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Sweet and bitter near-threshold solutions activate cross-modal correspondence between taste and shapes of cups

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Abstract

Recent studies have pointed out some cross-modal correspondences between flavoured beverages, as well as basic taste solutions, and specific geometric visual cues. Some of them associate known drink tastes to shapes of receptacles. In particular, sweetness is associated with curved receptacles and bitterness with sharp-angled ones. Our study aimed to test the hypothesis according to which near-threshold solutions might also activate this cross-modal correspondence. We used two different cup forms, one curved and the other sharp-angled, with pure sweet and bitter solutions just above sensorial thresholds. We designed two tasks using a two-alternative forced-choice test. Participants had to decide which drink was sweeter, Task 1, and bitterer, Task 2, from the curved and sharp-angled cups. Results showed the cross-modal correspondence but only when participants drank first from the curved cup and second from the sharp-angled cup. The effect disappeared when participants drank first from the sharp-angled cup and second from the curved cup. This suggests that the correspondence emerges using sweet and bitter near-threshold solutions in specific conditions. On the other hand, results also showed that confidence level of responses was significantly higher in the bitter task than in the sweet task. We discuss these complex results in the light of different theoretical proposals to explain this cross-modal correspondence.

Keywords: taste, shape, cross-modal correspondence, drinking receptacle, glass shape, beverage, multisensory interaction

1 Introduction

Taste perception contributes to the multisensory experience of flavour (Slocombe, Carmichael, & Simner, 2016; Zampini, Sanabria, Phillips, & Spence, 2007). Visual cues influence taste perception (Huisman, Bruijnes, & Heylen, 2016). Shape is an important visual feature that influences tasting experiences (Carvalho & Spence, 2018; Cavazzana, Larsson, Hoffmann, Hummel, & Haehner, 2017). Wang, Carvalho, Persoone and Spence (2017) found that round chocolates were expected to be sweeter, less bitter and creamier than angular-shaped chocolates. However, when it came to the post-taste chocolate ratings, there were no significant differences between shapes. Velasco, Hyndman and Spence (2018) showed that round typefaces enhanced sweetness and angular typefaces enhanced sourness. Velasco, Woods, Marks, Cheok and Spence (2016) suggested that tastes and shapes shared a semantic space, characterized by the intensity and hedonic value dimensions. They found an implicit association between the word “sweet” with round shapes, and the words “bitter”, “salty”, and “sour” with angular shapes. They also found that these taste/shape correspondences produced congruence effects even in the absence of a tastant.

We are interested in the influence of curved and sharp-angled drinking receptacles on taste perception. Spence and Van Doorn (2017) suggested that the shape properties of a vessel could prime certain expectations in the drinker. This priming would accentuate certain aspects of the tasting experience, likely as a result of the attention focused on the attributes that would have been subtly primed. Cavazzana et al. (2017) found that cola drink was rated as sweeter from a cola glass (more curved) than from a typical water glass (straight). Van Rompay, Finger, Saakes and Fenko (2017) showed that a cup with a sharp-angled surface increased perceived bitterness in coffee, whereas a cup with curved surface induced a sweeter taste in hot chocolate. Using beers, Deroy and Valentin (2011) found correspondence between sweetness, voluminousness, and roundness, and between bitterness, thinness, and angular shapes.

These findings suggest cross-modal correspondence between the shape of vessels and taste attributes. According to Velasco et al. (2018), we associate the preferred basic visual shape features with sweetness, whereas the less-preferred visual shape features are associated with bitterness. In general, curved shapes are preferred to sharp-angled shapes (Gómez-Puerto, Munar, & Nadal, 2016). Moreover, we implicitly associate curvature with positive valence and sharpness with negative valence (Palumbo, Ruta, & Bertamini, 2015). These associations might explain cross-modal correspondence between sweet taste and curved cups, and bitter taste and sharp-angled cups.

