Exploring influencing factors in shape-taste crossmodal correspondences with static and dynamic shapes

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Master thesis for Applied Cognitive Psychology
27,5 ECTS

August 1, 2019

Abstract

In recent years, many studies have been done, exploring factors in crossmodal correspondences between shape and taste. Building on this and an internship for TNO earlier this year, two online experiments have been done, examining these factors in crossmodal correspondence with both static and dynamic shapes. In experiment 1, a redesigned version of the experiment done in the internship, participants chose shape attributes that they associated most with the expected taste of four given food images. Analysis indicated that sweet expected tastes were associated with roundness, symmetry and a low number of elements in shapes. A high taste intensity was indicated to be associated to a higher number of elements in shapes, but only for sour foods. This confirms findings in earlier research linking sweetness to roundness and symmetry and provides insight in the link between taste intensity and shape complexity, as well as highlighting the importance of considering choices in instructing participants. In a second experiment, a possibe link between dynamic water patterns and taste was examined. Participants chose either 'sweet' or 'sour' for each of 30 dynamic textures, which had been classified with 7 descriptors (calmness, pleasure, arousal, interest, dominance, motion complexity and motion regularity). Analysis did not show any moderate correlations between the chosen taste and these 7 descriptors, giving evidence of an absence of a link between taste and dynamic textures.

Introduction

In 2011, Spence & Gallace (2011) published a paper "Tasting shapes and words", in which they explored the possibility of whether people would associate visual shapes to tastes and flavours. This inital idea was based on synaesthetes, people who experience automatic and involuntary stimulation of one of the senses when another sense is being activated. There are many forms of synaesthesia, of which colour-graphemic synaesthesia is probably the most well-known (the phenomenon in which letters and numbers are preceived to have specific colours). One case in particular interested Spence and Gallace, in which a man experienced a strong taste shape synaesthesia. Sugar was associated with round shapes, and a tangy note added a certain pointiness to food.

In their paper in 2011, Spence & Gallace (2011b) were successful in providing evidence for these taste shape crossmodal correspondences in non-synaesthetic people. Since that paper, many other papers have been published on this topic. Research into crossmodal correspondence has a lot of value for theories of multisensory interactions, bringing up new questions about relations between sensory modalities (Deroy & Spence (2016)). In this introduction, six different parameters are used to explain the different directions that have been taken and the possible underlying mechanisms that have been suggested for this effect.

Sounds, shapes and tastes

The Bouba-Kiki effect, first described in 1929 by Köhler, is an effect where humans match a certain nonsense sound ('Bouba') to rounded shapes and another sound ('Kiki') to more angular shapes. This effect has proven to be highly reliable and replicable, for example in toddlers and infants (Maurer et al (2006) and Ozturk et al (2013)) and also in non-Western cultures (Bremner et al (2013) and David (1961)). A likely underlying reason for this effect is that it constutites a type of crossmodal correspondence in human perception, where humans match rounded shapes to lower-pitched sounds and angular shapes to high-pitched sounds (as observed by Marks (1996) and Walker et al (1910)). Chen et al (2018) found that the confidence in classification of shapes to either Bouba or Kiki varied. The most round and angular shapes were classified with much higher confidence than shapes with elements of both roundness and angularity. The effect was also used by Spence & Gallace (2011) to demonstrate crossmodal correspondences between word sounds and tastes, paving the way for their other study in 2011 exploring the taste shape associations.

Roundness versus sweetness

In a study by Velasco et al (2015), a link was found between sweetness and roundness across multiple experiments. Round shapes were associated with sweetness. In addition, a more angular shape was associated with bitter, salty and sour. This not only indicated that sweetness is associated with roundness, but also that none of the other basic tastes are associated with it and and more likely to be linked to angular shapes. Additionally, in another study, Velasco et al (2015) found that these associations were also present with actual tastants instead of only taste words. Sweeter foods were also found to have a higher liking rating than less sweet foods. This gives evidence for the theory that pleasantness can be an influential factor in the correspondence between shape roundness/angularity and tastants. In a third study (Velasco et al (2016)), positively valenced words ("good", "mild") were more often associated with rounder shapes than negatively valenced words ("shallow", "bad", "harsh"). These findings have also been reported by Salgado et al (2015). Another study by Bar & Neta (2006) suggests that sharp transitions in shapes might convey a sense of threat, therefore eliciting a negative bias in humans. An object that is rounder in shape will not, or at least in a lesser degree, convey this threat, giving it a more positive connotation.

Symmetry versus sweetness

In the study by Salgado et al (2015), a link was found between symmetry and round shapes. Not only was a a symmetrical (round or angular) shape more often matched to the word 'sweet', it was also more often associated to the word 'pleasant'. In a study conducted by Turoman et al (2018), more evidence was found for a link between symmetrical shapes and sweetness. Bilateral and rotational symmetrical shapes were seen as much more pleasant than only bilateral symmetrical and asymmetrical shapes. This effect was present for both round and angular shapes, but pleasantness rates in general were significantly higher for round shapes than for angular shapes.

The number of elements in shapes

In the aforementioned study by Salgado (2015), a link was shown between the number of elements in a shape and the associated taste. The word 'sweet' was significantly more often paired with a shape that contained relatively few elements. Interestingly, these low element shapes were also rated as more pleasant than the higher element shapes. Shapes that were both asymmetrical and contained a high number of elements were rated as the most unpleasant.

Salgado et al (2015) also measured response times to potentially discover a pattern. Participants categorised angular and/or asymmetrical shapes significantly faster than round and/or symmetrical shapes. Participants were also significantly slower in categorising shaped with many elements, as opposed to shapes with few elements. Response times can give information about the confidence of participants in classifying a shape as either sweet or sour. Having shorter response times for angular and asymmetrical shapes only is an indicator that participants felt more sure of their answer in classifying these shapes.

