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Hedonic mediation of the crossmodal correspondence between taste and shape

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ABSTRACT

Crossmodal correspondences between gustatory (taste), olfactory (smell), and flavour stimuli on the one hand and visual attributes on the other have been extensively documented in recent years. For instance, people have been shown to consistently match specific tastes and flavours to particular visual shapes. That said, further research is still needed in order to clarify how and why such correspondences exist. Here, we report a series of four experiments designed to assess what drives people's matching of visual roundness/angularity to both 'basic' taste names and actual tastants. In Experiment 1, crossmodal correspondences between taste names and abstract shapes were assessed. Next, the results were replicated in a larger online study (Experiment 2). Experiment 3 assessed the role of liking in the association between taste words and morphed shapes along the roundness/angularity dimension. In Experiment 4, basic tastants were mapped to the roundness/angularity dimension, while the mediating role of liking for each taste was assessed. Across the 4 experiments, participants consistently matched sweetness to roundness. What is more, people's liking for a taste (but not their liking for imagined tastes) appeared to influence their shape matching responses. These results are discussed in terms of crossmodal correspondences, and a potential role for hedonics is outlined.

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Introduction

When probed, people will associate tastes with a variety of non-gustatory sensory stimuli (e.g., Knöferle & Spence, 2012; O'Mahony, 1983). In fact, the concept of crossmodal correspondences (e.g., Deroy & Spence, 2013; Spence, 2011, 2012), sometimes referred to as synaesthetic correspondences or synaesthetic associations (e.g., Marks, 1978; Marks & Mulvenna, 2013), has been proposed to describe the fact that people match information across the senses (often in ways that may initially seem surprising – hence the link to synaesthesia). To date, a variety of crossmodal correspondences have been documented between tastes/flavours and information in other sensory modalities (e.g., Spence, 2012; Spence & Deroy, 2013; Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014). Correspondences between tastes/flavours and shapes are particularly intriguing as the same food or ingredient is often presented in various different shapes (or forms), depending on the culinary ingredients, preparation, or packaging.

As highlighted by Spence and Deroy (2013), crossmodal correspondences between flavours and shapes also surface in language, with adjectives such as 'round' and 'sharp' being used to describe certain foods and drinks (e.g., wine). Indeed, roundness and angularity appear to play an important role in these intuitive associations between tastes and shapes (see Spence, 2012), which are not restricted only to the few reported cases of taste/flavour-shape synaesthesia, but also occur in the population at large (see Cytowic, 2003; Spence & Deroy, 2013, for reviews). In point of fact, synaesthetic metaphor, or the emergence of crossmodal metaphor in language (i.e., in phrases such as "a sharp taste" or a "bright sound"), has been reported elsewhere in the literature (e.g., Marks, 2013).

Using the shape stimuli originally outlined by Köhler (1929), Spence and Gallace (2011) reported that certain foodstuffs, such as, for example, sparkling water and Maltesers (a form of honeycomb-centred chocolate confectionary), were associated with angular shapes, whereas others, like Brie (a French cheese) or chocolate-covered caramel, were instead better associated with rounded shapes (see also Ngo, Misra, & Spence, 2011; Obrist et al., 2014; Spence, 2013; Spence & Ngo, 2012; Spence, Ngo, Percival, & Smith, 2013). Similarly, correspondences have also been documented between angularity and bitterness and between

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roundness and sweetness (Spence & Deroy, 2013). Crucially, these correspondences do not only appear under conditions of restricted choice (e.g., when participants are given just two options to choose between, e.g., Deroy & Valentin, 2011).

It appears that some of these correspondences can be observed across cultures, as shown by Ngo et al.'s (2013) study in which it was demonstrated that both in Colombia and the UK sweeter fruit juices were associated with rounder shapes whereas sourer-tasting juices were matched with more angular shapes (though see Bremner et al., 2013, for a cross-cultural study suggesting differences between cultures in the case of people matching chocolate and carbonation to shape, see also Wan et al., 2014a). Importantly, taste/shape crossmodal correspondences can influence human information processing as well, as shown by Liang, Roy, Chen, and Zhang (2013), who reported that rounded shapes, which were rated as more pleasant than other shapes, enhanced sweetness sensitivity (at least at near-threshold levels), whereas angular shapes did not.

Over and above the various correspondences that have been documented to date, it is still an open question as to how and why the roundness/angularity of shapes should be associated in the first place to tastes/flavour, and in particular to basic tastes, (see Spence & Ngo, 2012). One suggestion that has come from the study of crossmodal correspondences involving olfactory stimuli (Kenneth, 1923; Seo et al., 2010) is that participants tend to match pleasant odours to rounder shapes, while matching unpleasant odours to more angular shapes instead (see Hanson-Vaux, Crisinel, & Spence, 2013; also Velasco, Balboa, Marmolejo-Ramos, & Spence, 2014, for hedonic correspondences). A potential explanation for this phenomenon comes from the fact that people generally prefer curved over angular visual objects (e.g., Bar & Neta, 2006). Does this explanation generalise to basic tastes? Since reactions to tastes come with an hedonic component, would the fact that humans react more positively to sweetness and more negatively to bitter tastes (e.g., Steiner, Glaser, Hawilo, & Berridge, 2001) explain their choices of matching shapes? Four experiments were conducted in the present study to systematically investigate the way in which people match basic tastes[1] (names and tastants) to roundness/angularity (Experiments 1–3), and the role of liking in these associations (Experiments 3–4).