However, Machiels (2018) only partially corroborated these cross-modal correspondences. He used two hard transparent cups, one sharp-angled and the other curved. In Study 1,

participants assessed the perceived sweetness and bitterness of a strawberry-flavoured milk drink. Results did not show any difference between cups in sweetness or bitterness. In Study 2, participants tasted a caffeinated soft drink. No difference emerged regarding sweetness, but the taste from the curved cup was perceived as being less bitter than the taste from the sharp-angled cup.

According to Machiels (2018), two possibilities can account for his results in relation to the previous literature: (a) the specific receptacles (curved or sharp-angled) could be insufficient to induce expectations for sweetness or bitterness; (b) some beverage categories may be suitable to cause cross-modal effects and others may not. Most studies explored these cross-modal effects using known or categorical drinks such as cola (Cavazzana et al., 2017), beer (Deroy & Valentin, 2011; Mirabito et al., 2017), wine (Heatherly, Dein, Munafo, & Luckett, 2019), coffee and hot chocolate (van Rompay et al., 2017), and juice (Ngo et al., 2013), among others. Therefore, cross-modality effects between curved/angular shapes and sweet/bitter tastes might exist only for specific drinks or they might emerge regardless of the drink category.

Liang, Roy, Chen and Zhang (2013) measured the sweetness threshold using six sugar concentrations (0, 1.5, 3.1, 3.9, 4.7 and 5.5 g/L). They tested whether visual inputs affected sweet taste sensitivity in Chinese and Indian participants (Liang et al., 2016). Overall, they found that curved shapes and semantic familiar words increased sweet sensitivity. However, their experimental design only included sweet solutions, and they were presented in curved paper cups.

The cross-modal correspondence between shape and taste perception with pure solutions is unclear and a bit unexplored. The present study intended to examine this issue partially. We used near-threshold solutions in order to avoid effects from intensity and saturation. We designed an experiment using curved and sharp-angled cups with sweet and bitter near-threshold solutions that do not belong to any categorical drink (cola, coffee, hot chocolate, or others). The drinks were presented in two tasks: a sweet task and a bitter task. The two drinks were exactly the same in each task. Participants decided which drink was sweeter or bitterer from the curved or the sharp-angled cups. If the results showed the expected cross-modal effects, we would conclude that they do not depend on the beverage category. On the contrary, if the results showed no effect, we would conclude—in accordance with previous studies—that they depend on usual categories.

2 Materials and Method

2.1 Participants

With the aim of obtaining a statistical power of .95, an α error of .05 and a medium effect size based on previous findings, we calculated a sample size of 63 participants. This way, 66 participants (41 females, mean age = 25.8, range from 18 to 65 years, 13 smokers) took part after giving their informed consent. Smoker participants were asked not to smoke for at least 2 hours before the experiment. All of them were asked not to eat or drink one hour before the

experiment. The experiment received approval by the Ethics Committee of the University of the Balearic Islands and was conducted in accordance with the Declaration of Helsinki (2008).

2.2 Materials

We used two small transparent polystyrene cups: the same curved cup used in Machiels (2018) (height: 3 cm., diameter: 7.2 cm., weight: 9 g., capacity: 65 ml) and a sharp-angled cup (height: 4.5 cm., distance between angles: 5.5 cm., weight: 14 g., capacity: 65 ml.) (<https://osf.io/exnsq/>). The identical volume capacity of both cups makes them look quite similar in their visual apparent size despite the difference in height. We equalled the solution levels of the two cups in each trial in order to reinforce the perceived similarity between containers. The difference in weight was practically unnoticeable.

