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Review

Explaining Visual Shape–Taste Crossmodal Correspondences

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Abstract

A growing body of experimental research now demonstrates that neurologically normal individuals associate different taste qualities with design features such as curvature, symmetry, orientation, texture and movement. The form of everything from the food itself through to the curvature of the plateware on which it happens to be served, and from glassware to typeface, not to mention the shapes of/on food product packaging have all been shown to influence people's taste expectations, and, on occasion, also their taste/food experiences. Although the origins of shape–taste and other form–taste crossmodal correspondences have yet to be fully worked out, it would appear that shape qualities are occasionally elicited directly. However, more often, there may be a metaphorical attempt to translate the temporal qualities of taste sensations into a spatial analogue. At the same time, emotional mediation may sometimes also play a role in the affinity people experience between shape properties and taste. And finally, it should be acknowledged that associative learning of the relation between packaging shapes, glassware shapes, logos, labels and iconic food forms that commonly co-occur with specific taste properties (i.e., in the case of branded food products) may also play an important role in determining the nature of shape–taste correspondences. Ultimately, however, any attempt to use such shape–taste correspondences to nudge people's behaviour/perception in the real world is made challenging due to the fact that shape properties are associated with multiple qualities, and not just taste.

Keywords

shape, taste, symmetry, orientation, balance, texture, neatness

1. Introduction

Many years ago, the North American philosopher, logician, mathematician and scientist C. S. Peirce wrote that: ‘*Sight by itself informs us only of colors and forms. No one can pretend that the images of sight are determinate in reference to taste. They are, therefore, so far general that they are neither sweet nor non-sweet, bitter nor non-bitter, having savor nor insipid.*’ (Peirce, 1868). However, over the last 80 years or so, and contrary to the position espoused by Peirce, a growing body of food science research has demonstrated that most people do indeed associate specific colours with particular tastes (e.g., sweet, sour, bitter, salty and possibly also umami). So, for example, the majority of people will pick a pinkish-red colour for sweetness, bluish-white for a salty taste, yellow-green for sour and brownish-black for bitter (e.g., Spence *et al.*, 2015a; Wan *et al.*, 2014; and see Ikeda, 1909/2002, for early intuitions concerning the colour of umami).

According to one popular suggestion, such colour–taste correspondences may reflect the internalization of the statistics of the environment (e.g., Barlow, 2001; Lee *et al.*, 2013; Shepard, 1987; Spence, 2011a). However, until the last decade or so, there has been much less research on the question of whether people also associate shapes (forms) with tastes (though see Spence and Deroy, 2012, 2013a, for early reviews). Furthermore, it is not immediately clear whether a plausible statistical account can be forwarded for the cross-modal correspondences that have now been documented between shapes and tastes. This is especially obvious in the case of the shape properties that people tend to associate with drinks such as beer, wine and carbonated/still water (Deroy and Spence, 2013; Deroy and Valentin, 2011; Ngo *et al.*, 2012, 2013), given that the latter liquids typically do not have a specific form.

A small subset of synaesthetes report experiencing vivid shape concurrents in response to taste/flavour inducers, such as the synaesthete, Michael Watson, whose case was described by Cytowic (1993; Cytowic and Eagleman, 2009). He was once overheard saying that the roast chicken that he was preparing was burnt because it had ‘too many points’ (see Day, 2011, p. 12, pp. 16–17). He was also quoted as saying that: “Sugar made things taste ‘rounder’ while citrus added ‘points’.” (Cytowic, 1993, p. 66). At the same time, chefs have occasionally also described constructing menus based on the shape properties they metaphorically associated with tastes and flavours of the dishes, drinks and/or ingredients. For instance, Paul Bertolli of the Oliveto restaurant in Oakland, California includes one such shape-based menu at the end of his book *Cooking by Hand* (Bertolli, 2003). That said, for whatever reason, synaesthesia appears to be far less common amongst chefs than amongst other creative/artistic individuals (see Spence *et al.*, 2015b). Recently, those individuals with high autistic traits have also been documented to show fewer

consensual crossmodal correspondences between visual features and tastes than other members of the general population (Chen *et al.*, 2021a). Intriguing research (though totally underpowered by today's scientific standards) reported by Cytowic and Woods (1982) suggested that a gustatory–shape synaesthete tended to associate acidity with angularity. (The synaesthete in question was unusual in that the shape–taste synaesthesia only emerged in his twenties; in most cases, synaesthetes report that their peculiar inducer-concurrent mappings have been with them for as long as they can remember.) According to Cytowic and Woods (1982, pp. 37–38), when cooking: “He then adjusts seasonings (at times by trial and error) to alter the taste’s shape, making it “rounder,” giving it more “inclination,” “sharpening up” the corners, or unwinding the “curlicues.”” (see Note 1).

The use of shape/form language is also common in the world of expert wine writing (where terms such as linear, rounded, balanced, etc. are often used; Lehrer, 1975, 2009; Peynaud, 1987; see also Chamberlain, 1903). For example, at one point, the oenologist Emile Peynaud (1987, p. 221) wrote that: “I have searched through numerous texts and have encountered all the expressions that I mention here at least once, but can I be sure of having picked them all up? A wine is formless if its image on the palate is unclear. The following words immediately evoke simple forms: spherical, round, rounded, oblong, flat, threadlike, rectilinear, lanky or long limbed, square, angular, sharp, pointed, twisted, corked, concave, convex.” Meanwhile, Paradis and Eeg-Olofsson (2013, p. 28) highlight the seemingly common usage of the term ‘sharp’ to describe the smell, taste, touch and finish (or aftertaste) of wine, as in the following wine descriptions they identify: “(2) cinnamon, and white raisins can be found in the zesty sharp aromas of the 2001 Riesling Eiswein; (3) a medium-bodied wine with gorgeously proportioned, razor sharp flavours; (4) the high acidity levels give the wine a compressed sharp feel on the palate; (5) a pervasive weedy, earthy character in its flavours and a sharp finish.” [bold in original]. Similarly, the term ‘sharp’ is also commonly used to describe the taste of cheese (Spence *et al.*, 2013). The latter expression typically being considered as an example of sensory, or perceptual, metaphor (see Marks, 1996).

