A Moving Feast: Effects of Color, Shape and Animation on Taste Associations and Taste Perceptions

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ABSTRACT
Research into multimodal flavor perceptions has demonstrated associations between basic tastes and visual cues. Moreover, such associations have been found to influence taste perception. Here we are interested in how mixed reality technology in the form of projection mapping can be used to introduce such visual cues during consumption. First, associations between basic tastes and visualizations that differed in color, shape and animation speed were investigated in a crowdsourcing study. The study demonstrated associations between sweetness and red rounded shapes, and sourness and green angular shapes with a fast animation speed. A subsequent lab study where the visualizations were projected around a cup of yogurt that participants tasted confirmed these associations. Finally, specific combinations of visualizations and animation types were found to influence taste perceptions of the yogurt. The implications of these findings are discussed.

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H.5.1. Information Interfaces and Presentation (e.g. HCI): Artificial, augmented, and virtual realities

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Taste; Flavor; Mixed reality technology; Multimodal perception; Projection mapping

INTRODUCTION
Many of the tenets of modernist cuisine found in Michelin-star studded restaurants around the globe were pioneered by the Italian futurist movement. A manifesto entitled the Futurist Cookbook [33] presented a view on food that abolished pasta (!) and argued for the presentation of food as a work of art. The involvement of all the senses, not just the detection of basic tastes with the tongue, was a central innovation of the Futurist Cookbook. Scientific support for these at the time radical ideas has now been steadily building. The perception of flavor is now indeed thought to be multimodal, with all of the five senses contributing to the overall perception of flavor [5, 12, 54, 60]. While all the senses contribute to the perception of flavor we 'eat with our eyes first' [13], and visual impressions of food drive expectations of what the food will taste like, and can influence the actual taste [13, 32, 65]. For these reasons, it is important to consider the visual appearance of food items, not in the least because visual stimuli are relevant for the presentation of food in the form of plating [37], packaging [6, 43], and advertising [64].

Where the Italian futurists were inspired by technical innovations of the time [33], so too are current digital technologies inspiring the creation of food experiences that were not possible before [19, 58]. The influence of technology on the visual presentation of food and on the experience of food consumption becomes only too apparent when thinking of the use of smartphones to record, and share on Instagram [25], every meal. Considering the combination of food and technology, the use of mixed reality technology, technology that introduces digital elements into the real world [42], is especially promising because it allows for digital visual cues to be presented in combination with actual food items. The use of digital visual cues could allow for visual enhancements of food items in order to make them look more appealing, tasteful, or interesting [57].

Here we are interested in the use of mixed reality technology, particularly projection mapping, to introduce digital visual cues in the presentation of food. Projection mapping, a technique where projections are adjust to the area of projection, can be used to alter the color of a food item, and the color and shape of the setting in which the food item is presented [57]. Moreover, a unique aspect of projecting digital visual cues on top of and around food items, is that such visual cues can be animated (i.e. can visualize motion). Studies suggest that there are associations between specific flavors and speed of motion (e.g. fast lemons, slow prunes [63]). Thus, it might be possible to trigger such associations through the use of animated visual cues. Furthermore, musical compositions that are associated with certain specific basic tastes, use parameters such as musical articulation (short and strongly divided notes, or smooth connected notes) [30, 61]. For example, musical improvisations associated with sweet taste are characterized by slow motions, that possibly conjure up images of the viscosity and stickiness of honey [35]. Given these associations,

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it is plausible that the animation speed of projected visual cues can be associated with certain tastes.

In this paper we will present two studies in which we investigate the influence of visual cues on taste associations and taste perception. A crowdsourcing study served to investigate associations between visualizations and basic tastes. Stimuli from the crowdsourcing study were later used in a study where participants sampled two different yogurts presented with static and animated projections on top of and around the yogurt.

RELATED WORK

Multimodal flavor perception

It is possible to distinguish between the senses on the basis of the type of physical stimulation that they are sensitive to [8]. The sense of touch is sensitive to forces exerted on the skin, the auditory sense to sound waves, the visual sense to light, and the sense of smell to molecules in the air [8]. While often the senses are studied in isolation, most of what is experienced in the real world involves more than one sense, if not all the senses simultaneously [5, 8, 11]. Being able to draw information from multimodal inputs about the same object or event has the advantage of enhanced speed and accuracy of identification of objects [8, 60]. Both humans and animals make use of this kind of intermodal redundancy when data from one sensory modality can influence the interpretation of data from another sensory modality in a process called crossmodal integration [8]. Important to the current investigation is that such crossmodal integration can result in coherent perception.

The perception of flavor is a prime example of multimodal perception where crossmodal integration plays a central role [5]. The International Standards Organization (ISO) defines flavor as a "complex combination of the olfactory, gustatory and trigeminal sensations perceived during tasting. Flavor may be influenced by tactile, thermal, painful and/or kinaesthesic effects" [3]. In accordance with this definition it is only the (retro-nasal) olfactory, gustatory, trigeminal, and oral-somatosensory senses that contribute directly to the perception of flavor [4, 53]. Some argue that this definition of flavor is too narrow and make a case for distinguishing between interoceptive and exteroceptive flavor senses [53]. Interoceptive flavor senses are those that are activated during the consumption of food and are the same as those listed in the ISO definition, with the addition of the auditory sense (i.e. sounds while chewing food). The exteroceptive flavor senses are distal senses, activated prior to consumption, and influence flavor in an indirect way by shaping expectations. Vision, orthonasal olfaction, and audition are typically considered exteroceptive flavor senses [53]. Recent research has found that proprioceptive and tactile feedback of, for example, cutlery can also influence flavor perceptions [23], thus perhaps the sense of touch should also be considered a exteroceptive flavor sense in this regard.

Finally, it is argued by some that flavor perception should be considered a perceptual modality rather than a sensory modality [5]. This means that flavor does not arise from sensations detected by individual senses, but from perceptual information from multiple senses, including auditory and visual [5]. This view reserves a larger role for exteroceptive senses in the perception of flavor. For the present investigation we will now turn to the visual modality specifically, and will outline how visual stimuli influence flavor perceptions.