Experiment 1

Methods and materials

Twenty-six participants (17 females, mean age = 26.3 years, SD = 6.5) took part in the study. All of the experiments reported here were reviewed and approved by the Central University Research Ethics Committee at the University of Oxford. The participants signed a standard consent form, and the experiment lasted for approximately 5 min.

The experiment was designed and conducted using E-Prime 2.0 software (Psychology Software Tools, Inc.). The participants were seated approximately 60 cm in front of a 17 inch CRT-monitor, with a resolution of 1024 × 768 pixels, and a screen refresh rate of 60 Hz, in a darkened, sound-proofed experimental booth.

The taste words ('bitter', 'salty', 'sour', and 'sweet') were presented on the monitor in Courier New, font size 20. The participants' task consisted of rating those taste names along shape symbolic scales anchored with angular or rounded shapes (see Fig. 1) that have previously been used in various research on crossmodal correspondences between tastes and shapes (e.g., Spence & Deroy, 2013; Spence & Ngo, 2012, for reviews). Each pair of shapes shown in Fig. 1 was used as an anchor for one of the four different visual analogue scales (VAS) ranging from 0 to 100. Pairs A and D were anchored with the rounded shape on the left side and the angular shape on the right, while pairs B and C were anchored with the angular shape on the right and the rounded shape on the left instead. This counterbalancing was incorporated into the design in order to avoid any lateralized anchor position effects. The four taste names were paired with each of the four scales combinations and each pairing was shown twice, giving rise to a total of 32 trials. Trial order was randomised across participants. In every trial, the participants were asked to think of a food that has the taste presented in the trial, and to try to match it to a point on the scale. Analysis of the data was carried out using in SPSS (IBM, Chicago) and R statistical software (R Core Team, 2013).

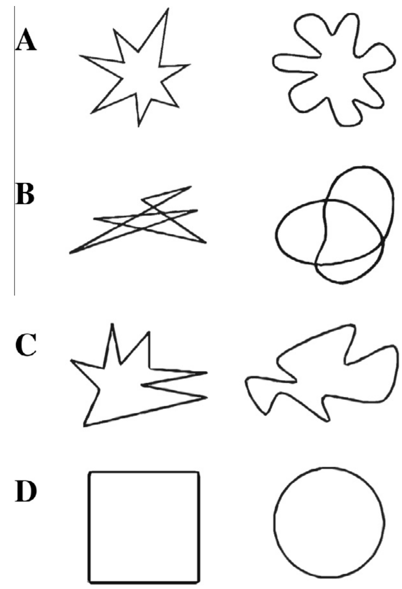

Fig. 1. The four pairs of angular and rounded shapes used as anchors for the different scales in Experiments 1, 2, and 4.

Results and discussion

Preliminary analysis revealed very similar pattern of results for the 4 scales. Consequently, they were collapsed into a broader category of shape roundness/angularity in order to assess any difference in taste-shape correspondences as a function of the taste word under consideration. A one-way repeated measures analysis of variance (RM-ANOVA), using the Greenhouse Geisser correction, revealed a significant effect of taste word, $F(1.857, 46.422) = 17.508$, $p < .001$, $\eta^2_{partial} = .412$. Pairwise comparisons (Bonferroni corrected) revealed that sweet was rated as rounder than any of the other tastes ($p \leqslant .001$, for all comparisons, see Fig. 2A).

In addition, one-sample *t*-tests were performed in order to determine whether the ratings on each taste differed from the mid-point of the scale (50). This analysis revealed that participants rated bitter, $t(25) = 3.711$, $p = .001$, salty, $t(25) = 3.257$, $p = .003$, and sour, $t(25) = 2.921$, $p = .007$, significantly toward the angular end of the scales, and sweet significantly toward the round end of the scales, $t(25) = -5.421$, $p < .001$. These results therefore suggest that rather than there being taste specific associations to roundness/angularity, the correspondence between shape and taste only seems to capture the distinction between sweetness and the other three most commonly mentioned basic tastes (bitter, salty, and sour). In order to confirm and extend this finding, the same design

[1] The ongoing debate as to whether there are 'basic' tastes, and how they should be defined (see Delwiche, 1996; Erickson, 2008), will not be discussed here.