In fact, an emerging body of crossmodal correspondences research now demonstrates that the majority of neurologically normal individuals do indeed tend to associate specific shape properties, such as curvilinearity and symmetry, with particular taste qualities (e.g., Spence and Ngo, 2012; Turoman *et al.*, 2018), at least amongst the four or five most commonly-mentioned basic tastes. When Devenyns (2019) attempted to describe the taste sensation that was associated with the addition of kokumi, the so-called sixth taste, he suggested that it added ‘roundness’ to food. To the extent that such shape-based descriptions of tastes/flavours appear relatively frequently in language/discourse, and furthermore, to the extent that people would intuitively appear

to understand the likely taste phenomenology that should be attached to such shape descriptions, it would seem as though shape properties are, in fact, a natural aspect of many people's taste experiences. Thus, it can be argued that shape–taste correspondences are far more than merely an artefact of academic studies of the crossmodal correspondences (i.e., something that only occurs when participants are forced to choose a shape to match a taste).

An emerging literature also highlights the existence of a range of consensual crossmodal associations between aromas/scents and shape properties. However, while intriguing, a detailed discussion of this literature remains outside the scope of the present review. The interested reader is nevertheless directed to one of the empirical/review papers already published on this topic (e.g., Deroy *et al.*, 2013; Hanson-Vaux *et al.*, 2013; Seo *et al.*, 2010; Spence, 2020). One of the generalizations that emerges from the literature that has been published to date on such shape-chemosensory crossmodal correspondences is that those tastes, aromas and flavours that stimulate the trigeminal nerve are more likely to be associated with angularity than are those stimuli, such as vanilla (see Spence, 2022a), that primarily, or solely, stimulate the olfactory nerve.

While a full understanding of the origin(s) of form–taste correspondences is yet to be forthcoming, that certainly hasn't stopped a growing number of innovative designers from incorporating such insights concerning the crossmodal correspondences as sources of inspiration in their creative practice, including in the world of food and drink experience design. In this narrative historical review, the literature on form–taste correspondences is summarized and a number of the recent attempts to apply the insights in the fields of design and experiential/sensory marketing are highlighted. The potentially fundamental importance of approach-avoidance motivation to the classification of stimuli (be they form or taste stimuli) is also discussed.

2. Visual Form Correspondences With Basic Taste Qualities

Although many form features can be assessed by touch/haptics as well as by eye, the majority of the empirical research that has been published to date has tended to assess shape–taste crossmodal correspondences visually. The most extensively studied visual design feature has undoubtedly been curvilinearity. However, as we will see below, researchers have also been intrigued by the taste qualities that people may consensually associate with volume, symmetry, and texture as well.

2.1. Curvilinearity

One of the most often reported findings in the literature is that people intuitively match roundness with sweetness, while picking angular forms to represent the other four basic tastes (Gallace *et al.*, 2011; see Spence and Deroy, 2012, 2013a, for reviews). Roundness is also associated with and tends to accentuate, creaminess (Baptista *et al.*, 2022; Spence, 2013, 2014; Wang *et al.*, 2017a; cf. Lenfant *et al.*, 2013). Meanwhile, sourness and spiciness are both associated with angularity (Gil-Pérez *et al.*, 2019; Velasco *et al.*, 2018a). One question that often crops up here concerns the cross-cultural generalizability of crossmodal correspondences, such as those that have been documented between shape and taste. Relevant here, participants from both India and China also match sweetness with roundness (Liang *et al.*, 2016).

At the same time, however, Bremner *et al.* (2013) reported a strikingly different pattern of taste–shape correspondences in the case of still/sparkling water and chocolate varying in terms of its bitterness. While Western consumers match carbonation (Ngo *et al.*, 2012) and increasing bitterness (e.g., in chocolate samples) with increased angularity (Ngo *et al.*, 2011; Ngo and Spence, 2011; Spence and Gallace, 2011), the Himba tribe of Kaokoland in Northern Namibia exhibited a very different pattern of results. In particular, the 34 unschooled semi-nomadic herders with little exposure to Western culture or artefacts who were tested in Bremner *et al.*'s study failed to exhibit a significant association between angularity and carbonation, while showing the reverse mapping when asked to pick the rounded *versus* angular shape in response to chocolate samples varying in cacao content (30%, 70%, 90%). As yet, no convincing explanation for this cultural difference in shape–taste crossmodal correspondences has been put forward, though it would be helpful to see this isolated empirical finding replicated (Note 2).

2.2. From 2D to 3D Forms

Cytowic and Woods (1982) introduced a range of 23 abstract shapes (one 2D outline and the rest abstract 3D shapes) in their early study. However, the very small sample size – one gustatory-shape synaesthete, one chef/restaurateur and two other control participants – did not allow for any concrete conclusions, as the authors themselves readily acknowledged. (Interestingly, one potential participant was removed from the study: “because he insisted there was no logical way in which taste and shape went together”; see Cytowic and Woods, 1982, p. 38). Deroy and Valentin (2011) had a larger group of participants ($n = 46$) match three beers to a set of 34 shapes, half of which were 2D shapes and the remainder 3D volumes. In the latter case, curvilinearity rather than the distinction between 2D *versus* 3D appeared to be driving the participants' crossmodal associations. That being said, there was a hint in the data that sweetness and voluminousness might be associated.