Visual 'flavor'

Research indicates that visual cues contribute strongly to expectations about taste and taste perception during consumption [18, 26, 45, 50, 55]. There are many types of visual cues, related to both the food itself and the broader environment it is served in, that can influence taste perception. Such visual cues include the color of the food [18], the color [22] and shape [44] of the plate it is served on, and the orientation of the food on the plate [36, 37].

Color has been found to be important for the identification of the flavor of a food item [18]. Characteristic color, such as a strawberry flavored drink colored red, aids identification of the flavor, while a non-characteristic color, for example a blue colored strawberry flavored drink, makes identification more difficult [18, 65, 66].

Visual cues can not only aid or hamper identification of a food item's flavor, it can also alter the intensity of a perceived taste or flavor [56]. For example in an experiment in which differently colored yogurts (i.e. pink or white) were sampled from differently colored spoons (i.e. red, green, blue, black, and white), it was found that pink yogurt sampled from a blue spoon tasted more salty than when white yogurt was sampled from the same spoon [23]. Moreover, both colors of yogurt were perceived as less sweet when sampled from a black spoon compared to a white spoon [23]. Similar effects have also been obtained for sampling a red strawberry-flavored mouse from either a white or black plate. The mouse sampled from the white plate was perceived as having a more intense and sweet taste than when sampled form the black plate [44]. Similarly, sweet popcorn is perceived as saltier when eaten from a white bowl compared to a blue bowl, while salty popcorn is perceived as sweeter when eaten from a red bowl compared to a white bowl [22].

It is likely that implicit associations between colors, and tastes and flavors moderate the effects reported above [32, 50, 52]. Visual cues can shape taste and flavor expectations, as there are consistent associations between colors and shapes on the one hand, and tastes and flavors the other [50]. Such associations are also highly relevant in, for example, food packaging design [6, 43]. Indeed in the yogurt study reported above [23] it was hypothesized that because salty snacks are often packaged in blue packaging, and consumers might expect saltiness when seeing white food on a blue background, the fact that this expectation was not met in the study might have made participants rate white yogurt from a blue spoon as less salty [23]. In another study participants from the United Kingdom and Taiwan were presented with differently colored beverages and were asked to judged, based on the color of the beverage alone, what flavor it would have [50]. Orange, yellow, blue, and brown beverages were judged differently by participants from the UK and Taiwan, but red, green, and clear drinks showed consistent color-flavor associations. For example, red was associated with cherry and strawberry, whereas green was associated with mint and lime [50].

Much of what is commonly thought of as flavor actually originates from the olfactory sense [5]. It is not surprising then, that color-flavor associations and color-odor associations have been found to show similarities. Participants consistently select colors for a given odor, for example, pink and red for a strawberry odor, or yellow and orange for a lemon odor [14]. What is more, odor identification is also influenced by visual cues. In a study, both laypersons' and flavor experts' odor identification of a beverage was biased by the color of the beverage [49]. In another study, where participants were asked to discriminate between strawberry and lemon odors, the accuracy of their judgments was positively affected by showing the shape of a red strawberry or yellow lemon, respectively [15].

Studies have shown that, like for color, there are consistent associations between shapes and tastes [16], though note this may be culture-dependent [10]. In one study, participants tasted different fruit juices and were asked to associated the taste of the juices with different geometric shapes. Juices that tasted sweeter and less sour were consistently associated with rounded shapes, whereas juices that tasted more sour were consistently associated with angular shapes [41]. Such associations occur for both basic taste words (e.g. sweet, sour) as well as actual tastants, and are most consistent for sweet tastes and rounded shapes, while sour, bitter, and salty tastes are all more strongly associated with angular shapes [59]. It has also been demonstrated that certain odors are associated with certain abstract shapes, and when odors and shapes are presented in a congruent manner odor identification accuracy is enhanced [48]. For example, odors that are generally regarded as pleasant, such as vanilla, were associated with rounded shapes, whereas odors generally regarded as unpleasant, such as Parmesan cheese, were associated with angular shapes [48]. Other studies have found similar results, for example, the odor of lemon has been found to be more strongly associated with angular shapes, whereas the odor of raspberry has been found to be more strongly associated with rounded shapes [21].

Next we will discuss how researchers have capitalized on multimodal flavor perception, in particular related to visual cues, in the design of installations using mixed reality technology in combination with food.

Human-food interaction and mixed reality technology

There are a number of ways in which researchers have used mixed reality technology in situations where people interact with food [19, 58]. First, combining food with technology allows for food to be used as a medium for communication, for example to present data [28], or for communication between two people [38]. Second, technology can be used to support the rituals surrounding cooking and dining. For example, dining together in remote locations using tele-presence technology [62], using augmented reality to teach cooking skills [34], and making the act of cooking more enjoyable through augmented appliances [20]. Many of the works found in this area are aimed at existing social structures, such as family dinner time [51]. Third, by leveraging the measurement capabilities and interactive nature of mixed reality technology, interventions can be created with the goal of changing eating behaviors. Here, there is an almost exclusive focus on healthier eating behaviors. Examples are teaching basic good eating habits to children [17], behavior change for healthy eating in general, such as eating more slowly [24], and technology used to change eating behavior in a clinical setting, such as treating obesity [9]. Fourth, technology can be used to simulate tastes, without actual consumption of food items. An example is a digital taste simulator using electrodes placed on the tongue that can produce sour tastes [46]. Finally, mixed reality technology is used in attempts to alter the perceived flavor of food items or beverages. Such efforts are strongly inspired by multimodal flavor perception and the notion that auditory, tactile, and indeed visual cues can alter flavor perception [57]. One system, for example, tracks food on a plate and projects an overlay over individual food items, such as a piece of meat, to change its visual appearance. The researchers propose that changing the visual appearance, such as projecting stronger saturation or projecting animations of, for instance, melting butter, on top of the food can make it more appealing [29]. Another system features a cup with an RGB LED embedded in the bottom that allows for the color of the drink in the cup to be altered [40]. An explorative study showed that this method of changing the color of a beverage affected perceived sweetness and sourness of the drink [40]. In a similar approach, the FunRasa system uses LEDs to alter the color of a drink, in this case water, but in addition uses an electrode on the tongue that by changing the current can simulate tastes [47]. In an informal study, participants reported tasting mainly sourness and saltiness, and associated these tastes with respectively green and blue colored drinks [47]. The MetaCookie+ system features a head-mounted display, camera, and olfactory display that allows the appearance and perceived flavor of an actual (plain) cookie to be altered through visual and olfactory cues [39]. Using the camera to detect the cookie, a digital visual overlay can change the appearance of the cookie from, for example, chocolate to almond, and can, depending on the visual overlay provide congruent olfactory cues [39]. An exploratory study indicated that users of the system indeed perceived a change in flavor depending on the combination of visual and olfactory cues [39].