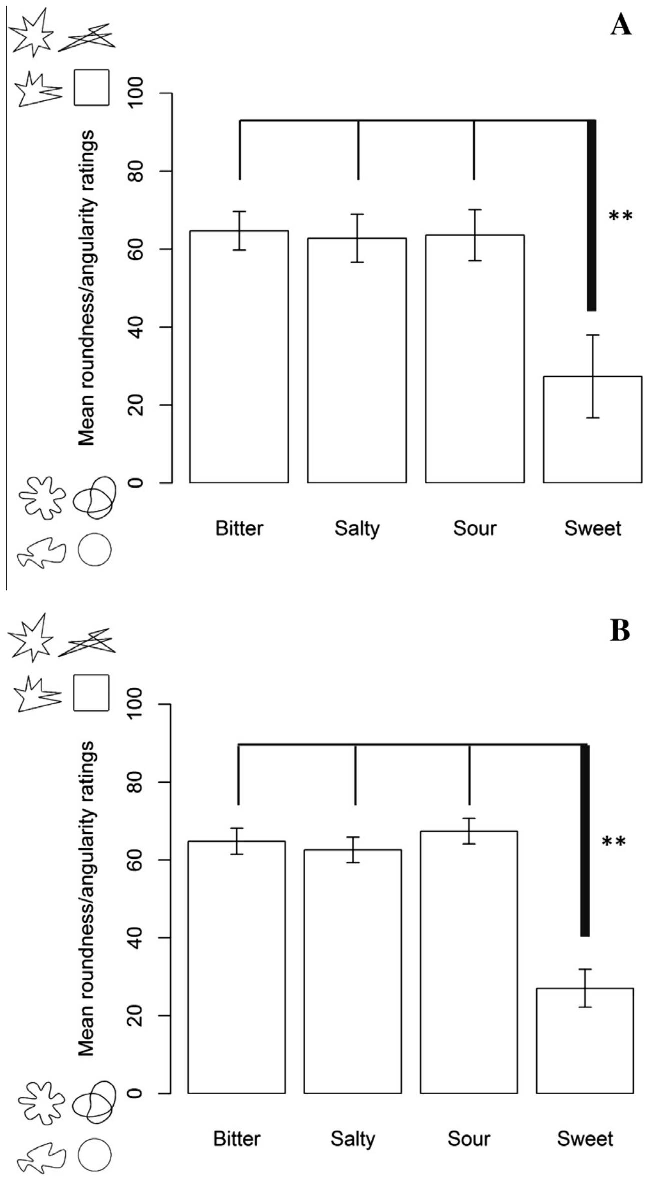

Fig. 2. Mean roundness/angularity ratings for each taste name in Experiments 1 (A) and 2 (B). The thicker line indicates the taste being compared and the asterisks highlight the significantly different ratings for sweet as compared to the other tastes ($p < .001$). The error bars represent 95% confidence intervals.

was implemented in an online study in Experiment 2, thus allowing us to test a larger and more varied sample of participants compared to the Oxford University students used in the first study.[2]

Experiment 2

Methods and materials

One hundred participants (40 females, mean age = 32.84 years, SD = 9.23 years) from the United States took part in the study online through the Adobe Flash based Xperiment software (http://www.xperiment.mobi). All of the participants were recruited using Amazon's Mechanical Turk in exchange for a payment of 1.25 USD and all were based in the USA. All of the participants agreed to take part in the study after reading a standard consent form. The same procedure used in Experiment 1 was also used here.

[2] See Henrich, Heine, and Norenzayan (2010), on the limited scope of research that only tests WEIRD participants from Western, Educated, Industrialized, Rich, and Democratic societies.

Results

The results of Experiment 2 replicate and extend those of Experiment 1. Once again, the ratings across the four scales were collapsed in order to assess any difference in terms of taste-shape correspondences as a function of the taste word under consideration. A one-way RM-ANOVA using the Greenhouse Geisser correction revealed a significant difference between the shape ratings of taste names, $F(2.404, 240.398) = 73.639$, $p < .001$, $\eta^2_{\text{partial}} = .424$. Pairwise comparisons (Bonferroni corrected) were performed and the results revealed that the "sweet" taste word was rated as rounder than any of the other taste names ($p < .001$, for all comparisons, see Fig. 2B).

One-sample *t*-tests revealed that the participants rated bitter, $t(100) = 6.898$, $p < .001$, salty, $t(100) = 6.105$, $p < .001$, and sour, $t(100) = 7.854$, $p < .001$, as significantly toward the angular end of the scales, while sweet was rated as significantly toward the round end of the scales, $t(100) = -11.140$, $p < .001$. As in Experiment 1, it would appear as though people tend to match roundness to sweetness while the other tastes do not differ in terms of their shape associations.

Why would people match shape roundness/angularity to taste names? And why would sweetness be associated with roundness while the other three basic tastes are associated with angularity instead? Previous research has shown that people prefer rounded over angular objects (Bar & Neta, 2006). It may be that the hedonic dimension of shapes can, to a certain extent at least, provide hedonic information which may sway a crossmodal taste-matching decision. In Experiments 3 and 4, the role of taste (words and tastants) and liking in taste-shape associations was assessed. It has been suggested that the hedonic properties of a stimulus can presumably be an important fact in explaining the way in which people form these associations (see Crisinel & Spence, 2012; Spence & Deroy, 2013) not to mention the way in which congruent associations influence information processing (e.g., Liang et al., 2013).