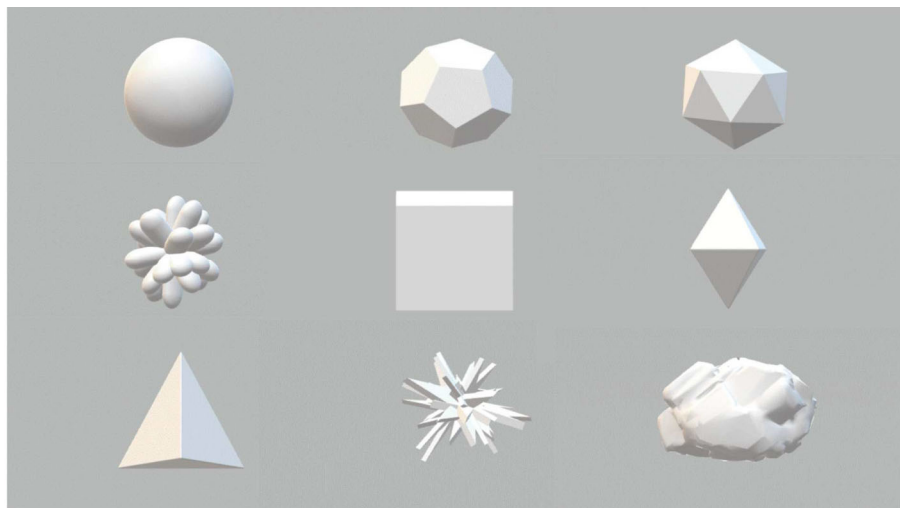


Figure 1. The nine shapes (including the five Platonic solids) that were associated with taste properties in Juravle *et al.*'s (2022) recent online research. Note that the participants saw each of the shapes rotating continuously in the actual study. Reprinted under Creative Commons CC BY 4.0.

Recently, Juravle *et al.* (2022) evaluated participants' taste associations with the so-called platonic solids together with several other 3D shapes (see Fig. 1). The sphere was strongly associated with sweetness and to a lesser extent with umami. By contrast, bitter and sour were associated with the more angular forms, replicating previous findings in the literature. None of the shapes was significantly associated with a salty taste. Given that umami and kokumi are both associated with mouth-filling sensations (Devenyns, 2019), it might be expected that they would be linked with more voluminous forms. Complicating matter somewhat here though, it has been suggested that kokumi substances have no taste in and of themselves, but 'merely' add 'roundness' and 'length' to sweet, salty and umami taste sensations.

Over the years, one of the generalizations that has emerged from the research that has been published on shape–taste crossmodal correspondences is that while correspondences involving sweet, sour and bitter, tend to be fairly robust (and hence easy to ascertain) those with salt taste tend to be somewhat weaker (with the exception of taste–colour correspondences), and thus harder to document empirically. One of the other generalizations to have emerged from the research is that while sweetness is associated with roundness, all of the other tastes tend to be associated with more or less angular forms instead (Note 3). It is at this point that one might consider recent suggestions that the taste system should be considered in terms of sensorimotor approach/avoidance (e.g., Di Lorenzo, 2021; Mattes, 2021). This might help to explain the

roundness sweet association as opposed to the angularity match for salt, sour and bitter, since sweetness provides a strong signal of a desirable (and hence approachable) food quality. Note here that the status of a fat (or fatty acid) taste is uncertain, while most carbohydrates have no taste.

2.3. *Symmetry*

There are several kinds of symmetry, including rotational, reflectional and translational. In a series of online studies conducted by Turoman *et al.* (2018), asymmetry was shown to be associated with acidity/sourness and bitterness in groups of participants from Taiwan and the West (UK, USA and Canada). At the same time, however, the latest research also provides some evidence to suggest that symmetry (or regularity of form) may, in some cases at least, be associated with sweetness as well (see Juravle *et al.*, 2022; Salgado-Montejo *et al.*, 2015).

2.4. *Texture*

Barbosa Escobar *et al.* (2020) demonstrated that people preferentially match specific tastes with particular visually-perceived textures. It is important to note that such crossmodal correspondences go beyond specific food forms that are semantically linked to specific taste qualities, such as, for example, the textural appearance of candyfloss being associated with sweetness (Spence *et al.*, 2019a). Intriguingly, back in the 1930s, the Italian Futurists had already intuited the existence of a certain relationship (or correspondence) between felt textures and tastes, a phenomenon they described as ‘Syn-tactilismo’ (Marinetti, 1932/2014). It is worth noting that the ubiquitous nature of such intuitive crossmodal associations, as documented by contemporary research has, though, tended to move people’s thinking away from searching for an explanation for such phenomena in terms of synaesthesia. The latter is a rare phenomenon, and defined in terms of idiosyncratic connections between inducer and concurrent (Grossenbacher and Lovelace, 2001). Instead, researchers have sought an explanation in terms of the increasingly popular crossmodal correspondences (Di Stefano and Spence, 2022; Spence, 2011a). Confusing matters somewhat, though, synaesthetes are presumably likely to experience many of the same crossmodal correspondences as non-synaesthetes, hence perhaps explaining the angularity-acidity connection picked-up in the responses of the taste-shape synaesthete in Cytowic and Woods’ (1982) early study. Intriguingly, there is mounting evidence to suggest that those textural cues that are seen and/or felt, can also accentuate certain taste and oral-somatosensory attributes of foods (see Biggs *et al.*, 2016; Carvalho *et al.*, 2020; Piqueras-Fiszman and Spence, 2012; Slocombe *et al.*, 2016; Velasco *et al.*, 2013; Wang and Spence, 2018). So, for example, participants have sometimes felt (and/or seen) a textured plate or cup, or else been asked to

rub a swatch of silk or a piece of sandpaper, say, prior to and/or while tasting a particular food or drink, and rating the latter's taste. In such cases, however, it is possible to imagine a more or less direct mapping, or translation, of seen/felt texture to the matching mouthfeel (though see Di Stefano and Spence, 2022). Texture descriptors such as 'smooth' are also commonly applied to taste (see Burke, 2009, p. 130), though, in such cases, it is easy to imagine that what is being described is the literal feel of a given foodstuff in the oral cavity rather than a more metaphorical description (Note 4).