Current approach

Previous work that uses visual cues and mixed reality technology to in some way alter the experience of food, has resulted in interesting prototype installations and explorative studies have shown that such systems might actually influence flavor perceptions. Many such systems have built upon work in the field of multimodal flavor perception, for example by digitally, instead of using dyes, altering the color of a beverage. A next step in using mixed reality technology in combination with food is to consider visual cues that cannot be introduced using traditional methods (e.g. food dyes, plate size, plate color). One such visual cue is the use of motion. Animated visualizations can be used to convey aspects of motion, and mixed reality technology allows for such visualizations to be introduced in the food experience. Interestingly, studies into crossmodal correspondence [52] have shown associations between certain flavors and aspects of motion [63]. For example, associations between lemon flavor descriptors and fastness, as well as prune flavor descriptors and slowness have been found [63]. This is not entirely unlike parameters used in musical compositions and auditory stimuli, that use musical tempo and articulation to express tastes such as sweet and sour. Sweetness, is more strongly associated with slow, consonant, legato music, whereas sourness is associated with fast, dissonant, staccato music [30, 35, 61].

Following previous work on multimodal flavor perception we hypothesize that color, shape, and animation speed are associated with certain basic tastes. Specifically, red color [14, 50], round shapes [41, 59], and slow animation speeds [63] are hypothesized to be associated with sweetness, whereas green color [14, 50], angular shapes [41, 59], and fast animation speeds [63] are hypothesized to be associated with sourness. To test these associations we conducted a crowdsourcing study. Furthermore, to test whether such visual-taste associations could alter the taste of a food item, a subsequent study was conducted in which participants tasted different yogurts, of which the visual appearance and appearance of the environment in which they were presented, was altered using projection mapping, and stimuli of different color, shape, and animation speed.

CROWDSOURCING VISUAL TASTE

An online crowdsourcing study was conducted using the crowdsourcing platform CrowdFlower [1]. Participants viewed a number of amorphous shapes (see Figure 1) that differed in shape (rounded or angular), color (green, red, or gray) and animation speed (still, slow, or fast). The stimuli were constructed in accordance with findings from prior research discussed in the previous section. In total, participants viewed 18 stimuli (2 shapes x 3 colors x 3 animations) and for each stimulus were asked to indicate to what extent they associated the basic tastes sweet, sour, salty, and bitter with the stimulus.

Participants

A total of 200 participants was recruited via the online crowdsourcing platform CrowdFlower [1], with trustworthiness settings set to the highest level. Every contributor was awarded $0.10 for participation, and an additional $0.90 was awarded when they completed the survey. After strict selection (see section Data Filtering), data of 131 participants (65.5%) was considered valid and included in the analyses. The mean age of these participants was 39.2, (*SD*: 10.2), and 43 were male (32.8%). Participants had either the American (62, or 47.3%), British (28, 21.4%), or Canadian (32, 23.7%), nationality, or no nationality information was provided (10, 7.6%).

Materials

A total of 18 different images was created using the 3D animation program Cinema4D. Each amorphous shape was created by means of a circle spline that was displaced by sparse Gabor convolution noise [31]. To end up with animations for both rounded and angular shapes that were perceived to be of the same velocity (either still, slow, or fast) animation speed and global noise scale were manipulated (rounded shape: global noise scale 500, animation speed 3 for slow, and 6 for fast; angular shape: global noise scale 100, animation speed 2 for slow, and 4 for fast). These parameters produced an animation in which the contour of the shape would move inwards and outwards. The colors of each shape were defined in RGB colors as follows: red (R=255, G=0, B=0), green (R=0, G=255, B=0), gray (R=147, G=147, B=147). Each animation was then converted to a 2D GIF file of 300 by 300 pixels. Animations looped continuously. See Figure 1 for samples of still images of the stimuli.

Measures

For each image, participants were asked "To what extent do you associate these tastes with the above image?". Participants rated the basic tastes sweet, sour, bitter, and salty on a 9-point Likert scale. The taste descriptor appeared above each individual

Procedure

A brief description on the CrowdFlower page explained the aim of the study to participants. After clicking a link, participants were redirected to a SurveyMonkey page [2], where the actual data would be collected. Prior to starting the study participants were asked to indicate their age, gender, nationality, and CrowdFlower ID (necessary for payment of the bonus). They were then presented with a test image (a still image of water) in order to acquaint themselves with the procedure of the study. After indicating their responses for the test image, participants were presented with all 18 images in random order. After rating the final image, participants were presented with four colorblindness test images displaying a number which they had to write down in a text field [27]. Finally, participants received a code that they had to input on the CrowdFlower platform in order to receive payment.

Data filtering

The 200 participants started 260 survey-entries, some participants restarted the survey before completing it. Of these 260 survey-entries, 110 were incomplete and these were removed from the data. Seven participants that completed the survey more than once were also removed from the data. Data from 1 participant was removed because his/her response time was higher than three times the standard deviation of the overall mean response time. Furthermore, data from 4 participants was removed because they made more than one mistake in the colorblindness tests or indicated that they were colorblind. The data of the remaining 131 participants was analyzed.