In a pre-test, two of the authors took part in the first experimental essays, one of them tasting and ignoring the solutions prepared by the other. We followed the general procedure in Hoehl, Schoenberger and Busch-Stockfisch (2010) to prepare the sucrose and caffeine solutions. We also utilized the recognition taste results from Velasco, Woods, Deroy and Spence (2015) when spring water was used as reference to prepare the initial sucrose and caffeine concentrations. Concentrations were diluted in bottled water (Font d'Or, Catalonia, Spain), and sucrose and caffeine were weighed with a precision scale (Compact Balances^{TM}, series JT, Model 600C). After these first and rather informal trials that took place several times a day for a week, both authors agreed that the lowest concentrations that they recognized were 1.3 g/L for sucrose and 0.27 g/L for caffeine. Both values were above the taste threshold recognition level in spring water for sweetness and bitterness (Hoehl et al., 2010).

Using those concentrations as initial references of distinguishable basic tastes, we proceeded to the pilot test with 8 participants (4 women), no one being familiar with taste sensitivity experiments. Seven of them did not discriminate the concentrations indicated above at the first informal test. Thus, we gradually increased the amounts of sucrose and caffeine in the solutions until they could detect the basic tastes. Following Hoehl's procedure, we tested solutions for sucrose at 2, 3, 4, and 5 g/L, and for caffeine at 0.5, 0.75, 1, and 1.2 g/L. The trials were conducted separately. The time between a trial and the next one was an hour. The sweet and bitter trials were counterbalanced. Participants had a response sheet to answer if they perceived the tastant or not (Y/N) and, if they answered yes, which tastant they perceived (free answer). Later, they had to place an X on a visual scale (7 cm long). The poles of the scale indicated: "smooth intensity of tastant" (left) and "tastant too saturated" (right). Participants were instructed to seek the concentration they could detect easily but was not too intense. We selected concentrations to which 100% of the sample responded "yes" for the first question, adequately described the tastant (sweet for the sucrose and bitter for the caffeine) and the response on the rating scale was around the midpoint (from 3.25 to 3.75 cm from the left). This resulted in the following values: 5 g/L for sucrose and 1.2 g/L for caffeine. The experimental solutions were prepared and bought from a professional chemist laboratory (Pharmacy Colom, Palma, Spain).

2.3 Procedure

The hypothesis was that the visual contour of the cups could influence the perceptual attributes of sweetness and bitterness. We used a paired comparison test or 2-alternative forced choice (2AFC) test. This is described by ISO standard (ISO 5495-1983) for determining whether there is any perceptible sensory difference between two samples concerning a sensory attribute. In fact, the paired comparison test is a forced-choice test between two alternatives.

In a quiet and well-ventilated room (20-25 C°), participants were seated in front of a table, with two cups placed in row. On the right-hand side, they had the response sheet, a glass of water to rinse their mouth, and a spittoon. The cups and solutions were prepared on another table behind an opaque screen. Both cups were filled with the same amount of drink (30 ml). The experiment consisted of a “sweet task” and a “bitter task”. In each trial, participants chose the solution that tasted sweeter or bitterer, depending on the task. The instructions were:

Please, take the first cup and take a large sip without swallowing it. Keep the liquid in your mouth for 5 seconds, passing it slowly over the whole tongue, while holding the glass in your hand. Afterwards, spit out the liquid here (indicating the spittoon). Rinse your mouth with water and spit again. Afterwards, take the second cup and repeat the procedure: keep the liquid in your mouth for 5 seconds, passing it slowly over the whole tongue, while holding the glass in your hand. Spit out the liquid in the spittoon and rinse your mouth again. You have to tell us which solution is sweeter (or bitterer), the first or the second one. Put an X on the response sheet. It may be difficult to assess the difference, as sometimes it is subtle. After making your choice, rate your confidence in your response, with 1 standing for “I am not at all sure”, and 7 standing for “I am absolutely sure”.