2.5. Orientation, Position and Movement

In recent years, a growing body of research has started to highlight the importance of the orientation in which food forms are presented to the viewer's aesthetic appreciation. The orientation in which (food) forms are presented can subtly influence people's food preferences. So, for example, triangular food forms (arrangements) are liked just that little bit less when the triangle points downward and/or toward the viewer than when the same food form is presented with the point directed upward/away from the viewer instead (e.g., Michel *et al.*, 2015). It has been suggested that downward-pointing angular shapes, such as an inverted triangle, automatically capture people's attention because of a link with brain's fear circuits (Velasco *et al.*, 2015a). This can either be a good or bad thing in the context of food product packaging, depending on the complexity of the search task facing the shopper when scanning the shelves (e.g., Shen *et al.*, 2015; Zhao *et al.*, 2020). In terms of taste correspondences, a downward-pointing triangle may be slightly more likely to be associated with bitterness than a triangle that points up/away from the viewer (cf. Spence *et al.*, 2015a) (Note 5).

In terms of orientation, it has been reported that linear food elements are preferred when they ascend to the right (rather than the left) on the plate (Youssef *et al.*, 2015). Intriguingly, this preference appears to hold regardless of language (and hence reading direction) and culture (Shibuya *et al.*, 2022; Spence, 2022b). Cardinal orientations for linear food elements are also often preferred over oblique orientations (see Spence, 2019; Spence *et al.*, 2019b, for evidence and reviews).

It has often been reported that (differences in) verticality provide a striking basis for metaphor in humans (e.g., Cian, 2017; van Rompay *et al.*, 2012, 2019). Similarly, the literature on 'sonic seasoning' (referring to the deliberate pairing of sound/music with taste/flavour in order to enhance, or modify, the multisensory tasting experience; Spence *et al.*, 2021) has also demonstrated robust crossmodal correspondences between basic taste and pitch height, with bitter tastes being associated with low notes whereas sweet and sour tastes tend to be associated with higher notes instead (e.g., Knöferle and Spence, 2012; Wang *et al.*, 2015). That said, the spatial (e.g., elevation) association

with the basic tastes does not appear to be particularly strong, with Velasco *et al.* (2019) documenting only weak evidence to suggest that people associate sweet tastes with higher locations than the other tastes.

By contrast, the association between tastes and speed (i.e., slow *versus* fast) would appear to be much more intuitive/strong for people (e.g., Smith, 2012; Woods *et al.*, 2013; though see also Barilari *et al.*, 2018). For example, the majority of people will spontaneously rate lemons as ‘fast’ rather than ‘slow’, whereas prunes and bananas are commonly rated as slow. It has been suggested that such speed–taste correspondences may, in part, link to the rate at which different taste sensations are experienced phenomenologically. Acidic tastes (such as the citric acid in lemons) are much more soluble in saliva than compounds such as carbohydrates, that give rise to the other basic tastes (Note 6). However, beyond the rate at which gustatory stimuli are transduced, it would appear that the texture of food also plays a role in determining the speed that people intuitively associate with different foods/flavours: For example, foods such as bananas, peanut butter, prunes, are all rated as slow (rather than fast). Here, though, it should also be noted that there may be a more general contextual association between speed and taste: For instance, between drinking an espresso and speed, given the arousal that the drink is likely to elicit and/or the speed with which it is typically consumed.

2.6. Balance, Neatness and Harmony

Several studies have revealed that balance, neatness and harmony are all relevant features as far as the aesthetic appreciation of food designs are concerned (Velasco *et al.*, 2016a). Food arrangements that embody the golden ratio also tend to be preferred over those that do not (Deroy and Spence, 2014). Ultimately, however, it is important to remember that consumers are normally drawn to energy density, and hence the spatial layout of food that happens to give rise to the impression of the greatest amount of food is likely to be preferred visually (Petit *et al.*, 2018; Rowley and Spence, 2018; Szocs and Lefebvre, 2015; Woods *et al.*, 2016). Relevant here, the preference for round plates for serving food might perhaps be explained by the psychophysical bias toward estimating circular food presentations as containing more food than rectangular presentations (Krider *et al.*, 2001; see also Li *et al.*, 2022a, on the suggestion that square food presentations are rated as more calorific than round presentations).

3. Explaining Shape–Taste Correspondences

The spatial aspects of taste sensation have long been linked to the so-called tongue map (see Spence, 2022c, for a review). That said, while the latter has long been discredited (Bartoshuk, 1993), contemporary research has started

to highlight a spatial component to certain oral sensations, each having a different spatial localization/volume. For instance, consider only how the sixth taste ‘kokumi’ is described as giving rise to a sensation of mouth-fillingness (Devenyns, 2019).

3.1. *The Shape of Taste Experiences*

To date, very few researchers have taken seriously the suggestion that a richer spatial dimension is present in flavour experiences, as compared to in the majority of other perceptual experiences. That said, this hypothesis appears in the writing of William James, who long ago considered that “in the sensations of smell and taste, (the) element of varying vastness seems less prominent but not altogether absent. Some tastes and smells appear less extensive than complex flavours, like that of roast meat or plum pudding, on the one hand, or heavy odours, like musk or tuberose, on the other.” (James, 1887, p. 2). James also put forward this perceptible spatial dimension as providing an explanation for the kind of correspondences that have been documented between taste and shape/form: “The epithet sharp given to the acid class”, he wrote, “would seem to show that to the popular mind, there is something narrow, and as it were, streaky in the impression they make, other flavours and odours being bigger and rounder” (James, 1887, p. 2) (Note 7).

Meanwhile, the famous French oenologist Emile Peynaud (1987, p. 220) once wrote that: “However lacking in imagination he might be, when a taster works the wine in his mouth and feels it with his tongue, he absorbs not only impressions of taste, but also impressions of volume, form and consistency. He forms a physical image of the wine. This is part of a curious ‘optical effect’ of a taste, a phenomenon which it would not be inappropriate to call *stéréogustation*.” (though see Jacobs *et al.*, 1998). Once again, the crossmodal matching would appear to be based on automatically-generated visual mental image of the form of the wine (Spence and Deroy, 2013b). A few pages later, Peynaud writes that: “Anyone who has tasted a Jurançon, the sweet wine from the Pyrenees foothills, will understand Orizet when he writes: “It is the contradictory nature of Jurançon to be rounded at one end, and pointed at the other.”” (Peynaud, 1987, p. 272).