Results

We conducted repeated measures ANOVAs to compare the effects of color, shape, and animation speed on the ratings of sweet, sour, bitter, and salty tastes. We conducted pairwise comparisons for the significant main effects and corrected for multiple comparisons using a Bonferroni correction. The effect of the independent variables on the four tastes is illustrated in Figure 2 for color, in Figure 3 for shape, and in Figure 4 for animation speed. Next the effects and interaction effects of the independent variables are discussed in detail per taste.

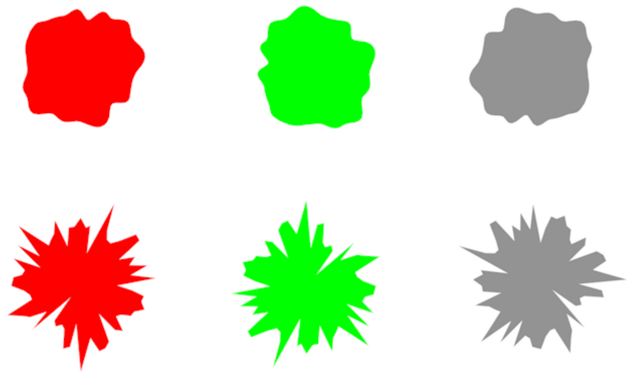

Figure 1. Examples of amorphous shapes used in the crowdsourcing and tasting study. Rounded shapes are displayed on the top row, angular shapes on the bottom row.

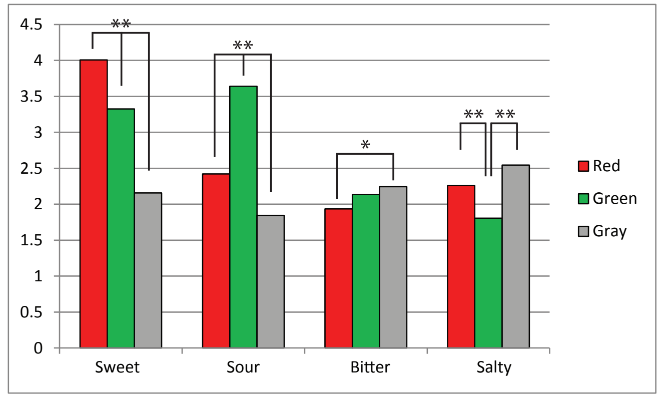

Figure 2. The effect of color on the ratings on sweet, sour, bitter, and salty. (*$p < 0.05$, **$p < 0.001$)

The effects of color

Sweet A repeated measures ANOVA showed that there was a statistically significant effect of color on participants' association with sweet, $F(2,260) = 60.74$, $p < 0.001$. Red was rated sweeter than green and gray, and green was rated sweeter than gray, see Figure 2. Pair-wise comparisons of the colors revealed that these differences were statistically significant ($p < 0.001$).

Sour A repeated measures ANOVA showed that there was a statistically significant effect of color on participants' association with sour. Mauchly's test indicated that the assumption of sphericity had been violated so the degrees of freedom were corrected using Greenhouse-Geisser,

$F(1.48,192.94) = 58.87$, $p < 0.001$. Green was rated more sour than red and gray, and red was rated more sour than gray, see Figure 2. Pair-wise comparisons of the colors revealed that these differences were statistically significant

Bitter A repeated measures ANOVA showed that there was a statistically significant effect of color on participants' association with bitter. Mauchly's test indicated that the assumption of sphericity had been violated so the degrees of freedom were corrected using Greenhouse-Geisser,

$F(1.84,239.61) = 3.69$, $p < 0.05$. Pair-wise comparisons of the colors revealed that gray was rated statistically significantly more bitter than red ($p < 0.05$), the other colors did not differ statistically significant ($p > 0.05$).

Salty A repeated measures ANOVA showed that there was a statistically significant effect of color on participants' association with salty. Mauchly's test indicated that the assumption of sphericity had been violated so the degrees of freedom were corrected using Greenhouse-Geisser,

$F(1.81,235.83) = 18.23$, $p < 0.001$. Pair-wise comparisons of the colors revealed that gray and red were rated statistically significantly more salty than green ($p < 0.001$), but that gray and red did not differ ($p > 0.05$).

The effects of shape

Sweet A repeated measures ANOVA showed that there was a statistically significant effect of shape on participants' association with sweet, $F(1,130) = 33.04$, $p < 0.001$. A pair-wise comparison of the shapes revealed that round was rated sweeter than angular shapes and that this difference was statistically significant ($p < 0.001$).

Sour A repeated measures ANOVA showed that there was a statistically significant effect of shape on participants' association with sour, $F(1,130) = 20.93$, $p < 0.001$. A pair-wise comparison of the shapes revealed that angular shapes were rated more sour than round shapes and that this difference was statistically significant ($p < 0.001$).

Bitter A repeated measures ANOVA showed that there was a statistically significant effect of shape on participants' association with bitter, $F(1,130) = 23.18$, $p < 0.001$. A pair-wise comparison of the shapes revealed that angular shapes were rated more bitter than round shapes and that this difference was statistically significant ($p < 0.001$).

Salty A repeated measures ANOVA showed that there was a statistically significant effect of shape on participants' association with salty, $F(1,130) = 5.46$, $p < 0.05$. A pair-wise comparison of the shapes revealed that angular shapes were rated more salty than round shapes and that this difference was statistically significant ($p < 0.05$).