Experiment 3

Methods and materials

Sixty-five participants (14 females, mean age = 28.24 years, SD = 7.51) from the United States took part in the online study, again run with Xperiment. All of participants were recruited using Amazon's Mechanical Turk in exchange for a payment of 0.60 USD.

Two visual roundness/angularity scales were designed based on the results of Experiments 1 and 2. The scales were as follows: A single shape was presented on the screen which could be morphed by the participant dragging their mouse up and down the screen. This was achieved by rapidly moving between a sequence of 100 gradually morphing images. Two pairs of shapes were used as the anchors and 100 images that represented the variation from one anchor (round) to another (angular) were created in order to represent a visual scale of roundness/angularity. Dragging the mouse fully to the bottom/top of the screen morphed the shape entirely into one of the anchor images. To generate a linear sequence of morphed images between the two original images, the original jpg-format images were first converted into vector images using Adobe Illustrator's trace feature, and then these vectors were imported into Adobe Flash Professional CS 5.5. The software's Shape Tween tool was used to morph one image into the other over a series of 100 frames, and then export these frames as still-images (see Fig. 3).

The words "sweet", "sour", "bitter", and "salty" were presented randomly twice, once for each angularity scale. Each trial started with a blank screen with the instructions to hold down the left mouse button (upon which an image for the scale was shown, specific to the mouse location on the screen) and to move the mouse up or down in order to morph the shape. The participants were instructed to press the Space bar on the keyboard in order to continue to the next trial once they were happy with the modified shape. At the end of the experiment, the participants were also presented with a drag-and-drop task, in which they had to arrange each taste word into a box, anchored with "not at all" on the left and "very much" on the right, according to the extent to which they liked the taste.

Results and discussion

The dependent variable was the image number that the participants chose to represent each taste-word. As the images were in sequence of gradually morphing images from an angular to a smooth shape, this number reflects how angular the chosen image was. First, a repeated measure ANOVA with factors scale (2 levels) and taste (4 levels) was performed in order to assess any effect of scale type, taste, or the interaction between scale type and taste. This analysis revealed a significant main effect of taste, $F(2.341, 149.804) = 13.084$, $p < .001$, $\eta^2_{\text{partial}} = .170$, while no effect of scale type or interaction between scale and taste was found. Pairwise comparisons revealed that the participants rated the word sweet as being significantly rounder than the other taste words ($p < .001$, for all comparisons, see Fig. 4A).

Since no effect was found for scale type, both scales were collapsed into one measure of roundness/angularity. One-sample *t*-tests revealed that the participants associated sour with the angular shapes, $t(64) = 3.402$, $p = .001$, while sweet was associated with round shapes, $t(64) = -4.913$, $p < .001$. A borderline significant effect was found for the bitter ($p = .079$), and salty ($p = .066$) tastes. The liking ratings for the taste words were assessed by means of repeated measures ANOVA. The results revealed a significant difference in liking ratings, $F(2.647, 169.399) = 67.641$, $p < .001$, $\eta^2_{\text{partial}} = .514$ (see Fig. 4B). The participants reported liking the sweet taste more than any of the other tastes ($p < .001$, for all comparisons), and salty and sour tastes more than bitter tastes ($p < .001$, for both comparisons). No correlation was found between the participants' liking of the tastes and the roundness/angularity ratings. The results of Experiment 3 replicated and extended those of Experiments 1 and 2. They also demonstrate that people seem to have a stronger preference for sweet and salty tastes, as compared to the other tastes. In addition, this study suggests that, regardless of a shape's identity, varying its roundness/angularity dimension

