threat). Significant main effects of symmetry (Pillai's Trace = .566, F (4, 123) = 40.12, p < .001, η_p^2 = .566) and of contour (Pillai's Trace = .656, F (2, 125) = 119.33, p < .001, η_p^2 = .656) were observed for people's pleasantness and threat ratings. However, the interaction was not significant (Pillai's Trace = .051, F (4, 123) = 1.65, p = .166, η_p^2 = .051). Follow-up ANOVAs revealed that round shapes were more pleasant than the angular shapes (F (1, 126) = 162.75, p < .001, η_p^2 = .564; $M_R - M_A$ = 20.33, p < .001, see Table 6 for all means and standard errors) and angular shapes were more threatening than round shapes (F (1, 126) = 240.54, p < .001, η_p^2 = .656; $M_A - M_R$ = 25.24, p < .001).

As for symmetry, quadruple symmetrical shapes were rated as being significantly more pleasant (F (1.88, 237.83) = 94.32, p < .001, η_p^2 = .428; $M_{QU} - M_{BI}$ = 15.12, $M_{QU} - M_{AS}$ = 16.38, both ps < .001) and less threatening (F (1.908, 240.43) = 25.617, p < .001, η_p^2 = .169; $M_{BI} - M_{QU}$ = 7.80, $M_{AS} - M_{QU}$ = 8.51, both ps < .001) than both bilaterally symmetrical and asymmetric shapes.

INSERT TABLE 6 AROUND HERE

Finally, the correlation results of Experiment 2 were replicated (see Table 7), 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.

INSERT TABLE 7 AND FIGURE 6 AROUND HERE

Experiment 3 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 2. 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 notable exceptions in the field). Moreover, this experiment supported the robustness of visually-presented symmetry, as its influence on shape-taste associations was consistent in Westerners and Easterners. However, culture may have had a mediating effect on shape appraisal (see also General Discussion). Namely, the Eastern sample in Experiment 3 did not show the significant interaction between contour and symmetry on appraisal ratings that was observed in the Western sample in Experiment 2; specifically, the bilaterally symmetrical and asymmetric shapes with the rounded contour were rated differently on pleasantness and threat by Western but not by Eastern participants. This did not appear to be critical, though, since the general trends that quadruple symmetrical 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 Eastern and Western participants.

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. It was the number of symmetry axes, rather than the type of Euclidean transformation (i.e., left-right or up-sown reflectional symmetry) that 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 Western Anglo-Saxon and East Asian participants.

In the initial comparison of symmetry types, it was curious that rotational symmetry was rated as the most pleasant and most associated with sweet taste. In fact, left-right reflectional symmetry was expected to show 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 in food (e.g., carbohydrates, ripeness; Breslin, 2013). However, there is evidence 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. This partly explains the lack of preference, and sweetness, of left-right symmetrical shapes observed in the present study. However, what drove the preference and sweetness of rotational shapes may have been the higher amount of symmetry (i.e., the number of axes of symmetry) present in these shapes, as compared to left-right symmetrical shapes. This was confirmed in subsequent investigations where the symmetry framework was changed from a comparison of symmetry types to a comparison of symmetry amount, i.e., number of axes of symmetry. Shapes with the comparatively largest number of symmetry axes (four axes in Experiments 2 and 3) were perceived as the sweetest, least bitter, most pleasant, and least threatening. This suggests that increasing symmetry leads to increases in perceived pleasantness, association with sweetness, etc., of two-dimensional shapes. However, to ascertain this would require a study design where symmetry amount progressively increased along a continuum, instead of by discrete categories.

The study also verified affective mediation as a possible substrate of crossmodal correspondences. Significant correlations were obtained between the pleasantness and threat ratings and sweetness and bitterness ratings of round and angular shapes, respectively. Given that sweet taste is generally perceived as pleasant, and bitter taste as threatening (e.g., Steiner, Glaser, Hawilo, & Berridge, 2001), the results of the present study suggest that affective factors such as pleasantness and threat may underlie the shape-taste correspondence. However, because correlational analyses cannot guarantee a causal link between shape appraisal and their association to tastes, future research may consider investigating this matter further. For example, if two similarly pleasant (or unpleasant) objects differing in contour or symmetry (e.g., Leder, Tinio, & Bar, 2011) were used as stimuli in a matching task involving tastes, one could assess whether people would still match the tastes to such objects as they did in the present study.