The effects of animation speed

A repeated measures ANOVA showed that there was a statistically significant effect of animation speed on participants' association with sour, $F(2,260) = 9.5$, $p < 0.001$. Pair-wise comparisons of the animation speeds revealed that fast animations were rated more sour than slow animations and stills, this difference was statistically significant ($p < 0.005$). Slow animations and still images did not differ statistically significantly

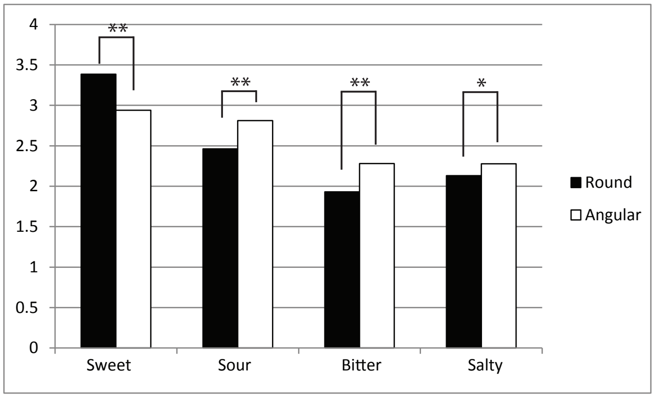

Figure 3. The effect of shape on the ratings on sweet, sour, bitter, and salty. (*$p < 0.05$, **$p < 0.001$)

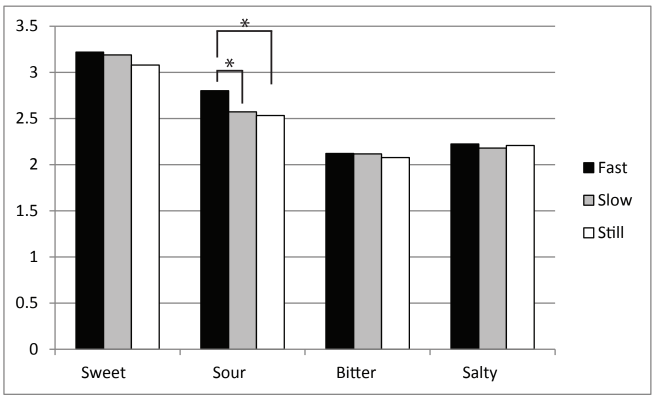

Figure 4. The effect of animation speed on the ratings on sweet, sour, bitter, and salty. (*$p < 0.005$)

($p > 0.05$). Animation speed did not have a statistically significant effect on the rating of sweet, bitter, and salt ($p > 0.05$).

Interaction effects

A repeated measures ANOVA showed that there was a statistically significant interaction effect of color and shape on participants' association with sweet, $F(2,260) = 7.87$, $p < 0.001$. Rounded shapes were rated as sweeter than angular shapes and this effect was strongest for shapes with a red color, also occurred for shapes with a green color, but not for shapes with a gray color (Figure 5). For ratings on sour, bitter, and salty there were no statistically significant interaction effects.

Conclusions and discussion

Results from the crowdsourcing study are consistent with earlier work on visual-taste associations, and show that basic tastes can be associated with specific colors and shapes [14, 41, 50, 59]. Specifically, it was found that sweetness was most strongly associated with the color red and round shapes, whereas sourness was most strongly associated with the color green and angular shapes. Bitterness was most strongly associated with the color gray and angular shapes, while saltiness was most strongly associated with both red and gray colors and angular shapes. To our knowledge, this is the first time that these type of visual-taste associations have been demonstrated using a crowdsourcing approach. This is encouraging as it could pave the way for research into cross-modal correspondence using this approach (see also [37]).

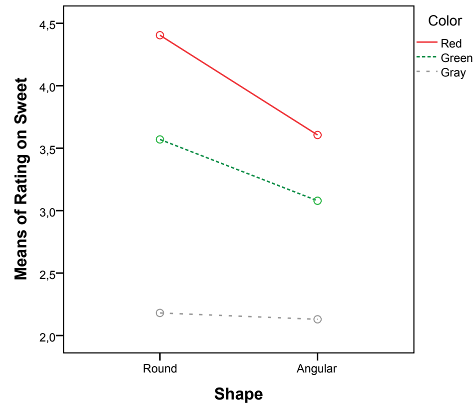

Figure 5. Interaction effect of color and shape on the rating of sweet.

A novel finding from the current study is that sourness was found to be associated with fast motion. Shapes that had a faster animation speed, rather than shapes with a slower animation speed or still shapes, were rated higher on sourness. This finding supports earlier findings on the association between 'fastness' and lemon flavors [63], and is in line with work on associations between music and tastes [30, 35, 61]. Furthermore, this finding suggests that animations have the potential to be used as a way to enhance flavors of food items. The use of mixed reality technology to display such animations in combination with actual food items is a viable approach in this regard [57].

The results from the crowdsourcing study informed the design of a study to investigate the influence of visual cues in a mixed reality setting on taste perception of yogurt that we will describe in the next section.

THE VISUAL TASTE OF YOGURT

The crowdsourcing study provided insights into associations between a number of basic tastes, and visualizations of amorphous shapes that differed in color, shape, and animation speed. To assess whether such associations could influence taste perceptions, a lab study was conducted in which participants sampled several yogurts that were either unsweetened (i.e. natural) or sweetened (see Materials section). Yogurt was used as previous research indicated that the taste of yogurt can be influenced by visual cues [23]. Projection mapping was used to project visualizations that were based on results from the crowdsourcing study, around a cup of yogurt. To limit the stimulus set, shape and color were combined in a congruent manner into two visualizations (i.e. rounded and red, angular and green) as indicated by the results from the crowdsourcing study. To investigate the effect of animation, still images of the visualizations were compared to visualizations with a fast animation speed.

For one group of participants, in addition to projecting around the yogurt, the projection was used to alter the color of the

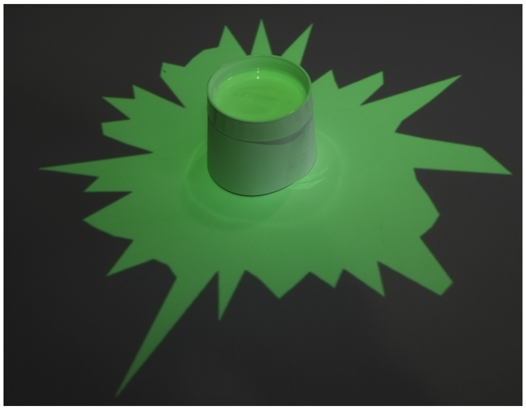

Figure 6. A photo of a low contrast projection (i.e. projection around as well as on top of the yogurt) of a green angular shape on a cup of yogurt.