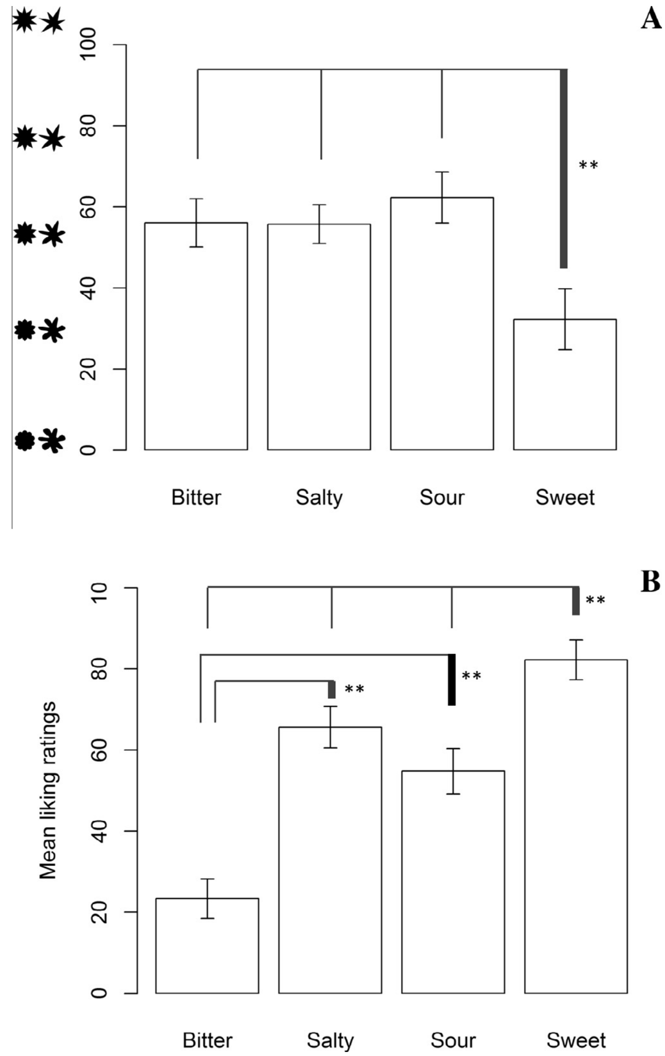

Fig. 4. Mean roundness/angularity (A) and liking (B) ratings for each taste word in Experiment 3. The thicker line indicates the taste being compared and the asterisks highlight the significant different ratings for sweet as compared to the others ($p < .001$). The error bars represent 95% confidence intervals.

can potentially provide similar information to that from a matching task.

Experiments 1–3 relied on taste words rather than real tastants, which has been previously highlighted as a potential limitation in taste research (see Simner, Cuskley, & Kirby, 2010). Certainly, although our participants were instructed to imagine a food with

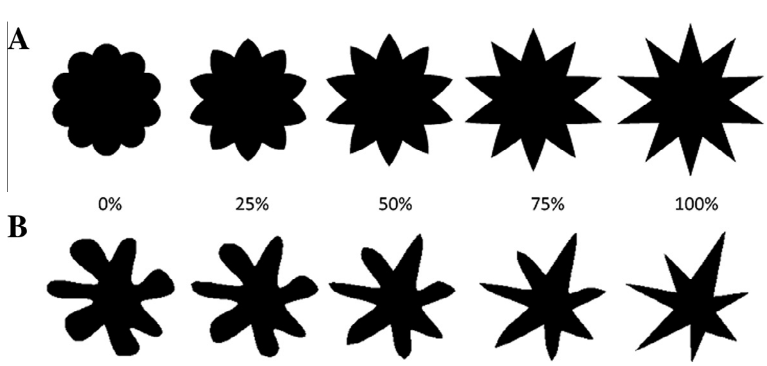

Fig. 3. Two morphed scales (A and B) created for Experiment 3. The figure presents five states of each scale corresponding to 0%, 25%, 50%, 75%, and 100% angularity (0% roundness).

the taste in each trial, taking into account the literature on sound symbolism (Marks, 1978; Parise & Spence, 2012; Sapir, 1929), one may wonder whether the sound of the words themselves may have influenced performance in the matching task. What is more, several studies have reported that people sometimes confuse the different basic tastes (e.g., Hettinger, Gent, Marks, & Frank, 1999; O'Mahony, Goldenberg, Stedmon, & Alford, 1979), which might help to explain why people gave similar roundness/angularity ratings to, for example, bitter and sour words. Although using real tastants may not resolve this issue, at least one can be sure that participants are responding to the actual tastes themselves. Real tastes can also be controlled for in terms of intensity, something that is probably unachievable when working with imagined taste. In Experiment 4, real tastants were therefore used, including the taste of umami, which is widely considered to be the fifth basic taste (e.g., Kawamura & Kare, 1987; Kurihara, 2009; Mouritsen & Styrbaek, 2014).

Experiment 4

Methods and materials

Twenty participants (12 females, mean age = 23.80 years, SD = 5.38) took part in the study through the desktop Adobe Air based version of Xperiment (http://www.xperiment.mobi). Before the experiment participants completed a questionnaire designed to make sure that they did not have any potential sensory dysfunction (visual or gustatory), and signed a standard consent form experiment. Participants were instructed not to wear any fragrances on the day of the sessions and not to have a meal, coffee, or to smoke at least 30 min before the experimental session.

Solutions of the five basic tastes, including sweet (sucrose, 24.00 g/L), sour (citric acid, 1.20 g/L), bitter (caffeine, 0.54 g/L), salty (sodium chloride, 4.00 g/L), and umami (monosodium glutamate, 2.00 g/L), were used and the solutions were prepared in accordance with Hoehl, Schoenberger, and Busch-Stockfisch (2010). Each taste stimulus was prepared as an odourless and colourless solution (distilled water, ReAgent, Runcorn, Cheshire, UK) as specified by ISO 3972. The participants received 20 ml of each stimulus in a 40 ml transparent cup.

The experimental design of Experiment 2 was modified in order to present the 'taste' blocks in a random order. In each taste block, the participants responded to the different shape scales for a particular taste. These scales were randomly presented within each block of trials. In addition to the shape scales, a 100-point VAS for liking, anchored with "not at all" and "very much" (the centre of each stimulus relative to the position on the box was recorded as the liking score), was also included in each block in order to assess the participants' liking for the basic taste solutions. In a final block, participants' liking of the different shapes included in the study was assessed by having participants arrange the stimuli as a function of how much they liked them by dragging and dropping each into a box (from 0 to 100) anchored with 'not at all' and 'very much' on the left and right respectively. Each taste was coded with a three digit number that was visually uninformative to the participants. The codes were as follows: 523 for sweet, 991 for sour, 414 for salty, 346 for umami, and 382 for bitter.