Consistent results were obtained in the present study across Eastern and Western culture, with the exception of appraisal ratings, as Easterners did not show the contour-symmetry interaction in pleasantness and threat ratings of shapes. This is not too surprising, given the known influence of culture on aesthetic judgements (e.g., Jacobsen, 2006, 2010, Tomasello, 2000). Even in the case of such a powerful feature as symmetry, a recent study has found that, in tribal Namibians, symmetrical patterns were not uniformly preferred over asymmetrical patterns, even though, in urban Germans, they were (Mühlenbeck, Liebal, Pritsch, & Jacobsen, 2016). But if culture influences affective appraisal as it does, and perceptual experience as discussed before, how were there no greater differences between samples in shape-taste associations?

It is possible that, rather than through affective mediation per se, associations between shapes and taste words arise due to shared semantic spaces of connotative meaning (Martino & Marks, 1999; 2001) that is consistent across cultures (Adams & Osgood, 1973; Osgood, 1960; see also Osgood, Suci & Tannenbaum, 1957). Indeed, taste words are not gustatory stimuli, but symbolic stimuli that represent taste on a higher-order semantic level. Thus, taste words such as ‘sweet’, ‘sour’, and ’bitter’ represent broader semantic spaces, which, beside prototypes of gustatory sweetness, sourness, and bitterness, include a variety of dimensions of connotative meaning, such as pleasantness and threat (Velasco et al., 2016c). The East-West similarity of this connotative meaning of taste words is supported by the cross-cultural replication of the relationship between taste and pleasantness ratings of shapes observed in the present study. Further support comes from the ways in which 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)[5]. Shapes, and other non-word stimuli, also have semantic spaces of connotative meaning (see Walker, 2012; Walker & Walker, 2016). For round shapes, this connotative meaning 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, is consistent across cultures, allowing the shape-taste correspondence to replicate. This highlights a potential importance of semantic factors in the shape-taste correspondence, which future research may consider investigating further.

Finally, our findings on the ways in which visual features communicate taste information and influence affective appraisal can guide food packaging and presentation in order to contribute to current issues. For example, to promote healthier eating (e.g., Fenko, Lotterman, & Galetzka, 2016; Velasco et al., 2016b), or to make insects – a more sustainable source of protein than traditionally consumed meats – palatable to Western populations (see

[5] Curiously, bitterness-related metaphors show more relation with unpleasantness rather than threat in the English language, whereas the opposite is true in Mandarin Chinese. This may explain why shapes were more sour than bitter for the Western sample, and vice versa for the Eastern sample (compare Figures 5 and 6).

Deroy, Reade & Spence, 2015). In the clinical realm, such findings could guide the design of hospital food to help ameliorate the taste-related deficits faced by cancer patients (e.g., Ravasco, 2005) and 60-74% of older adults (Correia et al., 2016; Welge-Lüssen, 2008).

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Author Contributions

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

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TABLES

Table 1.

Means and standard deviations of taste ratings and appraisal ratings for each level of symmetry and contour in Experiment 1.

	Symmetry						Contour			
	Left-right reflectional		Up-down reflectional		Rotational		Round		Angular	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sweet	6.67	.24	6.34	.24	7.47	.29	9.35	.25	4.31	.24
Sour	6.43	.26	7.09	.29	6.11	.48	4.88	.28	8.20	.41
Bitter	5.11	.29	5.87	.28	4.82	.27	3.10	.21	7.44	.32
Pleasantness	7.91	.26	7.47	.24	9.79	.20	10.54	.22	6.24	.22
Threat	5.29	.28	5.66	.24	3.94	.24	2.49	.20	7.44	.31

Table 2.