Curved shapes and emotion

Research by Velasco et al (2016) has shown that people think of sweetness and roundness as significantly more pleasant than sourness and angularity when experiencing actual sweet and sour tastants. When given a sweet dessert, there was a clear link between the perceived sweetness of the dessert and the roundness of the shape that participants associated with it. When given only taste words, liking of sweetness and sourness did not match up with the roundness of the chosen shapes.

Further research into this has been done by Blazhenkova et al (2017). They discovered that participants were significantly more likely to associate curved (round) shapes with smooth textures and relieved emotions, the colour green, femininity and a sweet taste. Angularity was most often linked to rough textures, the colour red, masculinity, sourness and excitedness.

Dynamic water patterns

One factor that all the aforementioned research has in common is that it has been focused solely on static, twodimensional shapes. The correspondence between static shapes and tastes has been studied in great detail, but it poses a problem. Completely static shapes are uncommon in real life. Even though we navigate a world of many static objects, people themselves are moving and shapes and objects are not twodimensional. What influence does movement have on our perception of taste and food in general?

In a study by Toet et al (2012), 30 different dynamic watter patterns were used to measure emotional responses from participants. Two sets of dynamic patterns were used, water and non-water. Participants were asked to choose appropriate adjectives from a list to each of these 30 dynamic textures. The list of adjectives consisted of 58 words, divided into 10 categories. Eight of these categories corresponded to the four axes of Russell's circumplex model of affect (pleasure, arousal, interest and relaxation) (Russell (1980)). The two remaining corresponded to dominance (eg strong - weak). While motion complexity was found to be mildly relaxing, the complexity of motion changes was found to be more arousing. A higher speed of the water motion was experienced as arousing and unpleasant, and the same was true for the amplitude of the motion. Highly regular movement was associated with being uninteresting but also mildly relaxing and mildly pleasant. These findings support the hypothesis that dynamic textures (in this case water) can elicit emotional responses.

More related to water patterns and food is the study by Li et al (2019). In this study, and experiment was done to explore the influence of dynamic water patterns on perceived food freshness. Participants judged the freshness of fruit in three conditions; fruit with no background, fruit with a background of implied static water and fruit with a background of implied moving water. Fruit with a background of implied moving water was rated as significantly more fresh than the other two conditions, and the average freshness of fruit with a background of implied static water was also significantly higher than that of the fruit with no background. In a second experiment these behavioural findings were replicated, giving more evidence that perceived freshness can be influenced by moving water, even if this is only implied movement.

Real life applications

Apart from a fundamental understanding of crossmodal correspondences, these links between shape and taste have value in a commercial sense. A study by Stewart & Goss (2013) revealed that a sweet dessert presented on a round, white plate tasted sweeter and was liked more than other plate shapes and colours. Velasco et al (2016) discusses a number of other studies on product packaging and taste. Packaging shape and colour influences its expected and perceived taste, making this very relevant for commercial applications.

The aim of this study

Based on the internship study and evidence already provided in the studies mentioned in this introduction, two experiments have been proposed for this study. Both explore a link between taste and visual objects (dynamic and static). These experiments aim to explore and define different factors in taste-shape crossmodal correspondences.

Study 1

Earlier this year, an internship was done at TNO (Elbertse (2019)), doing research into taste-shape crossmodal correspondences. This first study had the aim to replicate findings that were presented in the paper by Salgado et al (2015), revealing a correspondence between sweetness and three shape attributes: roundness, symmetry and number of elements. It also posed a new question: does taste intensity have any effect on the chosen shape complexity? The study by Salgado et al (2015) had focused on the taste words 'sweet' and 'sour', but had not introduced taste intensity as a possible factor in shape matching. In the internship study, taste intensity was explored as a possible influencing factor. In order to do this, not only sweet and sour food stimuli were used in this experiment, but the taste intensity was taken into account as well. This lead to four food stimuli, differing in basic taste and intensity of that taste.

During this online experiment, participants were asked to match a shape to an image of a sweet or sour food. After examining the design of this first pilot experiment, it became apparent that participants had not been instructed about the task properly. They had not been asked to think about the expected taste of the food that was shown to them, but only instructed to match a shape to the food image itself. Therefore there cannot be concluded that there is no association between the taste and the chosen shapes, as it cannot be confirmed that participants had been focused on the taste (instead of the shape or the colour of the images). Another factor was that participants were allowed to give a neutral answer instead of being forced to make a choice between two shapes. By instructing participants to focus explicitly on taste and by eliminating this neutral response, results obtained in this new experiment will be more reliable and can be used to draw conclusions based on the expected taste of the food stimuli, instead of their shape or colour.

Based on earlier research into the relation between taste and roundness, symmetry and shape complexity, it is expected that sweet food stimuli will be more often matched to shapes that are round, symmetrical and contain a relatively few number of elements. When examining taste intensity, it is expected that this will have an effect on the number of elements in shapes. The expectation is that if taste intensity (either sweet or sour) increases, the number of elements will also increase, based on the assumption that if a shape is experienced as more intense, the corresponding taste will also be more intense.

Both shape responses and response times will be collected. The former is collected to analyse whether these associations exist and come forward in this experiment, the latter is a measure to gauge the confidence of the participants' responses. It is assumed that if participants feel more confident in their answer, that they will also be able to respond faster than if they were unsure about their response.