Taken together, such observations would appear to suggest that the use of shape descriptors to describe complex taste experiences might, in certain cases at least, reflect a direct description of the spatial/voluminousness of the associated taste sensation. However, it is important to stress that, for most people, the reason why they choose to match a round shape with a sweet-tasting food and an angular asymmetrical shape with a sour-tasting food, say, is not literally because they experience these shapes in their mouth when tasting something sweet or sour.

3.2. Spatiotemporal Analogy

It has been suggested by some that there is some spatiotemporal analogizing at play in the matching of taste experiences with the temporal experience of tasting, such that taste sensations that evolve (temporally) a little more slowly on the palate, such as sucrose may be matched with curvature (i.e., analogous to a gradual spatial transition) whereas sour tastes, tend to rapidly appear and disappear from perceptual experience (Obrist *et al.*, 2014). Were such a spatiotemporal account to be correct, then it might predict that different sweeteners would be associated with different shapes, since they have been documented to exhibit very different temporal profiles in consumer experience (see Ketelsen *et al.*, 1993; Stuckey, 2012).

If one takes the Peynaud (1987) quote mentioned a moment ago, then there would seem to be a temporal component to taste experience in the case of wine. Furthermore, the rate of alcohol evaporation, and hence mouth cooling is often reported as being important for wine-tasting when an individual tries to judge the alcohol content hence hinting at rate of change of sensations also possibly being important. One might consider this as a kind structural isomorphism, or metaphorical crossmodal mapping (cf. Ravignani and Sonnweber, 2017; Wagner *et al.*, 1981). More generally, it turns out that the temporal aspects of the chemosensory experience of taste/flavour are currently starting to attract more attention from food science researchers (e.g., see Wang *et al.*, 2019; Wilson, 2022).

3.3. Emotional/Hedonic Mediation

Emotional, or hedonic, mediation has been suggested as a possible explanation of the crossmodal correspondence between taste and shape (e.g., Salgado-Montejo *et al.*, 2015; Turoman *et al.*, 2018; Velasco *et al.*, 2015b). The basic idea is that liked tastes (such as sweetness) are paired with preferred shapes (such as roundness; Blazhenkova and Kumar, 2018; Larson *et al.*, 2012; Leder *et al.*, 2011; though see also Bertamini *et al.*, 2016), whereas generally disliked (or dangerous) tastes such as bitterness and spiciness are associated with threatening shapes (e.g., those that are angular). In fact, according to the results of a series of studies conducted by Velasco *et al.* (2016b), a semantic differential space with the principal components (or dimensions) of hedonics and intensity can be used to account for people's responses to taste (cf. Velasco *et al.*, 2016c). Potentially relevant to the emotional mediation account, individual differences in the preference for curvature in objects have also been reported (Cotter *et al.*, 2017), possibly mediated by shape familiarity (Chuquichambi *et al.*, 2021), expertise (Silvia and Barona, 2009), self-construal (Zhang *et al.*, 2006), and even an individual's feelings of loneliness (Chen *et al.*, 2021b; see also Chuquichambi *et al.*, 2022) (Note 8).

Should emotional/hedonic mediation provide part of the explanation for why it is that certain tastes are matched with particular shapes, then there may be interesting research to be done by varying sweetness intensity of taste solutions, given that populations tend to split into sweet-likers, sweet-neutral and sweet-dislikers, as a function of increasing sweetness (e.g., Iatridi *et al.*, 2019; Looy *et al.*, 1992; Velasco *et al.*, 2016d). It might be predicted that the correspondence with curvature would be different in these three groups as a function of taste intensity. One might also consider whether supertasters (Bartoshuk, 2000), who have an increased response to a variety of taste and oral-somatosensory attributes, might match tastes to shape features differently from non-tasters (Marks *et al.*, 1988). In the extreme, there must presumably be a difference for those compounds, such as PTC (phenylthiocarbamide) and PROP (6-n-propylthiouracil) to which non-tasters are taste-blind, but which supertasters report as tasting extremely bitter. Some years ago, Crisinel and Spence (2012a) tried something along these lines when they assessed whether dark chocolate elicited the same crossmodal correspondence in two groups of individuals, one who liked dark chocolate and the others who did not.

3.4. *Semantic Associations Between Shape and Taste*

There are correlations between shape and taste (Arboleda and Arce-Lopera, 2020; Overbeeke and Peters, 1991; Velasco *et al.*, 2016e; Wang and Sun, 2006). Various iconic branded food products may come to take on semantic/branded association – be it iconic triangular shape of Toblerone, through to the seashell shape of Guylian chocolates (see Spence, 2014). Given cultural differences in the exposure to different food products/forms, one might also wonder whether there may be important cultural factors at play here. In Italy, for example, it has been suggested that there is a natural affinity (or appropriateness) between certain specific shapes of pasta and the sauces with which they should be paired (Hildebrand and Kenedy, 2010). In such cases, it might simply be assumed that particular iconic forms have taken on specific associations with taste/flavour, and/or texture as a function of associative learning (Note 9). Indeed, it is difficult to determine the extent to which the carbonation–angularity mapping is, for example, based on the common usage of angular logos in the marketplace (see Spence, 2012, for a number of examples). At the same time, however, it can be argued that visual design features of labels, logo designs, typeface, or product packaging are more likely to succeed in the marketplace if they are based on some underlying mapping (see Spence and Van Doorn, 2022).

Given that many branded food products tend to be associated with a distinctive product or packaging shape, logo design, typeface, etc., it would seem possible that in certain cases the shape properties associated with taste may be based on associative learning. Similarly, in the case of drinking vessels,

it would seem likely that people have internalized the statistics of the environment, in terms of specific glasses/shapes being associated with particular beverages (Wan *et al.*, 2015a, b). At the same time, however, many commentators have suggested that the shape/size of the wine glass exerts a direct physicochemical impact on the volatile aromas that collect in the headspace over the surface of the liquid in the glass (see Spence, 2011b). However, careful experimentation has shown that any such physicochemical impact of the shape of the wine glass is insufficient to impact taste/flavour properties (at least when the taster does not know which glass they happen to be drinking from; see Spence, 2011b; Spence and Wan, 2016).