Correlations between taste and pleasantness ratings, and taste and threat ratings for each shape in Experiment 1

	LR, R	LR, A	UD, R	UD, A	ROT, R	ROT, A
Sweet x Pleasantness	.177	.016	.177	.029	.215	.103
Sour x Pleasantness	.068	.054	.104	-.135	-.025	-.009
Bitter x Pleasantness	-.084	-.214	-.100	.015	-.020	.002
Sweet x Threat	.079	-.040	-.081	.170	-.194	-.039
Sour x Threat	.191	.062	.057	.342*	.166	.080
Bitter x Threat	.173	.076	.190	.060	.254	.142

LR = left-right symmetry; UD = up-down symmetry; ROT = rotational symmetry
R = round; A = angular
* = $p < .0001$

Table 3.

Means and standard deviations of taste ratings and appraisal ratings per level of symmetry for each level of contour in Experiment 2.

	Round			Angular		
	Bilateral	Quadruple	Asymmetric	Bilateral	Quadruple	Asymmetric

	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sweet	47.86	2.28	60.44	2.13	43.58	2.27	19.72	1.65	28.75	1.95	19.63	1.73
Sour	28.33	1.81	22.94	1.74	30.73	1.90	49.25	2.20	46.71	2.18	49.35	2.20
Bitter	24.60	1.73	19.10	1.56	26.51	1.89	44.03	2.16	35.60	2.12	46.67	2.20
Pleasantness	54.05	2.04	70.98	1.76	46.73	2.22	28.24	1.78	48.70	1.99	26.22	1.64
Threat	20.89	1.55	14.97	1.29	24.74	1.72	53.95	2.17	37.96	2.17	52.10	2.23

Table 4.

Correlations between taste and pleasantness ratings, and taste and threat ratings per shape family in Experiment 2.

	Bi, R	Bi, A	Qu, R	Qu, A	As, R	As, A
Sweet x Pleasantness	.501*	.313*	.456*	.379*	.573*	.429*
Sour x Pleasantness	.204	-.037	.073	-.197	.048	-.048
Bitter x Pleasantness	.061	-.023	.001	-.098	-.125	-.019
Sweet x Threat	.072	.052	.000	-.058	-.026	.117
Sour x Threat	.328*	.556*	.407*	.573*	.361*	.510*
Bitter x Threat	.379*	.526*	.474*	.459*	.461*	.528*

Bi = bilateral (1 axis); Qu = quadruple (4 axes); As = asymmetric (0 axes)
R = round; A = angular
* = $p < .0001$

Table 5.

Means and standard errors of taste ratings per level of symmetry for each level of contour in Experiment 3.

	Round						Angular					
	Bilateral		Quadruple		Asymmetric		Bilateral		Quadruple		Asymmetric	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sweet	49.60	1.86	62.73	1.83	48.35	1.98	22.02	1.42	29.60	1.70	20.32	1.32
Sour	29.32	1.31	27.61	1.45	31.77	1.57	48.82	1.73	49.86	1.97	50.47	1.82
Bitter	28.38	1.32	19.52	1.35	28.22	1.68	44.72	1.91	33.24	1.83	45.25	1.76

Table 6.

Means and standard errors of appraisal ratings for each level of symmetry and contour in Experiment 3.

	Symmetry						Contour			
	Bilateral		Quadruple		Asymmetric		Round		Angular	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Pleasantness	37.47	1.36	52.59	1.49	36.21	1.32	10.54	.22	6.24	.22
Threat	38.15	1.31	30.35	1.28	38.86	1.40	2.49	.20	7.44	.31

Table 7.

Correlations between taste and pleasantness ratings, and taste and threat ratings per shape family in Experiment 3.