Study 2

The aim of study 2 is to explore if there is a link between the emotional response elicited by dynamic water patterns and expected taste. The study by Toet et al (2012) focused on both water patterns and non-water patterns. This study will be focusing on water patterns only. The reason for that is the potential link to taste. Water has no taste by itself. This means that any tastes that could be associated with it in this study will come from the movement instead of the moving stimulus itself. This assumption cannot be made for other non-water stimuli, as they might have a taste or an associated taste which can interfere with the effect of the movement. For this study, the gathered emotional responses to the dynamic water patterns from the research by Toet et al (2012) will be used for the analysis of the pattern-taste matchings.

Research has shown different links between water patterns and emotion (Toet et al (2012)), water patterns and perceived freshness (Li et al (2019)), taste and emotion (Blazhenkova & Kumar (2017)) and taste and shape (Salgado et al (2015)), a logical next step would be to consider a transitional link between one of these attributes. If roundness is both related to calmness and sweetness, calmness and sweetness could be expected to be related as well. A dynamic pattern that has been classified as calming (a pattern with higher motion regularity and low complexity) in the study by Toet et al (2012) would therefore be expected to be classified as 'sweet'. A more irregular, and more arousing pattern is expected to be associated with sourness. Results from the study by Toet et al (2012) were obtained in order to compare these data to the data received from this second study.

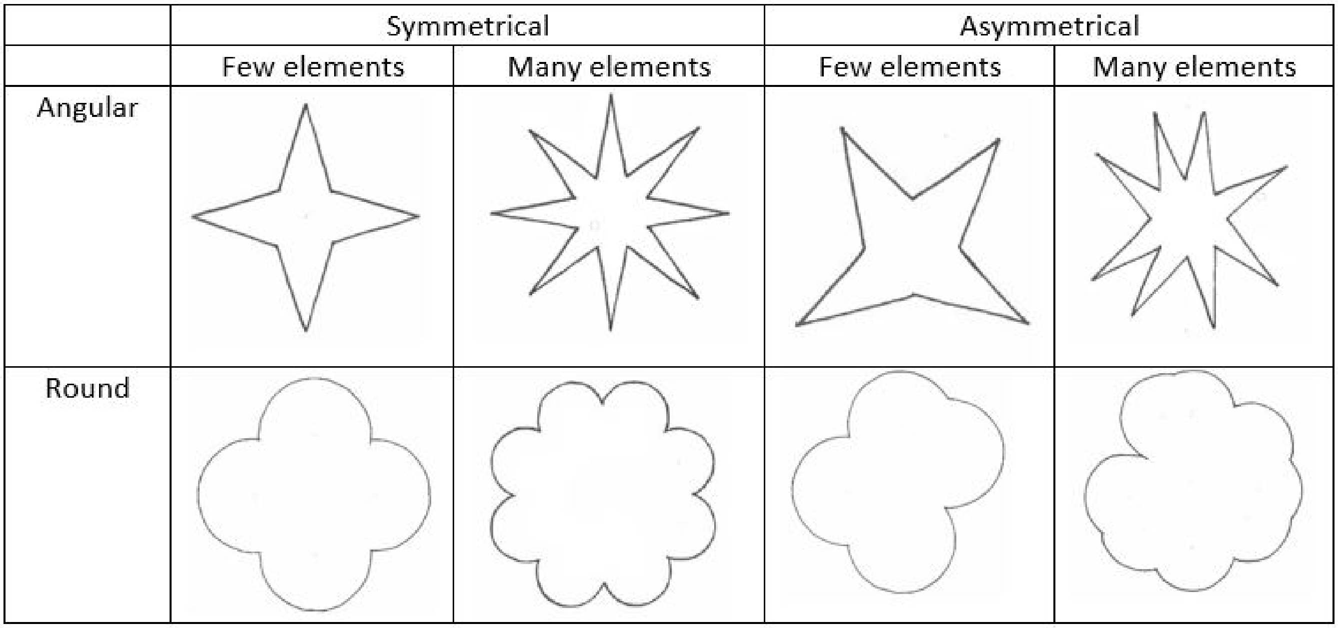


Figure 1: *The shapes designed for this experiment, differing in three aspects; roundness/angularity, symmetry and the number of elements in the shape. Out of these eight shapes, 12 different pairs were made, each differing in one attribute (roundness/angularity, symmetry and number of elements).*

Experiment 1

Method

Participants

63 participants took part in this online experiment, 34 male and 28 female (and one person who preferred not to specify). They were recruited in Prolific (https://prolific.ac/). All participants were between 18 and 35 years old, with a mean age of 24 ($\sigma = 4,6$). All consented to take part in this experiment via an online consent form.

Stimuli

Food images

Four diffent food stimuli were used in this experiment, taken from the FRIDa food database (by Foroni et al (2013)). Two of these images show a sweet food item (strawberries and chocolate) and two images show sour foods (pickles and lemon) (see figure 5 in the appendix). As Velasco et al (2015) have shown in their experiments, participants tended to group the basic tastes sour, salty and bitter together in choosing shapes, matching these to more angular shapes than the sweet stimuli. In the study by Salgado et al (2015), only the words ”sweet” and ”sour” were used as choices. As a result of that, comparing sweetness to any other taste is expected to yield similar results than comparing sweetness to another basic taste. Because of this, stimuli in this experiment only contain sweet and sour stimuli. Two of the four food images are expected to have a relative low taste intensity (strawberry (sweet) and pickle (sour)) and the two other images show high intensity tastes (chocolate (sweet) and lemon (sour)).

Shapes

8 different shapes have been designed specifically for this experiment and for the previous pilot study (dur-

ing the internship), varying in three different attributes: roundness, symmetry and the number of elements (either 4 elements or 8) in the shape (see Figure 1). This results into 8 different shapes. During the experiment, choices had to be made between two different shapes at a time, which differed in exactly one of the three attributes, for example a round, symmetrical shape with few elements would be paired with a round, symmetrical shape with many elements, in essence limiting the choice between few or many elements. 12 different pairs of shapes could be combined out of the eight shapes shown in figure 1.