Three conditions, one experimental and two distracting conditions, were created for the “sweet task”, and three conditions, one experimental and two distracting conditions, were also created for the “bitter task.” In the experimental condition (8 trials), participants chose between the curved and the sharp-angled cups, indicating which one tasted sweeter (or bitterer). In the distracting conditions, they chose either between two curved cups or two sharp-angled cups (4 trials for each). The distracting conditions aimed to minimize participant attention to the relationship between cup shapes and tastes. In all conditions, the solutions were the same concentration for both cups. Participants carried out 32 trials, 16 for the sweet task and 16 for the bitter one. Sweet and bitter, curved and sharp-angled, distracting and experimental conditions were counterbalanced.

3 Results

As the distracting trials were not the objective of the study, we mainly analysed the experimental ones. All data and codes required for the valuation and reproduction of the

results have been made available online at Open Science Framework (<https://osf.io/exnsq/>).

We analysed the selection of the cup by dichotomous responses (curved or sharp-angled cup) with generalized linear mixed effects models. Analyses were carried out within the R environment for statistical computing. We used the *mixed()* function of the *afex* package (Singmann, Bolker, Westfall, & Aust, 2016), with likelihood ratio tests to produce the inferential statistics and *p-values*. *lsmeans()* from the *lsmeans* package (Lenth, 2016) was used to create the predicted means for fixed factors.

As our hypothesis indicated that the selection of the sharp-angled cup would depend on the task, we used type of task as fixed effects factor, and participant as random effects factor. Results showed effect of the task on the probability of choosing the sharp-angled cup, $\chi^2(1) = 3.93, p = .05$.

However, we observed that participants selected the second cup (.61) considerably more than the first one (.39). This higher proportion of the sequence position was similar in the distractor trials, .62 with the second cup and .38 with the first cup. For this reason, we additionally carried out an exploratory analysis with a second model, including the interaction Task by Sequence of the cups as predictor. The interaction also showed a significant effect, $\chi^2(1) = 59.3, p < .001$. This significance is illustrated in Figure 1. Post hoc tests (Odds Ratio) with Tukey adjustments revealed a significant difference between choosing the sharp-angled cup in the sweet task and choosing it in the bitter task when the sharp-angled cup was the second, $OR = 1.81, SE = 0.32, z = 3.284, p < .001$. However, there was no difference between the two tasks when the sharp-angled cup was the first one, $OR = 0.91, SE = 1.63, z = 0.5, p = .96$. On the other hand, we also found significant difference between choosing the curved cup in the sweet task and choosing it in the bitter task when the curved cup was the first, despite both values were below .5 – $OR=0.55, SE=0.1, z=3.284, p=.003$. However, there was no difference between the two tasks when the curved cup was the second, $OR=1.06, SE=1.96, z=0.5, p=.62$. With this experimental design, we cannot know what drives the effect: the curved/sweet correspondence, the sharp-angled/bitter correspondence, or both.

Figure 1

A model was built to predict confidence based on fixed effects factors of Response (curved or sharp-angled) and Task, and their interaction. Participant was also used as random effects factor. The interaction, $\chi^2(1) = 0.39, p = .53$, did not show significant effects. Surprisingly, the Task factor showed a significant effect, $\chi^2(1) = 66.01, p < .001$. Participants showed higher confidence in their decisions when the task was about bitterness ($M = 4.58$) than about sweetness ($M = 3.88$), regardless of the response (Figure 2). On the other hand, the main effect of response was non-significant, $\chi^2(1) = 3.07, p = .08$, but the rates were non-significantly higher when participants chose the sharp-angled cup (4.27) instead of the curved one (4.1).