	Bi, R	Bi, A	Qu, R	Qu, A	As, R	As, A
Sweet x Pleasantness	.567*	.296*	.489*	.281*	.544*	.465*
Sour x Pleasantness	.227	.118	.137	.123	.022	-.007
Bitter x Pleasantness	.268	.125	.035	.029	.078	-.053
Sweet x Threat	-.097	.087	-.056	-.102	.079	.052
Sour x Threat	.351*	.377*	.263*	.313*	.281*	.366*
Bitter x Threat	.345*	.438*	.375*	.344*	.377*	.409*

Bi = bilateral (1 axis); Qu = quadruple (4 axes); As = asymmetric (0 axes)
R = round; A = angular
* = $p < .0001$

FIGURES

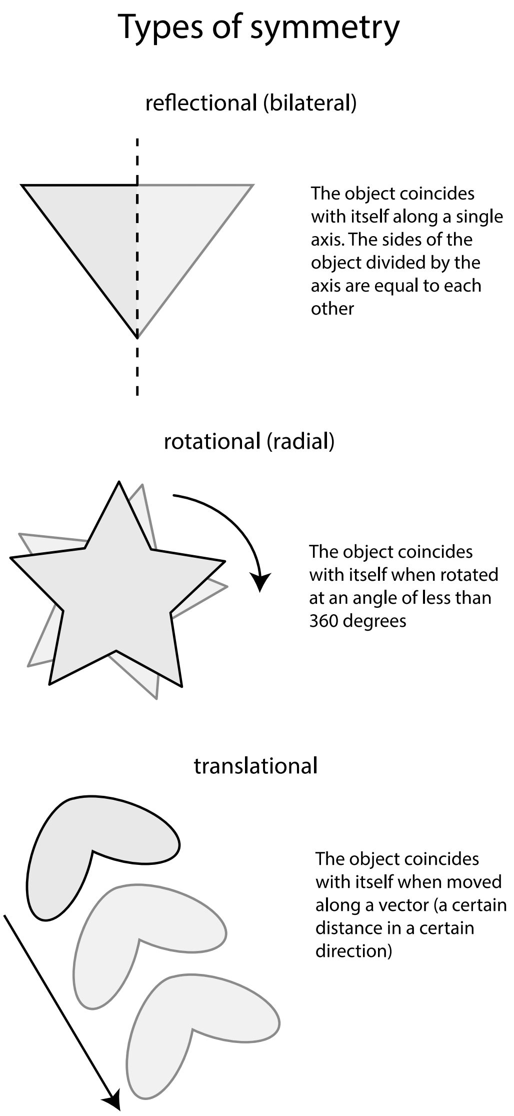

Figure 1. A graphic example of the basic types of Euclidean transformations in the plane, i.e., reflectional, rotational, and translational symmetry.

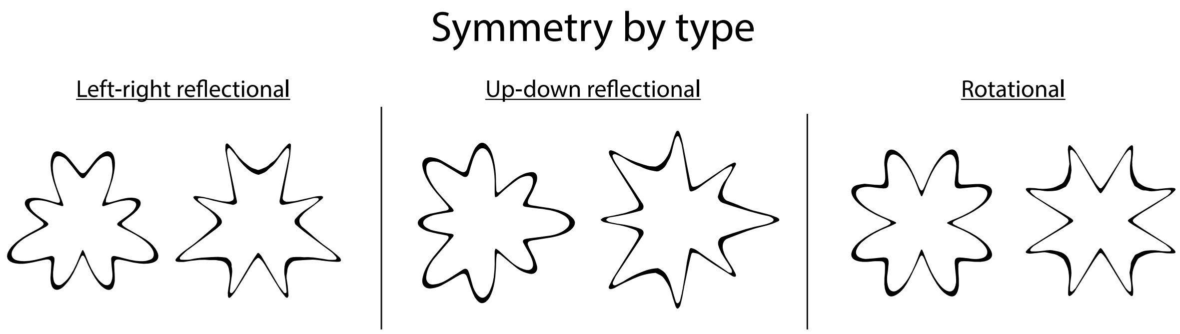

Figure 2. Shapes used as visual stimuli in Experiment 1. All were presented in black against a white background. All of the shapes had the same line thickness and number of elements.