Procedure

The experiment was constructed and hosted using Gorilla (https://gorilla.sc/). It consisted of a shape-matching task (visual examples can be found in Figure 2). Participants received a written instruction before the task, and were asked to look at food images, imagine what they would taste like, and to choose a shape that they felt matched this expected taste the best. Every trial contained one food stimulus at the top center of the screen, with a sliding scale underneath, anchored with two shapes that differed in one aspect (roundness/angularity, symmetry/asymmetry or few/many elements). Participants were forced to make a choice between these two shapes, as the slider could not be left exactly in the middle (score 50). There was no time limit in which each trial had to be completed, although participants were asked to not think too long about their answer, in order to attempt to record the first association that came to mind.

12 different shape pairs and sliders were shown for each of the 4 different food images (chocolate, strawberries, lemon and pickles), giving 48 trials per participant and thus resulting in 48 responses between 0 and 100 (minus the neutral 50, as this response could not be recorded). In addition, response times were recorded per trial. The duration of the experiment was 5-10 minutes.

Data analysis

All data analysis for the experiment was done in R (Version 1.1.463, https://cran.r-project.org/). Three different analyses were done based on the three different attributes in the shapes; roundness, symmetry and number of elements. The images of chocolate and strawberries were grouped together as "sweet" and the images of lemon and pickles were grouped together as "sour". The mean chosen roundness, symmetry and number of elements of the sweet and sour stimuli were each compared separately via means of t-tests.

For analysing the effect of the taste intensity on the chosen number of elements, the four stimuli were again divided into two groups, one with low taste intensity (pickles (low sour intensity) and strawberries (low sweet intensity)) and one with a high taste intensity (lemon (high sour intensity) and chocolate (high sweet intensity)). The mean number of elements chosen in the shapes for both these groups were compared in a t-test. As research has also seen a higher effect of the number of elements in sour stimuli only (Salgado et al (2015)), a t-test was also done to compare only the mean responses (of the chosen number of elements) for lemon and pickles.

Lastly, the mean response times of the sweet (chocolate and strawberries) and sour (lemon and pickles) were also compared in a t-test, to see whether partici-

Figure 2: *Three of the screens in the online experiment. A picture of food is shown, a sliding scale is placed underneath it with two shapes at the ends. The first example shows two shapes differing in symmetry, the second in roundness and the third one differs in the number of elements.*

pants were faster in selecting shapes for sweet stimuli than for sour stimuli.

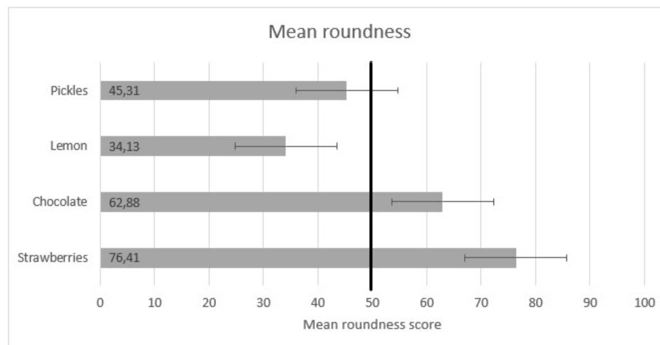
Results

Effects of sweet stimuli on chosen attributes in shapes

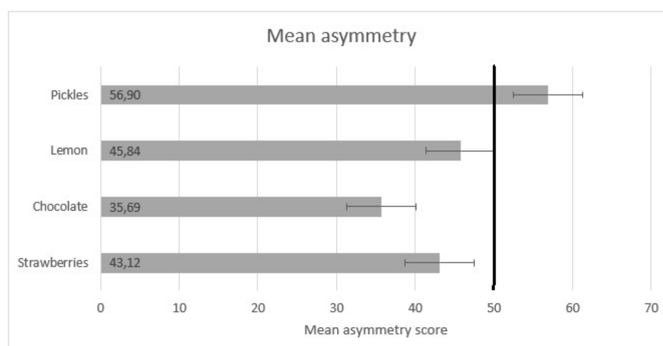
Firstly, the roundness of chosen shapes was examined (see figure 3a). A two-sample t-test indicated that the roundness of chosen shapes was significantly higher for sweet foods (chocolate and strawberry) ($M = 65.3$, $SD = 27.2$) than for sour foods (lemon and pickle) ($M = 41.9$, $SD = 31.1$), ($t(1644) = 16.4$, $p < 0.001$, $d = 0.80$).

In a second two-sample t-test, the average asymmetry (figure 3b) was compared for both sweet and sour foods. The test indicated that asymmetry in chosen shapes was significantly lower (meaning a higher symmetry) for sweet foods ($M = 39.0$, $SD = 32.5$) than for sour foods ($M = 51.4$, $SD = 33.4$) ($t(969) = -5.83$, $p < 0.001$, $d = 0.37$).

Last of the three attributes was the number of elements in shapes (figure 4a). A third two-sample t-test shows that the chosen number of elements in shapes is significantly lower for sweet foods ($M = 43.2$, SD



(a) Mean roundness in chosen shapes, depicted per food stimulus.



(b) Mean asymmetry in chosen shapes, depicted per food stimulus.

Figure 3: *a) This graph depicts the mean responses of all participants, from all the shape pairs that differed in roundness only. The mean scores are shown per food stimulus. A score under 50 indicates an more angular shape, a score above 50 a rounder shape.*
b) Graph B shown the mean responses to shape pairs that differed in symmetry only, depicted per food stimulus. A score below 50 indicates a more symmetric shape, a score above 50 a more asymmetric shape.