In order to verify the possibility that the results of confidence had something to do with the previous results about Sequence, we carried out a new model adding the interaction of this

factor with the other two: Task and Response. Only the interaction Sequence by Response showed significant results, $\chi^2(1) = 12.31, p < .001$. Participants were more confident when they chose the second cup than when they chose the first one. This way, participants were more confident about the curved cup when it was the second in the sequence ($M = 4.31$) than it was the first one ($M = 3.89$), and they were more confident about the sharp-angled cup when it was also the second in the sequence ($M = 4.42$) than it was the first one ($M = 4.13$)

Figure 2

4 Discussion

We tested the possibility that the shape of a cup influences the sweetness and bitterness perception of near-threshold solutions, using a direct comparison between containers. By near-threshold sweet or bitter solutions, we refer to a drink that does not belong to any usually known category: water, cola, coffee, wine, soft drink, among others. Participants tasted drinks from two cups, one curved and the other sharp-angled. They had to decide which was sweeter (Task 1) or bitterer (Task 2). The two drinks were the same in each task. In the analysis, we compared the answers to the two tasks to determine whether participants change their selection from one task to the other. We did not compare between vessels because the characteristics of the cups could lead to a systematic selection of one of them, regardless of the task.

Participants chose the sharp cup significantly more in the bitter task than in the sweet task in a specific condition but not in the other. The specific condition was when the first cup was curved and the second was sharp-angled. The cross-modal effect did not appear when the first cup was the sharp-angled one.

Additionally, the results showed a recency effect whereby participants chose the second cup more than the first one, regardless of the task, cup and type of trial, distractor or experimental trial. Daniel and Katz (2017) also observed a recency effect with different drinks. They found that the last liquid that participants had tasted was more recognizable with short delays between stimuli. In our experiment, the second cup may have been chosen more than the first one due to better recognition of the sweet or bitter taste in the second cup. This is also consistent with our results about the greater confidence when participants selected the second cup.

The results also showed a significant interaction between the cross-modal effect and the sequence of the cups. The combination of the recency effect and consumer preference for curved contours (da Rosa, Spence, & Tonetto, 2018) might lead to one of the possible explanations of that interaction between the cross-modal effect and the sequence of the cups. The explanation is based on the idea that the cross-modal effect would occur in both sequence conditions. However, it would be cancelled as a result of the combination of the recency effect and consumer preference for curved contours (da Rosa et al., 2018) in the condition in which the sharp-angled cup was the first. This means that the curved cup would be chosen the same number of trials in the sweet task as in the bitter task as a consequence of the two

mentioned effects counteracting the cross-modal effect. Conversely, when the curved cup was the first, the recency effect was on the sharp-angled cup, likely counteracting only the effect of preference for curvature and allowing the emergence of the cross-modal effect. However, this hypothetical explanation requires further research.

This way, in specific conditions, results showed a significant modification in taste perception modulated by the contour of the cup. They partially agree with the reported cross-modal correspondences (Cavazzana et al., 2017; Deroy & Valentin, 2011; Spence & Van Doorn, 2017; Velasco et al., 2015; Velasco, Woods, Petit, Cheok, & Spence, 2016) between curved shapes and sweet tastes (Fairhurst, Pritchard, Ospina, & Deroy, 2015; Salgado-Montejo et al., 2015; van Rompay et al., 2017), and sharp-angled shapes and bitter tastes (Cavazzana et al., 2017; Machiels, 2018).

Other studies failed to find evidence for the mentioned correspondences. Using strawberry mousse, Piqueras-Fiszman, Alcaide, Roura and Spence (2012) showed that the effect of plate (round vs. square) did not reach significance in sweetness. Bremner et al. (2012) found that the Himba tribe tended to match milk chocolate samples with sharp-angled rather than with curved shapes, contrary to Westerners. Mirabito et al. (2017), using beer with curved and straight glasses, did not find shape effects on sweetness, but they did so on fruitiness. Machiels (2018) failed to find correspondence between curved shapes and sweet tastes, using a strawberry drink and a caffeinated soft drink. However, he found a correspondence between sharp-angled cup and a bitterer taste for the soft drink.