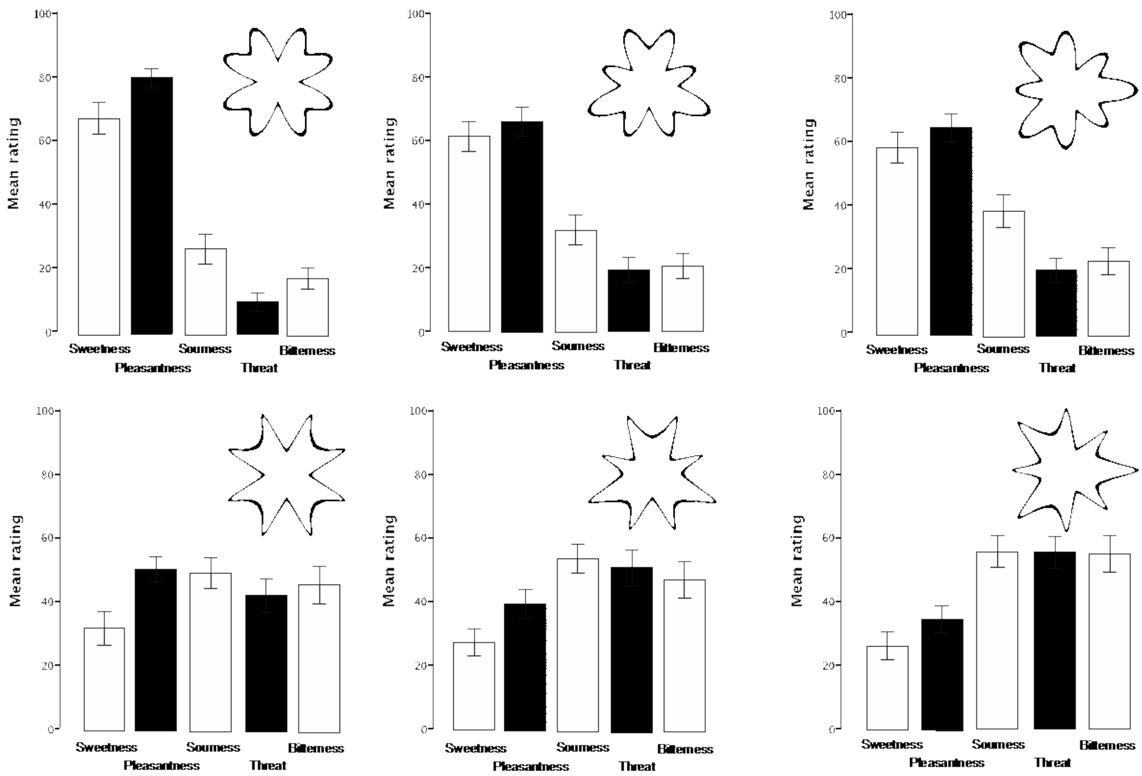

Figure 3. Ranked comparison of shapes by mean taste and appraisal ratings in Experiment 1. White bars represent taste ratings and shaded bars represent appraisal ratings. Shapes are presented in order from the sweetest and most pleasant through to the most bitter and most threatening (read: upper row, left to right; lower row, left to right). Error bars are 95% confidence intervals.