That said, when people are aware of the shape properties of the glass that they are drinking from (which is normally the case), then serving beer and wine in curved glasses brings out the fruitiness in the drink (Cliff, 2001; Delwiche and Pelchat, 2002; Mirabito *et al.*, 2017; see also Ribeiro *et al.*, 2021). In such cases, while it may be natural to consider the shape features of the glassware as affecting physicochemical properties of the volatiles in headspace over the glass, it would seem more likely that it is the psychologically-determined crossmodal correspondence between taste and shape that is really doing the work in terms of automatically priming taste expectations, especially given research showing that simply varying outer texture of drinking vessel can also bias taste ratings (see Van Rompay and Groothedde, 2019; Van Rompay *et al.*, 2017, 2018). There would also appear to be a correspondence between the shape of a coffee cup and the expected taste of the contents (Carvalho and Spence, 2018; Van Doorn *et al.*, 2017; see also Machiels, 2018; Pich *et al.*, 2020) (Note 10).

In passing, it is perhaps worth considering whether there may be some form of imprinting of taste–shape correspondences based on early childhood experiences (one can perhaps think of this as a very special kind of associative learning). After all, the earliest conscious taste experiences for newborn humans are presumably based on the sweet–umami taste of breast milk associated with distinctive rounded red-purple aureole. Relevant here, researchers have shown that by only a few months of age, babies are already internalizing the crossmodal statistics of the environment in which they find themselves (cf. Fernandez and Bahrick, 1994; Gogate and Bahrick, 1998).

3.5. *Interim Summary*

Several speculative accounts have been put forward in recent years to try and explain why it should be that people consensually match various form features with specific taste qualities. It is important to note that the various explanations need not be treated as mutually exclusive, and indeed, several of them may help to explain some proportion of the empirical data that have been published to date. One important point to bear in mind here, though, is that just

because people consensually match shape/form properties with basic tastes when invited to do so, that does not mean that such crossmodal correspondences should necessarily be thought of as being dominant (or top-of-mind) under those conditions (or in those contexts) where other visual stimulus parameters (such as colour or material properties/texture) might also be varying (see Motoki and Velasco, 2021; Motoki *et al.*, 2022; Turoman *et al.*, 2018).

It has often been suggested that colour is the most salient visual attribute. As such, one might have imagined that people would find it more natural to describe tastes in terms of colours rather than necessarily in terms of form/shape features. That being said, it is striking how shape language would appear to be what wine writers, and others, reach for when trying to explain the particular taste properties of wine (e.g., Lehrer, 1975, 2009; Peynaud, 1987; see also Paradis and Eeg-Olofsson, 2013), perhaps because the colour of the wine is already given (see Spence, 2010a, b). Other commentators have also spontaneously chosen to use form descriptors in order to describe the tastes experience that is associated with specific tastants (such as, for example, kokumi; Devenyns, 2019) or everyday foods (James, 1887, p. 2). At the same time, however, one might only consider how often sensory metaphors (sometimes referred to as synaesthetic metaphors; Day, 1996), such as describing a cheese as tasting ‘sharp’ are found in natural language (see also Liu and Kennedy, 1997).

4. Sensory Nudging With Form – Taste Correspondences

While Peirce (1868) may well have been right in the sense that shape (like colour) is not ‘determinate’ with respect to taste, nevertheless, as the present review has highlighted, there are a number of consensual crossmodal correspondences between shape features (typically presented visually) and taste qualities. Furthermore, the wider literature would appear to suggest that shape descriptors come naturally to many people when trying to describe complex taste experiences. In fact, a number of researchers have considered whether such crossmodal correspondences can be used to bias consumer behaviour, presumably as a result of some sort of automatic taste priming by shape/form properties (Note 11). At the same time, however, it is important to recognize the more general approach motivation that round forms afford (e.g., Bar and Neta, 2006; Dazkir and Read, 2012; Liu *et al.*, 2018; Reilly, 2013; Thömmes and Hübner, 2018; Vartanian *et al.*, 2013; Zhu and Argo, 2013; see also Palumbo *et al.*, 2015; Spence, 2022d). What this means in practice is that any design decisions that happen to be based on shape–taste correspondences might be considered as only of secondary relevance; Or, put a little differently, one might want to consider whether the approach motivation associated with round forms will normally override any ‘processing fluency’ (Reber, 2012)

that may be associated with aligning shapes with tastes (see also Jiang *et al.*, 2016).

To make the logic here concrete, it has, for example, been suggested that the form in which a food is presented can bias the likelihood that people will try it. For instance, leading UK ‘nose-to-tail’ chef, Fergus Henderson, was once quoted as follows: “Disgust is always rooted in a perception of asymmetry,” he says suddenly. “Geometry cures it. Take the haggis, for instance. It’s made of sheep’s stomach and sheep’s lights, but people will eat it because it’s comfortably round. Sausages have always been allowed in because of their shape. People are somehow reassured.” (Gopnik, 2012, pp. 138–139; though see also Zhou *et al.*, 2021). At the same time, however, Li *et al.* (2022b) recently suggested that people’s preference for symmetry in foods may be linked to (i.e., mediated by) perceptions of naturalness (Note 12).

Similarly, rounded labels, and rounded packaging forms are both thought to be more approachable. For instance, many years ago, Cheskin (1957) anecdotally reported how he thought rounding the angular corners of the Fleischman’s gin bottle label would make the product more approachable to women (who were the primary purchasers at the time; cf. Dichter, 1971; Simmonds *et al.*, 2019; Westerman *et al.*, 2012, 2013). In the various examples just mentioned, therefore, it would appear to be the approach motivation associated with roundness (at whatever spatial scale) that overrides any taste-signalling that may be associated with shape features.