Before the experiment started, the participants were given 20 ml of distilled water to rinse their mouth and then to expectorate into a disposable cup. Next, a taste code appeared on the computer monitor; the participant would tell the number to the experimenter, who then gave the appropriate tastant to the participant. The participants held the tastant in their mouth for approximately five seconds, and then expectorated the liquid into a glass. After responding to the different scales for a particular taste, the participants were then instructed to cleanse their palette again before moving to the next trial.

Results and discussion

A one-way RM-ANOVA, using the Greenhouse Geisser correction, revealed a significant difference between the shape ratings of tastes ($F(4,76) = 6.511$, $p < .001$, $\eta^2_{\text{partial}} = .255$). The results of pairwise comparisons (Bonferroni corrected) revealed that the sweet taste was rated as rounder than any of the other tastes ($p \leqslant .02$, for all comparisons, see Fig. 5A).

One-sample *t*-tests revealed that the only value that differed significantly from the mid-point of the scale was sweet toward the round shapes, $t(19) = -5.283$, $p < .001$. For sour, a borderline significant effect was found, $t(19) = 1.909$, $p < .072$. Once again, the results confirmed that the participants associated sweet tastes with rounded shapes, not only when a taste word is presented but also when responding to an actual tastant. Participants' liking of the tastes was assessed by means of a RM-ANOVA. A significant difference between ratings was found ($F(4,76) = 14.557$, $p < .001$, $\eta^2_{\text{partial}} = .434$). Pairwise comparisons revealed that the participants

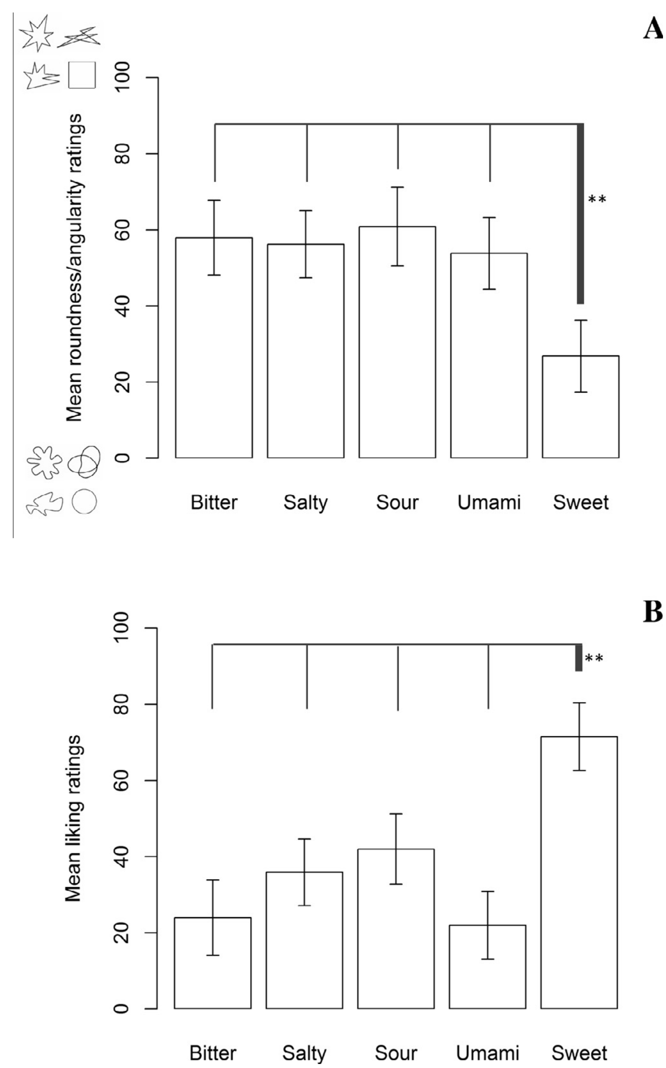

Fig. 5. Mean roundness/angularity (A) and liking (B) ratings for each tastant in Experiment 4. The thicker line indicates the taste being compared and the asterisks highlight the significantly different ratings for sweet as compared to the other tastes ($p \leqslant .02$ for roundness/angularity and $p \leqslant .002$ for liking). The error bars represent 95% confidence intervals.

liked the sweet tastes more than any of the other tastes ($p \leqslant .002$, for all Bonferroni-corrected comparisons, see Fig. 5B).