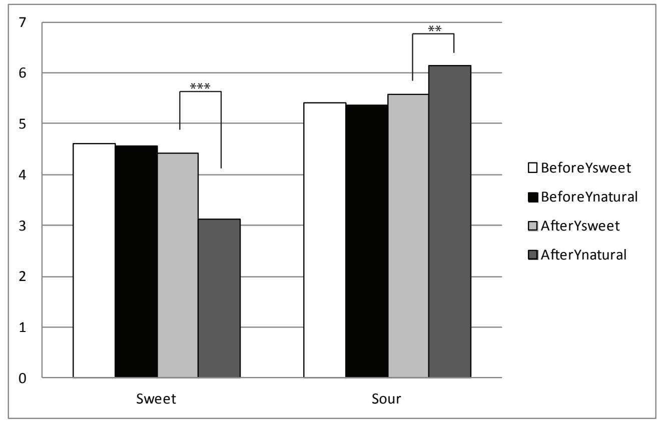

Figure 7. Ratings of the two yogurt types, before and after tasting. (** $p < 0.01$, *** $p < 0.001$)

yogurt as well. This distinction between projection types was based on research that suggests that the influence of color has to do with color contrast rather than color per se [22, 23]. With projecting only around the yogurt, the color of the yogurt remains white, thus there is a stronger contrast between the yogurt and the visualizations, whereas projecting around and on top of the yogurt reduces contrast between the color of the yogurt and the visualizations.

To summarize, projection type (high contrast, low contrast) was used as a between subject variable, while shape (round + red, angular + green), animation (still, fast animation), and yogurt (natural, sweetened) were used as within subject variables. Thus, participants in each group would sample 8 yogurts.

Participants

A convenience sample of 48 university students was recruited by the collaborators mentioned in the Acknowledgments. Participants that failed a test for colorblindness (n=3) were excluded from analyses. The resulting 45 participants had a mean age of 25 (SD=10.1), 12 were female, and 34 had the Dutch nationality. None were allergic to any of the food items that were presented during the experiment.

Materials

The visualizations were identical to the rounded red still/fast and angular green still/fast shapes used in the crowdsourcing study except for size. The shapes were projected onto an off-white table (see Figure 6) using a projector mounted above the table. The size of the projection was approximately 30 by 30 cm. For each tasting, participants were presented with a white plastic cup with approximately 135ml of low-fat yogurt (Jumbo Magere Yoghurt). The cup had a slight conical shape so that top-down projections would not cast a shadow on the area around the cups. For each tasting, participants used a new white plastic spoon. After tasting a yogurt, participants would take a byte of a dry cracker and a sip of water.

Sweetened yogurt manipulation check

Two samples of yogurt were used in the experiment. Both samples were a commercially available low-fat yogurt. One of the yogurt samples was sweetened using a colorless artificial sweetener (Natrena Classic). For each liter of yogurt, 30 drops of the artificial sweetener were added to give the yogurt a slightly sweet taste.

A manipulation check was conducted to see if the sweetened yogurt was indeed perceived as more sweet than the natural yogurt. Participants (N = 15), none of whom participated in the main experiments, were all students or employees of a university. Participants were presented with a sample of the sweetened and unsweetened yogurt. The presentation of the yogurt was counterbalanced across participants. Participants were asked to take one spoon of the first yogurt, and rate its taste using 9-point rating scales for each of four basic tastes (sweet, sour, bitter, salty; e.g. 1 = not sweet at all, 9 = very sweet). The same procedure was followed for the second yogurt.

Paired samples t-tests were conducted to compare the sweetness ratings of the sweetened yogurt with those of the unsweetened yogurt. The sweetened yogurt (M = 5.40, SD = 2.10) was rated as significantly sweeter than the unsweetened yogurt (M = 3.46, SD = 1.55) ($t(14)$= -4.88, p <.001). Ratings for sour, salty, and bitter did not differ significantly between the sweetened and unsweetened yogurt. Though note that ratings for sour showed the largest mean difference between the sweetened (M = 5.00, SD = 1.69) and unsweetened (M = 5.8, SD = 2.01) yogurt samples. Because the yogurts differed significantly on perceived sweetness, results of the manipulation check were deemed satisfactory, and both samples of yogurt were used in the main experiment.

Measures

First participants indicated their age, nationality, and food allergies. For each yogurt participants indicated how they expected it to taste based on their first visual impression, using 9-point rating scales for each of four basic tastes (sweet, sour, bitter, salty; e.g. 1 = not sweet at all, 9 = very sweet). After tasting the yogurt, they rated the taste they perceived on the same type of scale. Before the conclusion of the experiment, participants were presented with a colorblindness test [27].

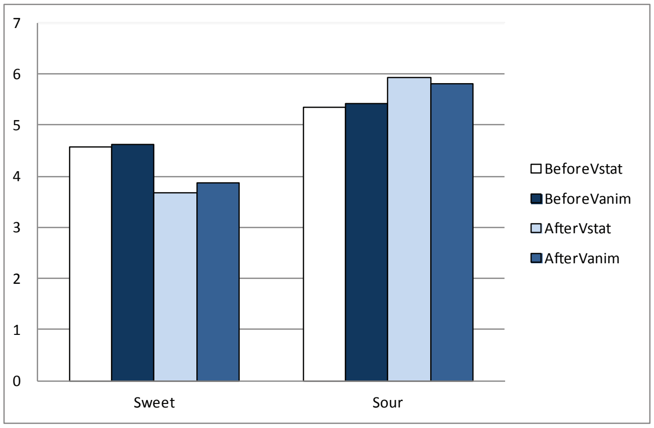

Figure 8. Ratings split for static and animated, before and after tasting.