= 32.3) than for sour foods (M = 55.9, SD = 32.4) ($t(960)$ = -6.08, $p < 0.001$, d = 0.39).

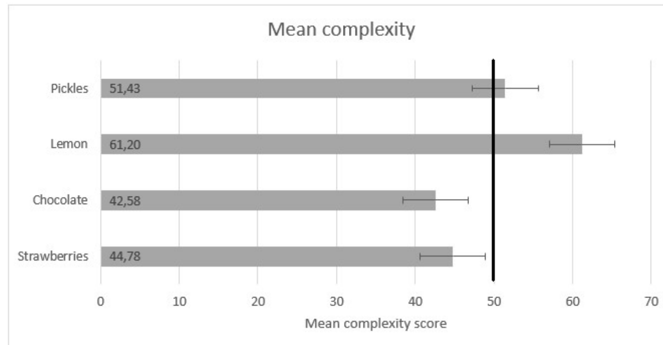
Effect of taste intensity on the number of elements in shapes

For this analysis, the four food stimuli were divided into two groups: low taste intensity (strawberry and pickle) and high taste intensity (chocolate and lemon), instead of the earlier divide between sweet and sour. A two-sample t-test indicated that the number of chosen elements was not significantly higher for high taste intensity foods (chocolate and lemon) (M = 51.7, SD = 33.8) than for low taste intensity foods (pickle and strawberries) (M = 47.9, SD = 32.3) ($t(913)$ = 1.72, p = 0.086, d = 0.11).

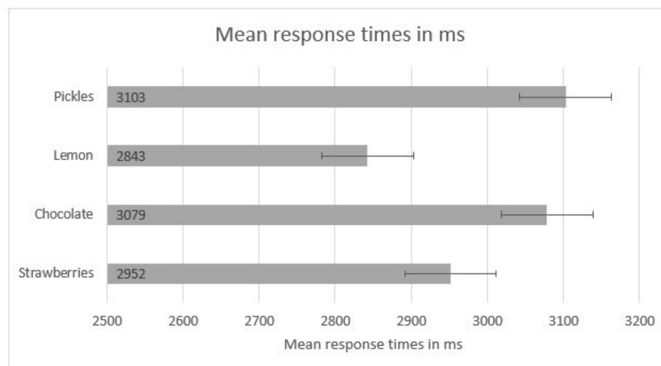
A second two-sample t-test was done, examining if the taste intensity did have an effect on the chosen number of elements in shapes when only taking the sour foods into effect (pickle for low intensity, lemon for high intensity). This t-test did indicate that the number of elements in shapes was significantly higher for the lemon stimulus (M = 61.2, SD = 32.1) than for the pickle stimulus (M = 52.6, SD = 32.7) ($t(462)$ = 2.86, p = 0.004, d = 0.26).

Response times

Response times (figure 4b) were sorted into two groups; one for both sweet stimuli (chocolate and strawberries) and one for both sour stimuli (lemon and pickles). A two-sample t-test did not indicate any significant difference between the response times of sweet foods (M = 4487 ms, SD = 7683 ms) and sour foods (M = 4438 ms, SD = 5841 ms) ($t(5363)$ = 0.27, p = 0.79, d = 0.007). However, when looking at the graph (figure



(a) Mean number of elements in chosen shapes, depicted per food stimulus.



(b) Mean reaction times for all shape pairs together, shown per food stimulus.

Figure 4: *a) Depicted is the mean shape complexity score (meaning the number of elements in the shape) in chosen shapes for all participants, shown per food stimulus. Each shape pair included in this graph differed in the number of elements only, with a lower score (under 50) indicating a low number of elements (but at least 4 elements) and a higher score (over 50) a higher number of elements in the shape (at the most 8 elements). b) Shown are the mean reaction times for all 12 shape pairs, per food stimulus.*

4b) there are clearly big differences between response times of all four food stimuli, without revealing a clear pattern between sweetness and sourness and low and high taste intensity.

Experiment 2

Method

Participants

74 participants took part in this online experiment. 43 were male, 31 were female. Participants were recruited using Profilic (https://prolific.ac/). The mean age of the participants was 29 ($\sigma = 7.7$). All consented to take part via a standard online consent form.

Stimuli

30 different dynamic textures of water were used during this online experiment in an .mp4 format. These textures come from the DynTex database by Péteri et al [14]. All textures are categorised using five descriptors, rating the temporal frequency, optic flow and spatial frequency of the water movement. Each dynamic texture was shortened to 10 seconds playing time.

Procedure

The experiment was constructed and hosted using Gorilla (https://gorilla.sc/). During the experiment, participants were shown dynamic water patterns and asked to match these to one of two basic tastes (sweet or sour). In each trial, one dynamic water pattern was automatically played during 10 seconds. Underneath, a sliding scale was placed, anchored with the words ”sweet” and ”sour”. Although nuance was possible with the scale, participants were essentially forced to make a choice between these two tastes, as the slider could not be left in the neutral position (score 50). This resulted in 30 taste-matching trials, giving 30 responses (per participant) between 0 and 100.

Data analysis

All data for experiment 2 was analysed in R (Version 1.1.463, https://cran.r-project.org/). Responses were be compared to the full results of the study by Toet et al (obtained specifically for this analysis). In this study, five different emotional responses were recorded for every dynamic texture (calmness, pleasure, arousal, interest and dominance) and two different values for the textures themselves, motion complexity and motion regularity. The sweetnes/sourness scores resulting from experiment 2 have been compared to these 7 descriptors separately by calculating Pearson's r per descriptor. Values of Pearson's r below 0.3 can be considered weak, values between 0.3 and 0.5 as a moderately strong correlation. Values above 0.5 indicate a strong correlation between the two compared groups.