In order to assess any relationship between participants' roundness/angularity and taste liking ratings, Pearson correlations with one-tailed (a negative correlation was expected, see Hanson-Vaux et al., 2013; Seo et al., 2010) significance tests were performed. A significant negative correlation was observed between taste liking and roundness/angularity for bitter ($r = -.742$, $p < .001$), umami ($r = -.530$, $p = .008$), and sweet ($r = -.632$, $p = .001$). Although the correlations were not significant for salty and sour, a borderline significant trend was found ($p = .075$, and $p = .071$, respectively). These correlations suggest that the more a taste was liked, the more it was associated with one of the rounded shapes, whereas the less a taste was liked, the more it was associated with an angular shape instead. Fig. 6 shows a scatterplot in which roundness/angularity and liking are presented, together with a regression line for each of the tastes, in which the later point is illustrated.

A simple linear regression analysis was used to test whether taste liking predicted roundness/angularity ratings for those tastes in which a significant correlation was found between liking and roundness/angularity. The results of the regression analysis indicated that for bitter, liking explained a significant proportion of the variance, $R^2 = 0.550$, $F(1,19) = 21.986$, $p < .001$. Liking significantly predicted taste roundness/angularity, $\beta = -0.742$. For umami, liking also explained a significant proportion of the variance, $R^2 = 0.281$, $F(1,19) = 7.019$, $p = .016$. Once again, for umami, liking significantly predicted taste roundness/angularity, $\beta = -0.530$. Finally, liking explained a significant proportion of the variance for sweet, $R^2 = 0.400$, $F(1,19) = 11.977$, $p = .003$. Sweet liking significantly predicted taste roundness/angularity, $\beta = -0.632$. Taken together, then, these results provide some of the first evidence in support of the idea that taste liking is an important factor in the crossmodal matching of tastes to shapes.

In order to assess any differences in the angular vs. round shapes, the scores of the task in which the participants rated how much they liked each of the shapes used to anchor the scales, were collapsed. A paired-sample t-test revealed that the participants in Experiment 4 liked the round shapes ($M = 64.18$, SD = 13.49) significantly more than angular shapes ($M = 39.18$, SD = 16.61), $t(19) = 4.132$, $p = .001$, Cohen's $d = 0.92$), thus adding further weight to the claim that people prefer round over angular shapes (Bar & Neta, 2006; Westerman et al., 2012).

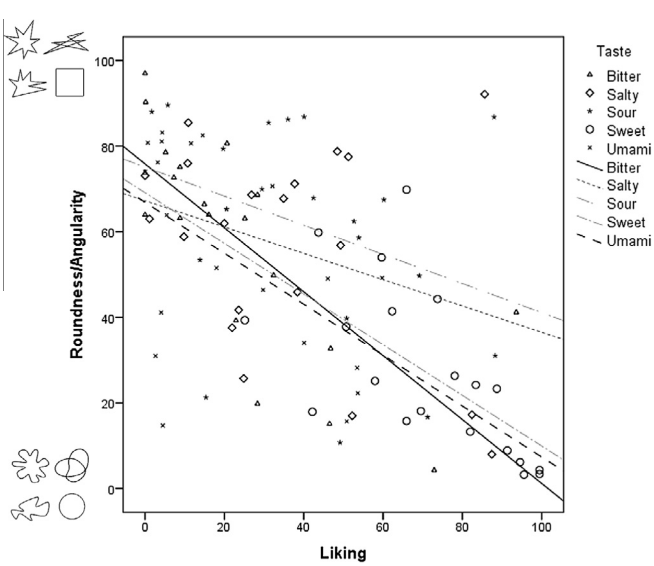

Fig. 6. Scatterplot and regression lines for the liking and roundness/angularity ratings in Experiment 4.

The results of Experiment 4 revealed that the hedonic properties of the stimuli presented in different sensory modalities (e.g., Barbiere, Vidal, & Zellner, 2007; Palmer, Schloss, Xu, & Prado-Leon, 2013) can in fact be extended to the case of correspondences between taste and vision. Experiment 4 provides some of the first empirical evidence to support the idea that taste pleasantness can be an influential factor in the correspondence between shape roundness/angularity and tastants.

General discussion

In the present study, we report four experiments designed to evaluate the crossmodal correspondence between basic tastes and shape roundness/angularity. The results of Experiment 1 demonstrated that people consistently match taste words to shapes. The results demonstrate that there is a distinction between sweetness which was matched to roundness, and other tastes (bitter, salty, and sour) which are matched to angularity instead. Experiment 2 replicated and extended these results in a more varied population with a larger sample size. Experiment 3 replicated the findings of Experiments 1–2 but failed to show any relationship between taste words liking and roundness/angularity ratings. Finally, in Experiment 4, actual tastants (including umami) were used. The results confirmed the match between sweetness and roundness. However, in contrast, no particular crossmodal correspondences were obtained for the other four tastants (bitter, sour, salty, and umami). In addition, these results of Experiment 4 demonstrated that taste liking explains part (28–55%) of the roundness/angularity matchings to tastes.