Therefore, we need an explanation about why a cup's shape induces sweetness or bitterness taste in near-threshold concentrations and why this does not happen in specific conditions (Machiels, 2018; Mirabito et al., 2017), like our results with the sharp-curved sequence. The undertaking is not easy. Several non-mutually exclusive explanations have been proposed to explain this kind of cross-modal correspondences. Martino and Marks (2001) stated that high level mechanisms might connect information across sensory systems that evolve from developmental experiences with percepts that are coded into language, which affects different levels of information processing. Deroy and Valentin (2011) suggested that perceptual correspondence, rather than purely linguistic association, underlies the correspondence between shapes and tastes. According to Velasco et al. (2015), some researchers have suggested that the hedonic nature of sensory information may explain the way in which people match information across the senses or, in other words, stimuli in different sensory modalities may be associated by their common hedonic properties. In this line, liking might be a more fundamental explanation underlying the correspondences between taste and shape. Other studies have suggested that people match shape dimensions with tastes on the basis of their common affective connotations (Salgado-Montejo et al., 2015; Velasco, Salgado-Montejo et al., 2016). Van Rompay et al. (2017) proposed that these kinds of relationships might be grounded in embodied physical interaction with objects. Finally, Spence and Van Doorn (2017) proposed that the shape of the drinking receptacle could prime certain expectations in the drinker.

The fact that the correspondence we found was between near-threshold sweet and bitter drinks –without any previous experience with the drinks and containers– in a direct comparison between vessels supports proposals similar to a low-level perceptual correspondence (Deroy & Valentin, 2011) or an embodied explanation (van Rompay et al., 2017), and seems a disadvantage for the idea that those cross-modal correspondences require the involvement of language (Martino & Marks, 2001). However, the results that correspondences did not appear in the sharp-curved sequence indicates that they are not so strong as to be supported by a low-level perceptual relationship or an embodied explanation. In our opinion, they could be better supported by the idea of a priming effect (Spence & Van Doorn, 2017) that works in specific situations. However, we already mentioned that the combination of the recency effect and the preference for curvature could explain those negative results of the correspondence.

An interesting final result to highlight was related to the degree of participants' confidence in their judgments depending on taste, significantly higher when they tested bitter solutions. To our knowledge, such an intriguing effect has not been noticed in previous research on taste and flavour topics, and probably has to do with the function of bitterness as signal of potential toxicity of edible products. In any case, this evolutionary hypothesis merits further research.

However, we highlight a couple of possible limitations associated with our experimental procedure and results. First, the pre-test to match the perceived intensity of the sweet and bitter near-threshold solutions was based on a small sample of participants. Second, the apparent recency effect whereby participants selected the second cup more frequently in the sequence shows that an alternative forced choice task is not the best test to reveal the potential cross-modal correspondence between the shape of the drink receptacle and the basic taste. In our results, this possible correspondence seems to be masked by the recency effect. Third, the weak evidence of the sharp-bitter and curved-sweet correspondences with drinks we found was only using near-threshold solutions. It is possible that other kinds of effect appear with saturated solutions.

5 Conclusions

We found cross-modal correspondence between sharp-angled and curved cups, and bitter and sweet tastes with near-threshold sweet and bitter solutions in specific conditions. As far as we know, it is the first study that reveals the mentioned correspondence conveyed by the cup shapes with near-threshold sweet and bitter drinks. In our procedure, taste and shape were linking in the same “sensory consumption”, interacting taste, visual, and haptic perception. Liang et al. (2013) showed the correspondence with different visual shapes in a screen, separated from the cups (only curved) and drinks. According to our results, it seems that this correspondence is easily masked by other phenomena, like the recency effect and the preference for curvature. In our opinion, it indicates that it is not a strong effect. We think that the correspondence is only noticed in very specific conditions or in favourable combinations with other effects, as perceptual preferences or memory effects. Nonetheless, it is very interesting to know where it comes from, either from an evolutionary origin or from a more

associative perspective. If we knew more about it, we might make the correspondence more evident.

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Figure 1. Estimated probability of choosing the sharp-angled cup depending on the task (sweet or bitter) and position of the cup.

Figure 2. Confidence probability depending on the task and the response (curved or sharp cup).