Results

In order to compare the taste responses to the emotional responses to each of the 30 dynamic textures, results were taken from the study by Toet et al [22]. These results contained 7 different scores per dynamic water texture, of which 5 were elicited emotions: calmness, pleasure, arousal, interest and dominance. The last 2 categories applied to the dynamic textures themselves: motion complexity and motion regularity. Each of the 7 categories was plotted against the reponses gotten from this second experiment and for each Pearson's r was calculated to see whether a correlation was present. In the appendix, a table with all means and standard deviations (figure 6) and a scatterplot can be found of all responses of all participants to each dynamic water texture (figure 7).

Emotion descriptors

None of the emotion descriptors were a strong correlator for taste ratings in the dynamic water textures. Calmness ratings did not turn out to be a strong negative correlator for sourness associations ($t(28)$ = -0.63, r = -.12, p = 0.53). Pleasure ratings gave a similar result ($t(28)$ = -0.86, r = -.16, p = 0.40), as did the interest ratings ($t(28)$ = -0.24, r = -.05, p = 0.81).

The other emotion ratings were found to be even weaker. Arousal did not correlate strongly positive with sourness ($t(28)$ = 0.46, r = 0.09, p = 0.65), as did the dominance ratings ($t(28)$ = 0.09, r = 0.02, p = 0.93).

Movement descriptors

Movement complexity ratings did not correlate with the taste assocations of the dynamic water textures ($t(28)$ = 0.46, r = 0.09, p = 0.65). Movement regularity ratings was also not correlated with a sweeter associated taste ($t(28)$ = -1.62, r = -.29, p = 0.12).

Discussion

The aim of the first study was to provide further evidence for the link between sweetness and roundness, symmetry and a low number of elements in shapes. Furthermore, it introduced a new possible factor to influence shape matchings, the intensity of the expected tastes. This was also the aim of the original study done in the internship, of which this study is a second version after a redesign of the experiment itself. It was expected that the sweet foods (strawberry and chocolate) would be matched to more round, symmetrical shapes with few elements, and that the sour foods (pickles and lemon) would be matched to more angular, asymmetrical shapes with many elements. It was also expected that the taste intensity of these foods would have an effect on the chosen number of elements, in particular that a low taste intensity would be matched to shape with few elements and a high taste intensity to a shape with many elements. Lastly it was expected that participants would respond faster to sour foods than to sweet.

After looking at these associations for static shapes, we examine the link between taste and dynamic shapes. As regular, low complexity patterns are linked to calmness and low arousal (Toet et al (2012)) and sweet tastes are also linked to calmness (Blazhenkova & Kumar (2017)), it was expected that the patterns that are linked to calmness would also be linked to sweetness. This second study was more explorative, trying to strengthen the link between (dynamic) shape, taste and emotion. If a link between dynamic shapes and emotion exists, and between taste and emotion, this link would be more powerful if there was also an association between dynamic shape and taste (as it clearly does for static shapes).

Study 1

When comparing this study to the original internship, the results are very different. The original experiment did not show any links between taste and shape attributes, and also not between taste intensity and shape. After making the changes to the new experiment, making the focus on taste more explicit and changing the task into a forced choice, links between tastes and shapes became much more apparent. What this means for the experiment in general is that participant instruction is highly important. Making a choice between being explicit in the instruction or deciding not to give much information leads to drastically different conclusions. Changing the means of responding from a sliding scale to a sliding scale without a neutral position could also have had an influence in showing different results.

This study was successful in replicating findings also reported by Salgado et al (2015). These findings support evidence for a link between sweetness and roundness, symmetry and a low number of elements in shapes. It also provides evidence for the taste intensity being an influencing factor in taste shape cross-modal correspondences. While the number of elements in shapes did only increase with a higher taste intensity for sour food and not for sweet, there may be an explanation for this. A more intense shape is matched to a more intense sour flavour, as both a sour flavour and a very pointy shape are arousing (Blazhenkova et al (2017)), while a sweeter taste and a rounder shape were more likely to be experienced as relaxing and calming. A very intense sweet taste might therefore not be matched to a more intense round shape, but to a shape that would also feel as calming, which would be a more simple round shape. Another possibility is that a round shape with many elements might be perceived as less round than a more simple looking rounded shape, therefore lessening the association with sweetness in general.

Neither in the original study nor in this study did there emerge a clear pattern from response times. This indicates that participants did not feel more or less confident in choosing shapes for sweet foods than for sour, or for low or high taste intensity, even though response times did vary per individual food stimulus. As these differences cannot be explained by either basic taste or taste intensity, there may be other reasons for this at play. For instance stimulus shape, colour, liking or disliking of a particular food could be reasons for participants to respond faster to one food than to others. No conclusive remarks can be made about this, as participants were not asked for their liking of the foods, and were also asked explicitly to only consider the expected taste of the food, not the shape or colour.

It should also be noted that there was no time limit on each trial. Participants were instructed to not think too long about their answer, but they were not asked to respond as fast as possible. The study by Salgado et al (2015)) did find significantly faster response times for the word 'sour', but it was not specified whether these trials had a time limit or how the participants were instructed to respond. In order to further study participant confidence in matching tastes and shapes, instructing participants to respond as fast as possible could eliminate noise in response times and show a clearer pattern.

Study 2

Looking at figure 8 (appendix), a scatterplot of all responses by all participants in experiment 2, there is a clear absence of a clear pattern in responses. Each of the 30 dynamic water textures received taste responses that vary from sweet (score 0) to sour (score 100).