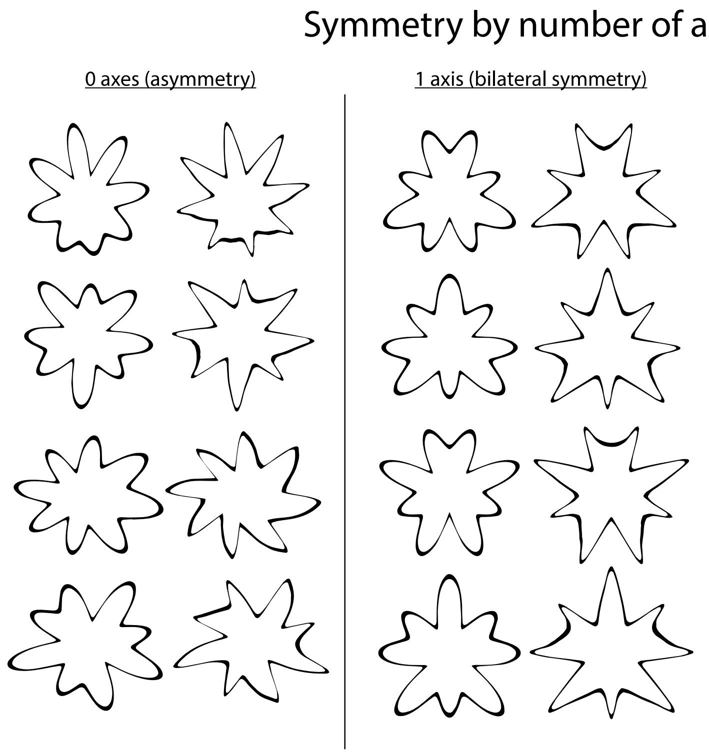

Figure 4. Shapes used as visual stimuli in Experiment 2, and in subsequent experiments.

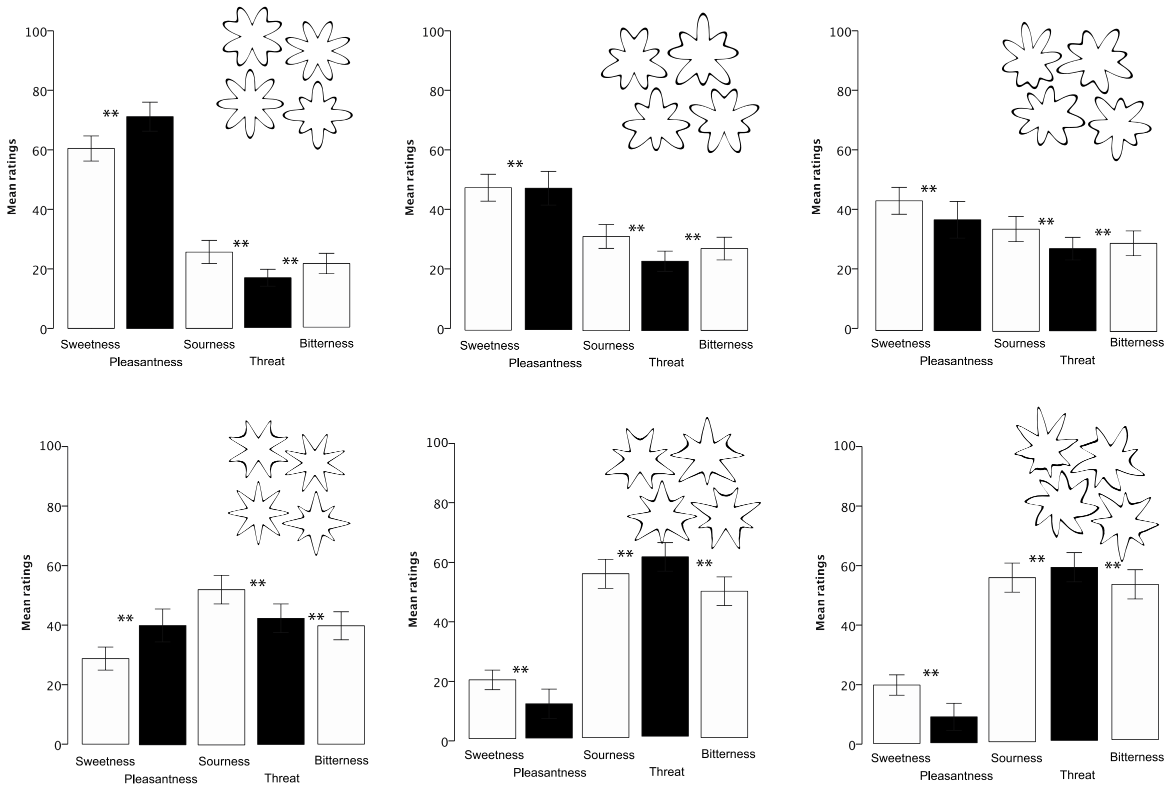

Figure 5. Ranked comparison of shape families by mean taste and appraisal ratings in Experiment 2. White bars represent taste ratings and shaded bars represent appraisal ratings. Shape families are presented in order from the most sweet and most pleasant to the most bitter and most threatening (read: upper row, left to right; lower row, left to right). Error bars are 95% confidence intervals. Significant correlations between taste and appraisal ratings are marked with ** ($p < .001$).