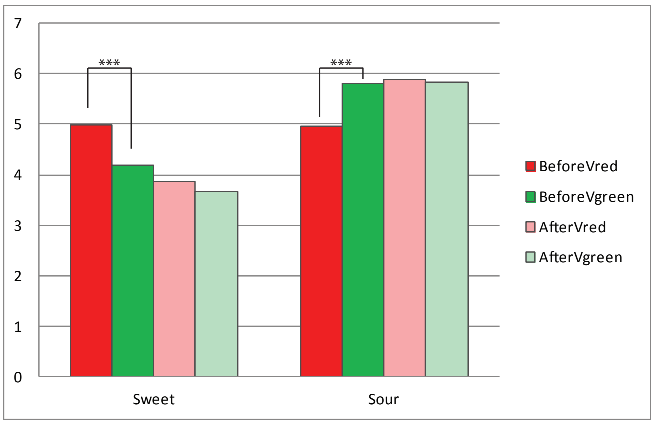

Figure 9. Ratings split for shape and color, before and after tasting. (***$p < 0.001$)

Procedure

When a participant entered the experiment room, he/she was greeted by two experimenters and was directed to a table. The table was surrounded by black curtains in order to control ambient light conditions, minimize distractions, and hide the area where the yogurt samples were prepared. The participant signed an informed consent form and was given a written explanation of the experiment. It was explained that he/she would taste 8 yogurts that might differ slightly in taste, and that were presented with different visualizations. No information was given about the hypotheses of the study.

Next, the participant filled out the demographics questionnaire on a laptop computer. After completing the questionnaire, the participant was presented with the first yogurt and visualization. Yogurts and visualizations were presented in a counter-balanced order. Each cup of yogurt was placed in the middle of the table, about 25cm from the participant, directly under the projector. The participant was instructed to, upon presentation of a yogurt, take some time to look at it, and indicate on a laptop computer how they anticipated it would taste. The participant then took a clean plastic spoon, and tasted the yogurt. After tasting, the participant used the laptop to indicate how the yogurt tasted. The participant then took a bite of a dry cracker and a sip of water to cleanse his/her palate. The experiment ended when the participant indicated their responses for all 8 eight combinations of yogurts and visualizations.

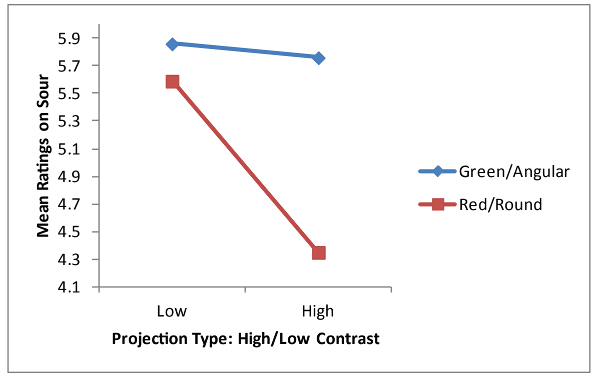

Figure 10. Interaction effect of color and shape, and projection type for ratings on sourness, before tasting the yogurt.

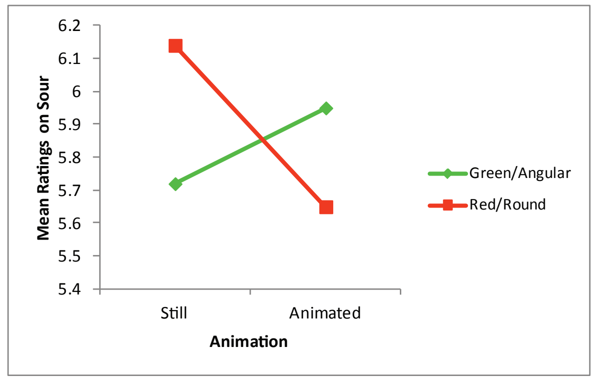

Figure 11. Interaction effect of color and shape, and animation speed for ratings on sourness, after tasting the yogurt.

Results

We conducted mixed measures ANOVAs to compare the effects of color and shape, and animation speed on the ratings of expected taste of sweet and sour before tasting, and experienced taste of sweet and sour after tasting. Projection type (high or low contrast) was a between-subject variable. We conducted pairwise comparisons for the significant main effects and corrected for multiple comparisons using a Bonferroni correction. Note, that due to the page limit only the results for the sweet and sour tastes are reported here.

Figure 7 shows that the taste manipulation of the yogurts did not impact how participants thought the yogurt would taste before actually tasting it. The ratings of the two yogurts did not differ statistically significantly before tasting: $F(1,43) = 0.18$, $p > 0.05$ for ratings on sweet and $F(1,43) = 0.15$, $p > 0.05$ for ratings on sour. However, after tasting the yogurts ratings did differ statistically significantly: $F(1,43) = 25.72$, $p < 0.001$ for ratings on sweet and $F(1,43) = 10.45$, $p < 0.01$ for ratings on sour. Participants rated the sweetened yogurt significantly more sweet than the natural yogurt ($p < 0.001$) and the natural yogurt more sour than the sweetened yogurt ($p < 0.001$). These findings confirm the results from the yogurt manipulation check for sweetness, and show that the natural yogurt was perceived as more sour than the sweetened one. Note that the natural yogurt only showed a trend towards being rated more sour in the manipulation check.

The taste associated with the visual stimuli is the only thing the participants can base their ratings on before tasting. To reiterate, we compared visual stimuli shape (round + red; angular + green) and animation (still, fast animation). Figure 8 shows that animation had no effect on the ratings of expected taste, the differences were not statistically significant for ratings on sweet ($p > 0.05$) and sour ($p > 0.05$). Figure 9 illustrates that the shape and color of the visualizations does have an effect on ratings of expected taste and this effect was statistically significant for sweet ($F(1,43) = 18.92$, $p < 0.001$) and sour ($F(1,43) = 16.82$, $p < 0.001$). Participants expected red round shapes to taste sweeter than green angular shapes ($p < 0.001$) and green angular shapes to taste more sour than red round shapes ($p < 0.001$). These results confirm the results from the crowdsourcing study and show that the association between amorphous shapes and the basic tastes sweet and sour also occur with projections in a lab setting.