Water movement has been shown to have influence on food freshness (Li et al (2019)), but it might simply have no influence on actual basic tastes. Basic tastes have been shown to influence and be influenced by emotions (Blazhenkova & Kumar (2017)). We have also seen that dynamic textures can influence and elicit certain emotions Toet et al (2012)). This online experiment has been designed to explore a possible link connecting these emotions and basic tastes via the dynamic water textures, but this link may simply just not exist.

If indeed these links between taste and dynamic shapes do not exist, this indicates a clear difference in linking static and dynamic shapes to other senses. For static shapes, different shape attributes were used (roundness, symmetry, complexity) than for dynamic textures (motion regularity and complexity). Roundness, symmetry, a low number of elements, high motion regularity and low motion complexity have all been linked to positive emotions, calmness, boredom and relaxation (Blazhenkova (2017) for static shape attributes, Velasco et al (2016) and Bar & Neta (2006) for roundness, Turoman et al (2018) for symmetry, Toet et al (2012) for motion attributes), as have sweet tastes. The fact that these links between emotion, taste and shape exist for static shapes for not for dynamic shapes provides new research questions. Dynamic textures do have a link to food, as evidenced by the influenced perceived freshness of food (Li et al (2019)) by these textures.

There are also possible reasons that these links do exist, but that this study was not able to show them. Not many studies directly explored the link between water movement and taste, especially not in an online experiment without actual tastants. One of the possible reasons that this experiment has not shown any clear assocations between taste and dynamic textures may lie in the experiment itself. Looking again at figure 8, there is no clear concensus between participants about a well-fitting taste to each of the dynamic textures. It is possible that the instruction that participants received was not adequate enough to be able to choose a taste. The instruction might simply have been too abstract, as participants were only asked to match a taste to every texture. They were not asked to pay special attention to movement regularity or complexity, but simply were expected to go with a ”gut feeling”. Another possibility as that the effect may not have been shown in the current way that this experiment was designed. Extensive testing was done to make sure that every dynamic texture ran smoothly during the experiment, but movement or image quality may have been impaired due to bandwidth. Every participant completed this experiment online via their own device, and image and movement quality could not be guaranteed during the experiment.

Conclusion

Being able to find assocations between sweetness and roundness, symmetry and low shape complexity in study 1 brings more support for this hypothesis of taste-shape crossmodal correspondences. Not only does this lead to a more fundamental understanding of these processes, it also has valuable applications in real-life situations and in a commercial setting. Knowing that if a dish is expected to have a sweet taste, this taste could be elevated or diminished by using a the right plate shape and ambiance.

The absence of a link between taste and dynamic water patterns gives interesting new approaches for research, either identifying another factor that has effect on taste shape correspondences in dynamic shapes, or providing evidence that this link exists after all.

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Appendices

Food stimuli

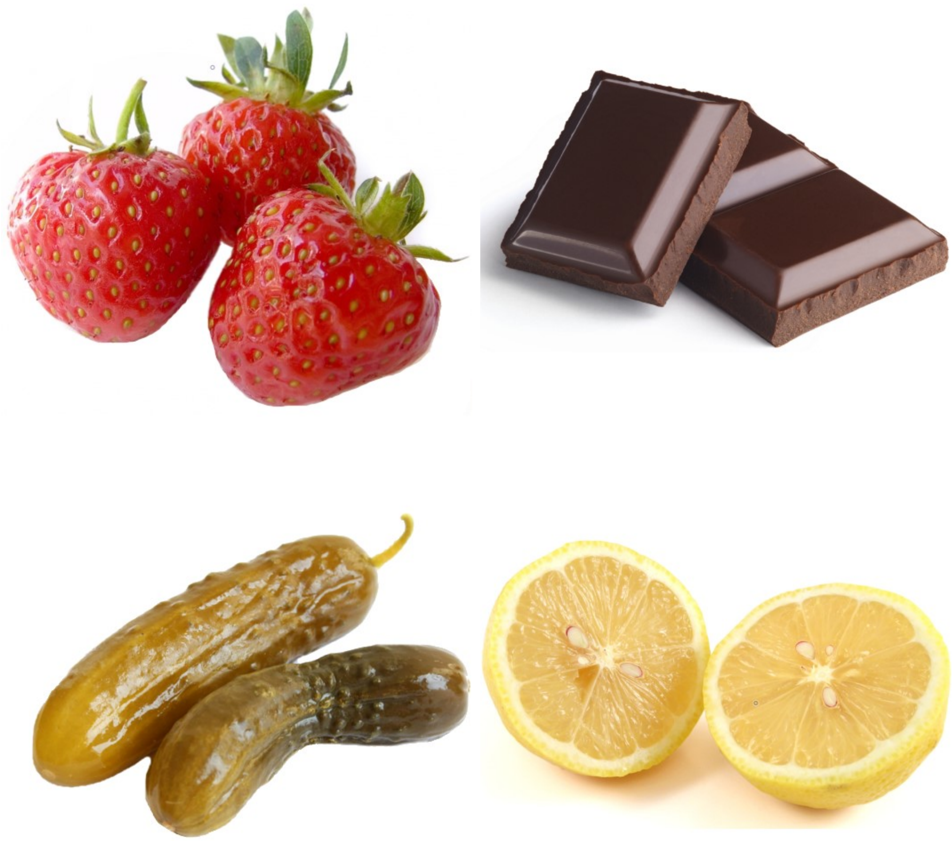

Figure 5: *In this figure all four food stimuli are shown that were used in experiment 1. These images were taken from the FRIDa food database [8]*