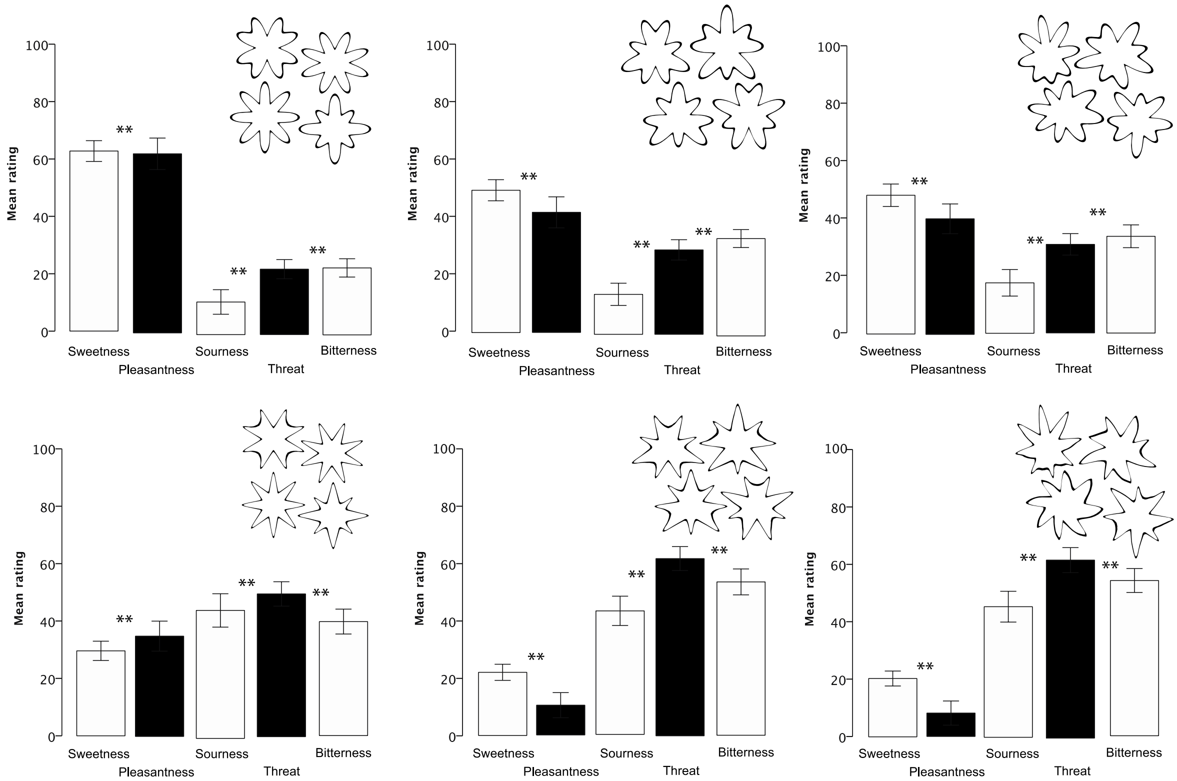

Figure 6. Ranked comparison of shape families by mean taste and appraisal ratings in Experiment 3. White bars represent taste ratings and shaded bars represent appraisal ratings. Shape families are presented in order from the most sweet and most pleasant to the most bitter and most threatening (read: upper row, left to right; lower row, left to right). Error bars are 95% confidence intervals. Significant correlations between taste and appraisal ratings are marked with ** (p < .001).