The main between-subject effect projection type (high or low contrast) was not statistically significant for both ratings of sweet and sour, $F(1,43) = 0.01$, $p > 0.05$ and $F(1,43) = 0.77$, $p > 0.05$ respectively. Thus the contrast between the color of the yogurt and the color of the visualizations did not affect participants' taste associations or perceptions. However, ratings on sour from before tasting the yogurt showed a statistically significant interaction effect with the shape and color, and the projection type, $F(1,43) = 7.70$, $p < 0.01$ (see Figure 10). Higher contrast lowered the sourness ratings of the red round shapes, compared to the effect contrast had on green angular shapes. This interaction effect was not statistically significant for ratings on sweetness ($p > 0.05$).

Finally, ratings on sourness after tasting the yogurt showed a statistically significant interaction effect of color and shape, and animation, $F(1,43) = 5.27$, $p < 0.05$. Animated shapes that were red and rounded were rated less sour than their still image counterparts. While animated shaped that were green and angular were rated as more sour than their still image counterparts (see Figure 11). This finding indicates that these specific combinations of color/shape and animation influenced the perception of taste of the yogurts.

CONCLUSIONS AND DISCUSSION

In the crowdsourcing study it was found that sweet tastes were associated with the color red, and rounded shapes, whereas sour tastes were associated with the color green, and angular shapes, corroborating findings from previous research [14, 41, 50, 59]. Additionally, the crowdsourcing study revealed that sourness is associated with fast animation speed. This is a novel finding that matches with earlier work on associations of sourness with 'fastness' [63] and associations of sourness with certain types of musical compositions [30, 35, 61]. The findings on visual-taste associations, with the exception of the findings for animation speed, were largely supported by findings from the lab study, which showed, prior to tasting, associations between sweetness and red/rounded shapes, and sourness and green/angular shapes. Despite the fact that the crowdsourcing study did not allow for exact control of stimulus presentation (e.g. participants' display type and settings), results from the crowdsourcing study and lab study were relatively consistent, adding support to the notion that crowdsourcing is a valid method to quickly and cost-effectively reach large groups of participants [7]. The validity of crowdsourcing as a research method opens up the possibilities for future research on visual-taste associations (see also [37]).

The lab study on the other hand, used projection mapping to present the visual stimuli to participants. The presentation of visual images in mixed reality then, seems to elicit similar visual-taste associations as those found in studies using either screen-based digital images, or direct manipulation of food items or utensils (e.g. [23, 66]). The fact that projections resulted in similar visual-taste associations prior to tasting, suggests that projection mapping is a viable approach for presenting visual cues in human-food interaction. This opens up new opportunities for research into crossmodal correspondence and multimodal flavor perception, as digital images that have the potential to influence flavor can easily be manipulated, and presented in different ways using different projection techniques.

Previous research has found that associations between visual cues, such as color and shape, and certain basic tastes can influence taste perceptions [23, 59]. No such effect was found in the current lab study: the color and shape of the visualizations did not influence taste perception of the yogurt after tasting. However, an interaction effect was found that showed that specific combinations of the visualizations with animation type did influence taste perceptions of the yogurt. Specifically, yogurts that were presented with red/rounded still visuals were rated as more sour than when presented with green/angular stills, but when the visualizations were animated (i.e. fast motion) this effect reversed: when yogurts were presented with green/angular animated visuals the yogurts were rated as more sour than when they were presented with red/round animated visuals. This indicates that projected animations can actually influence the taste perception of yogurt, but that the effect depends on the design of the visualizations in terms of their color and shape. Results from the lab study show that mixed reality technology in the form of projection mapping offers unique ways in which the taste perception of food items can be influenced; in this case through the careful design of animated visualizations.

It is worth noting that not all visual-taste associations that were found in both the crowdsourcing and lab study affected taste perceptions after tasting the yogurts. Based on previous research into multimodal flavor perception it would be expected that color and shape would influence taste perceptions [22, 23, 59], but no such effects were found here. One suggestion is that visual cues need to 'match' with the food item for an influence on flavor perception to occur. For example, Harrar and Spence [23] found that using a blue, white, or black spoon while eating a yogurt influenced the perceived taste of the yogurt, yet they found no difference for other colored spoons. This suggests there is some dependency between the color used and the food product sampled; some colors do influence the perception of taste while others do not. In addition, food preference may play a larger role in taste perception than it does in visual-taste associations, thus its impact may have been more pronounced after tasting the yogurt. The effect of food preference was however, not taken into account in the current study. Finally, the visualizations created with mixed reality technology are, despite our best efforts, clearly recognizable as alterations, and thus recognizable as part of the experimental setup. While the color of yogurt itself or of the spoon from which it is eaten can be convincingly altered with food dye or colored plastics, achieving such a convincing effect is much harder using projections. Additionally, color saturation is likely lower with the projection used in the current study than compared to visual stimuli used in other studies. On top of that it is possible that color contrast differs for specific colors, as indicated by the interaction effect found for high and low contrast projections and red/round shapes for sourness ratings. The fact that the projections were recognizable as an alteration, as well as the color saturation of the stimuli may have affected the extent to which the visualizations influenced taste perceptions.

The approach presented here shows the potential of using mixed reality technology in human-food interaction to influence taste associations and taste perceptions. Directions for further exploration of this technology can be suggested. For example, it would be interesting to use projection mapping and vision-based tracking technologies (e.g. Microsoft Kinect) to dynamically alter the color, shape, or animation of visuals projected on top of and around food items during consumption. This way, the flavor experience of the same food item could potentially be altered during consumption, and visualizations could be used to, for instance, communicate about eating speed. Additionally, it would be interesting to explore combining visualizations such as those used in the current study with multimodal cues. For example, olfactory displays could be used in conjunction with the projections. Moreover, the animations of the projections could be matched to specific pieces of music that are associated with certain basic tastes. Such a multimodal approach could not only result in fascinating installations and food experiences, but could also shed further light on the multimodal perception of flavor. Finally, the current approach can be seen as encouraging for restaurateurs who are exploring the use of mixed reality technology in modernist restaurants.

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