Results dynamic water patterns

Dynamic textures	M	SD
54ab110.mp4	51,02013423	19,05662607
54pf110.mp4	49,87919463	17,40414394
54pg110.mp4	48,87162162	15,95370872
55fa110.mp4	54,46621622	19,75544893
571b110.mp4	52,10135135	15,76344685
571b310.mp4	51,26174497	15,16102577
644c610.mp4	47,93918919	19,03924567
647b110.mp4	48,7972973	16,70918093
647b210.mp4	51,97297297	16,51630649
647b410.mp4	51,43243243	16,26655605
647b710.mp4	55,76666667	17,42921125
647b810.mp4	49,59060403	16,00380589
647c310.mp4	53,27702703	14,00137065
6484f10.mp4	49,91216216	18,89387802
6484i10.mp4	47,37162162	18,06273286
6485110.mp4	50,09459459	19,61511906
6485210.mp4	50,94594595	18,00142994
6487510.mp4	42,32432432	16,51971249
6489510.mp4	43,67567568	16,90961012
648e510.mp4	46,2027027	17,92082339
649dd10.mp4	55,58783784	17,75453532
649de10.mp4	53,36486486	18,20934523
649h310.mp4	47,76351351	18,08045567
649i410.mp4	41,84459459	16,96122542
649i810.mp4	38,52702703	17,73326401
649ic10.mp4	40,32	17,83229858
64adf10.mp4	47,05405405	17,72840596
64adl10.mp4	43,62416107	19,33085914
64cb810.mp4	50,87919463	19,82760591
6ame100.mp4	42,38666667	18,74655643
Grand Total	**48,60624438**	**18,12770016**

Figure 6: *Shown in this table are the mean responses and standard deviations of the responses per dynamic water texture (30 in total).*

Scatterplot of taste responses to dynamic water patterns

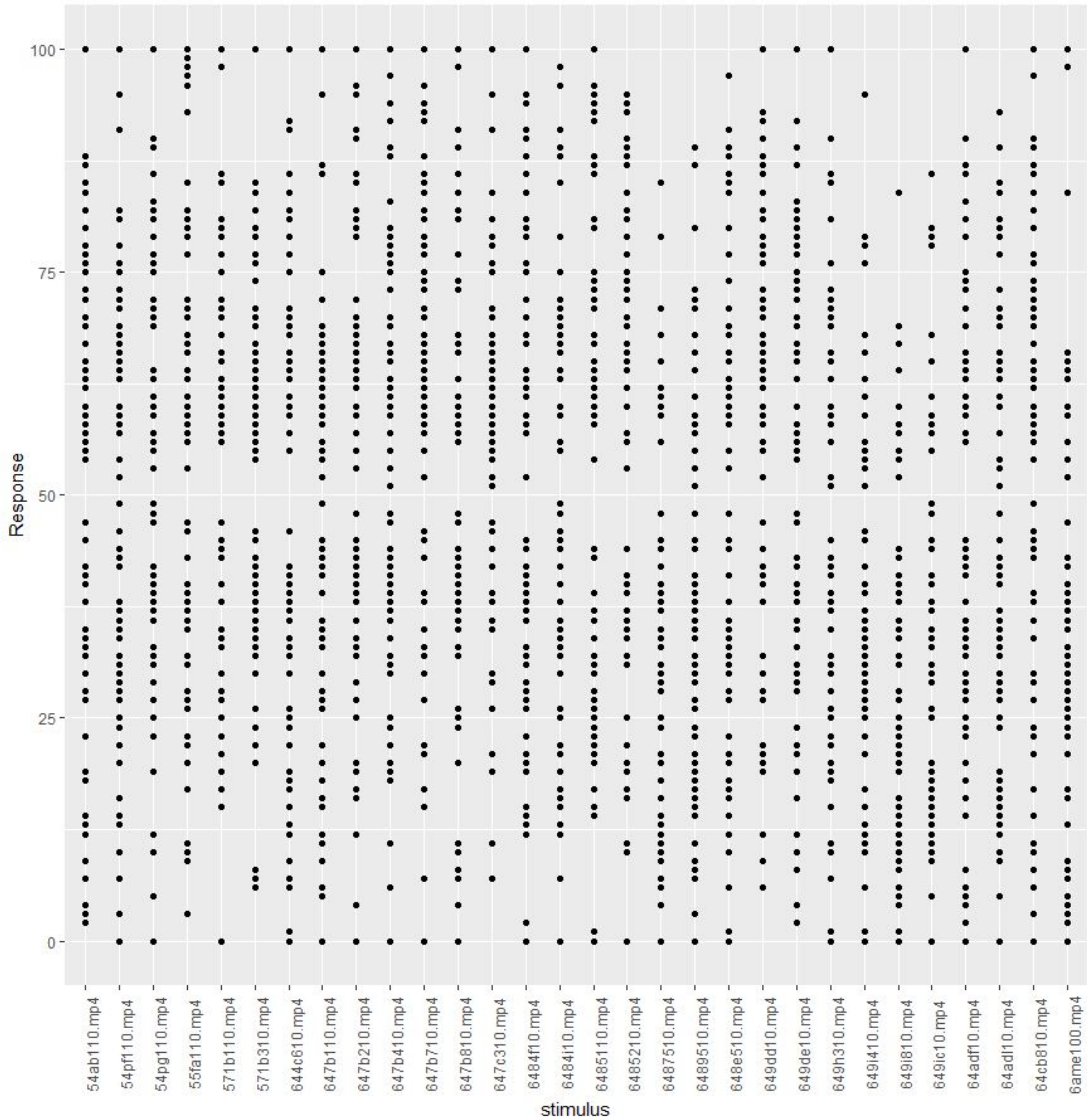

Figure 7: *Shown in this scatterplot are all taste responses by all participants to each dynamic water texture. A low response (<50) indicates an associated taste that is sweet, a higher response (>50) indicated a sourer associated taste.*