Spence (2011) presented three (non-mutually exclusive) types of, and mechanisms possibly underlying, crossmodal correspondences: structural, statistical, and semantic (see also Parise & Spence, 2013). In addition, researchers have suggested that the hedonic character of sensory information may explain the way in which people match information across the senses (Collier, 1996; Hartshorene, 1934; Kenneth, 1923; Marks, 1978; Osgood, Suci, & Tannenbaum, 1957). Deroy, Crisinel, and Spence (2013), following a proposal initially made by Kenneth (1923), forwarded an *indirect hypothesis*, which states that stimuli in different sensory modalities may be associated, indirectly, over their common hedonic properties. Whilst certain correspondences such as those between pitch and elevation may be explain by the statistical regularities of the environment (e.g., Parise, Knorre, & Ernst, 2014), it is difficult to think of a statistical explanation for taste/shape correspondences since the same taste may come in a number shapes (e.g., think of sweet and sour fruits, for example). That said, our results lead to the indirect hypothesis in that they demonstrate that the hedonic character of tastes can guide people's associations to shapes, at least, to a certain degree.

Furthermore, tastes and shapes may also share a common meaning. The semantic differential technique which was introduced in the late 1950s suggested that objects are categorized through a number of common dimensions such as good/bad and strong/weak and that information across the senses that are categorized consistently on the same polarity of these dimensions tend to go together (Osgood et al., 1957; Snider & Osgood, 1969). This line of thought has been extended by researchers studying crossmodal correspondences (e.g., Karwoski, Odbert, & Osgood, 1942; Martino & Marks, 2001; Walker, Walker, & Francis, 2012).

Martino and Marks (2001) introduced their semantic coding theory (see also Walker et al., 2012, for another account of common dimensions and connotative meaning) which states that high level mechanisms that connect information across the senses may evolve from developmental experiences with various percepts that are coded into language, which later affects multiple levels of information processing. One possibility here is that an early sensitivity to different associations between sensory information (e.g., Walker et al., 2014) shapes a suprasensory network of meaning (see also Walker, 2012; Woods, Spence, Butcher, & Deroy, 2013). Perhaps, both shapes and tastes are categorized along a (linguistically-related) hedonic dimension, which may explain the way in which people match them.

A number of points are raised by the results of the present study. First, it is important to note that although a subtle variation in terms of the results obtained can be observed when online and lab-based studies are compared, and when the results from taste words and actual tastants are compared, sweetness was consistently matched with rounded shapes. How can the fact that sweetness is consistently matched to rounder shapes and that the other tastes (or taste words) were associated with either angular shapes or neither rounded nor angular be explained? One alternative explanation concerns the fact that people prefer, or have more positive responses, to sweet tastes, as well as to odours and flavours that are associated with sweet tastes (Steiner et al., 2001; Stevenson & Boakes, 2004), which gives it a special hedonic character.

Noticeably, the tastants used here are rarely experienced in isolation and in the format used in the present study. As a consequence, other variables such as taste intensity (think also of other dimensions such as those used by the semantic differential technique) may also play an important role in determining the way in which people match tastes or flavours and shapes. Intensity has been proposed as a key suprasensory (or amodal) feature (e.g., Marks, 1978; Spence, 2011). What is more, the shapes used in the present study were consistently different in the roundness/angularity dimension but other shape features may also be relevant (Palmer, Schloss, & Sammartino, 2013). In particular, while our study provides some of the first evidence pointing to a hedonic mechanism for taste/shape correspondences, future research may include sweet liking as an experimental factor in order to further explore the underlying mechanism.

How to explain the fact that liking predicted some of the roundness/angularity ratings with tastants and not with taste words? Presumably, when people are given taste words, they may think of sweetness in a more general fashion. That is, when given a word such as "sweet" a number of flavours may come to mind, while when presenting an actual tastant, people are directly mapping a specific sensation. An alternative could be related to the different tasks used in Experiments 3 and 4. While in Experiment 3 participants had to arrange the taste words into the box ranging from "not at all" to "very much", in Experiment 4, participants responded to each taste on an independent VAC for liking with the same anchors. An interesting question here is whether liking might be a more fundamental explanation underlying the crossmodal correspondences that have been documented between flavour-taste and shape. As mentioned earlier, it has been documented that carbonated drinks (Spence & Gallace, 2011) and chocolates (Ngo et al., 2011) are associated with angular shapes. Nonetheless, a study in a remote population (the Himba tribe of rural Namibia) did not show an association between carbonation with angularity (Bremner et al., 2013). Is it possible that, when moving from basic tastes to actual foodstuffs, shapes can also take on symbolic meaning (Spence, 2012; Spence & Ngo, 2012, for reviews) that may be shaped by contextual factors such as a culture or even the packaging or branding in which a food is presented (see Velasco et al., 2014; Wan et al., 2014b, for examples in the domain of colour/flavour associations).

In summary, our results demonstrate that, among the basic tastes, sweetness has a special character in that it is consistently matched to round shapes. In addition, we provide evidence for the idea that taste liking predicts, at least in part, people's associations between tastes and shapes (and not taste names and shapes). While our results point to a hedonic mediation (indirect hypothesis) of crossmodal correspondences between tastes and shapes, they also open up a number of interesting questions relating to, for example, other suprasensory dimensions that may contribute to explain the way in which people match tastes to the roundness/angularity dimension of shapes.

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