The evidence that has been published to date goes beyond merely demonstrating that people share a range of consensual mappings between shape properties and taste qualities. These natural affinities may even bias people’s food behaviours. For example, researchers have started to investigate whether it is possible to nudge people’s choice behaviour in relation to food through manipulating typeface curvilinearity (see Seo, 2020, on the notion of sensory nudging). While different typeface designs vary in a number of visual design features including curvilinearity and weight (Velasco and Spence, 2019), early research on taste–typeface by Velasco *et al.* (2015c) demonstrated that people associate sweetness with a more rounded typeface while associating a more angular typeface with the other basic tastes (at least in the Western participants whom they tested). Velasco *et al.* (2018b) subsequently went on to show that the same typeface curvature-to-taste correspondence applied to participants from Colombia and China (i.e., in different languages involving, in the latter case, a different script). Other researchers, meanwhile, have investigated the taste qualities that are associated with the curvilinearity of typeface in the context of food product packaging (de Sousa *et al.*, 2020; Velasco *et al.*, 2014) and even the design of a chalkboard menu for beer (Otterbring *et al.*, 2022; Rolschau *et al.*, 2020).

Here, though, it is important to distinguish the several ways in which curvature might end up biasing people's choice behaviour. At the simplest, there is an association, or taste correspondence. When such shape features are then embedded in food form (such as round or angular chocolate) or plate shape or typeface design, they may bias approach/avoidance and even people's food choice/perception. However, there are a multitude of other factors that may also intervene in such cases, including an individual's taste expectations, their taste preferences and taste experience (possibly giving rise to a 'disconfirmation of expectation' response if the taste expectation and the taste experience do not match up; see Piqueras-Fiszman and Spence, 2015, for a review).

People rate sweet-sour jelly beans as tasting slightly sweeter if presented in a bowl with curvy typeface saying 'Eat me', as compared to eating jelly bean from a bowl with angular typeface instead (Velasco *et al.*, 2018b). Rolschau *et al.* (2020) conducted an intriguing study where they manipulated the angular *versus* curvy typeface on a chalk beer menu. They were able to show that the curvature influenced taste expectations, though the biasing effect on choice behaviour and taste perception was slightly unexpected ('seeing sweet but choosing sour', as the title of their paper put it). In a subsequent study, the same research group went on to show typeface angularity effects on older, but not younger, consumers (Otterbring *et al.*, 2022). Again, why this should be is currently unclear, but the unexpected nature of the results suggests that further research is needed. Indeed, it is important to stress how contrasting round *versus* angular forms (be it of plateware or glassware) has not always been shown to influence people's taste ratings (see Machiels, 2018; Piqueras-Fiszman *et al.*, 2012; Wang *et al.*, 2017a). And, of course, beyond being associated with specific taste qualities, shape properties such as symmetry in product packaging are also associated with various other product properties such as premiumness (e.g., Romeo-Arroyo *et al.*, 2023). Researchers have also documented an association between shape/symmetry and healthfulness (Rosa *et al.*, 2019). All of this to say that in any real-world setting, it is presumably going to be hard to know which of the various associations with shape properties, be it taste, premiumness, naturalness, approachability, or something else will end up being primed in any given situation.

The shape of food itself, as well as the shape of the plateware on which it happens to be presented (Chen *et al.*, 2018; Fairhurst *et al.*, 2015; Stewart and Goss, 2013) have all been shown to bias both people's explicit taste expectations and, on occasion, also their taste experiences (Baptista *et al.*, 2021; Wang *et al.*, 2017a). Researchers have also investigated the impact of shapes presented on/over the plate itself (Huisman *et al.*, 2016; Zhang *et al.*, 2022). Researchers have suggested that staring at angular shapes can bring out the sharpness of foods such as cheddar cheese (Gal *et al.*, 2007; Veffen *et al.*, 2022). Meanwhile, Liang *et al.* (2013) published research a decade ago

demonstrating that participants showed a small, but significant reduction in their threshold for tasting sweetness after being presented with subthreshold visual images that were either rounded or angular. That being said, it is worth noting that people may associate different degrees of curvilinearity with the aroma, taste and mouthfeel/texture of complex foods such as, for example, cheeses (Spence *et al.*, 2013).

5. Conclusions

In recent years, a number of putative explanations have been put forward in order to try and help explain the consensual crossmodal mappings that have been documented between shape and taste/mouthfeel characteristics. Ultimately, while it is still unclear which of these explanations may help to explain the existence of shape–taste correspondences, they are increasingly being incorporated in the design of foodscapes and the built environment. There have also been a number of creative examples of digital content designed to match, and possibly also modify/enhance the tasting experience based on such form–taste correspondences (Cornelio *et al.*, 2022; Velasco *et al.*, 2013; see also Wang *et al.*, 2017b; see Fig. 2), sometimes combined with elements of ‘sonic seasoning’. The latter can be considered another kind of crossmodal correspondence (e.g., Knöferle and Spence, 2012; Wang *et al.*, 2015). Of course, shape features do not occur in isolation: They typically also have colour and possibly also texture. In the years ahead, we will likely see more thorough investigation of the combined influence of shape features with other visual design elements such as colour (e.g., Chen *et al.*, 2020; Spence, 2017; Spence *et al.*, 2014; Velasco *et al.*, 2013) (Note 13).

Ultimately, such research can be seen as taking us beyond the traditional, synaesthetic approach to design (Haverkamp, 2014), and toward a multisensory approach that focuses on the consensual crossmodal correspondences that are shared within a population, and possibly universally (though see Bremner *et al.*, 2013). The growing interest in such cross-sensory phenomena having been predicted a quarter of a century ago by the cultural trend-spotters Meehan *et al.* (1998) when they wrote that the new millennium would bring a “sensory blending of tasting shapes, hearing colors, and seeing smells.” Indeed, it is striking how many multisensory-designed tasting experiences have, over the last decade, started to explicitly incorporate the emerging literature on the crossmodal correspondences between form, colour, etc. and taste/flavour qualities into experiential tasting events/installations (e.g., Birkner, 2016; Glenday, 2017; ‘Guinness VR Immersive taste sensation MPC Creative’, 2017; Hills-Duty, 2017; Kulal, 2021; Monks, 2015; ‘Stella Artois and The Roots stimulate the senses with a one-of-a-kind song you can taste’, 2016; Velasco *et al.*, 2013). At the same time, however, it is intriguing to see how plateware

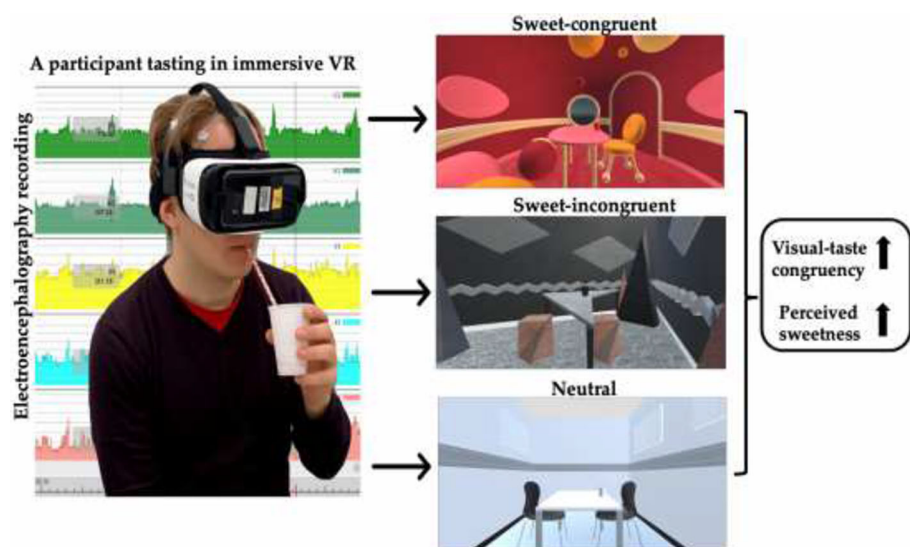


Figure 2. Sweet–congruent, sweet–incongruent (i.e., bitter), and neutral VR environments that were presented to participants in Chen *et al.*’s (2020) studies. The round shapes and pink–red colours of the sweet environment enhanced sweetness as predicted when compared to sweetness in the bitter environment with black and grey colours and angular shapes. Reprinted under Creative Commons CC BY 4.0.

designers and chefs have also been stimulated to create dishes that embody the emerging insights concerning these surprising, yet surprisingly consensual, crossmodal mappings between visual features and taste/flavour attributes (e.g., Hauer-Bain, 2018; Spence, 2022b; Spence and Youssef, 2019; Spence *et al.*, 2015a). The emerging knowledge regarding such crossmodal correspondences are also allowing food and drink marketers to more effectively communicate with the consumer *via* visual communications (Bolognesi and Strik Lievers, 2018a, b; Crisinel and Spence, 2012b; DeRosia, 2008). Looking to the future, it will be intriguing to see whether the emerging 3D food printing technology is harnessed to enable food designers to play with the form of food along the lines suggested by the emerging literature on shape–taste correspondences (Mantihal *et al.*, 2020; see also Callahan, 2014).

Notes

1. The synaesthete studies by Cytowic (1989) suggested that the taste of lemon was “a pointed shape ... it’s like laying my hands on a bed of nails.”
2. One speculative possibility here would be to consider whether bitter-tasting foods might form an important part of the Himba diet. Were this

to be the case, one could imagine how this taste quality might be treated differently than it is in the West.

3. Here, one is reminded of O'Mahony's (1983) study in which associations with basic tastes, including with colours, were taken as evidence regarding the status of sweet, sour, bitter, and salty as basic tastes.
4. Ogle (1870) describes a patient who had lost their sense of smell but was able to distinguish port from claret in terms of what the patient described as a difference in roughness. Meanwhile, Riofrio-Grijalva *et al.* (2020) revealed that sweetness was related to tactile descriptors such as 'smooth' and 'velvety', while sour was more so associated with 'gritty' and 'sharped'.
5. At the same time, however, certain forms may take on a different meaning as a function of the orientation in which they are presented. So, for example, consider only how a curved horizontal line is associated with a smile or frown depending on its orientation with respect to the viewer (Karim *et al.*, 2017; Salgado-Montejo *et al.*, 2015; see also Kühn *et al.*, 2014).
6. It is interesting to consider whether the fact that acids are hydrophilic may help to explain why it is that lemons are rated as fast whereas lipophilic-tasting foods are rated as slow, since the latter are processed more slowly.
7. Aristotle recognized that bitter taste elicits rejection, a feature he ascribed to "its heaviness" (*De Sensu et Sensibilibus*, 4c).
8. Intriguingly, the preference for curvature is not uniquely human (Gómez-Puerto *et al.*, 2016), but has also been documented in great apes (Munar *et al.*, 2015).
9. Of course, playing with the shape of a product and/or its packaging can act as a design innovation strategy (Berkowitz, 1987; Miller, 1994; see also Ghoshal *et al.*, 2016; Parise and Spence, 2012).
10. The shape of the glass has also been shown to influence drinking behaviour (Attwood *et al.*, 2012), though the mechanism is likely to be somewhat different from the shape–taste correspondences discussed in the main text.
11. Though note that shape-based affective priming has also been reported (Wang and Zhang, 2016).
12. In fact, according to Ingrid Lee (2018), author of *Joyful: The Surprising Power of Ordinary Things to Create Extraordinary Happiness*, the reason round forms are appealing is because of their link to the shapes found in nature.

13. It is worth noting that almost a quarter of a century ago, Favre and November (1979) were already combining different colours and shape properties in order to convey taste qualities in their marketing book on the use of colour in communication (see also Matthews *et al.*, 2019; Veflen *et al.*, 2022).

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