Exploring the mechanisms that underlie the crossmodal correspondences between shapes and tastes

Assessing the role of aesthetics, anthropomorphism, emotional valence, and embodied cognition

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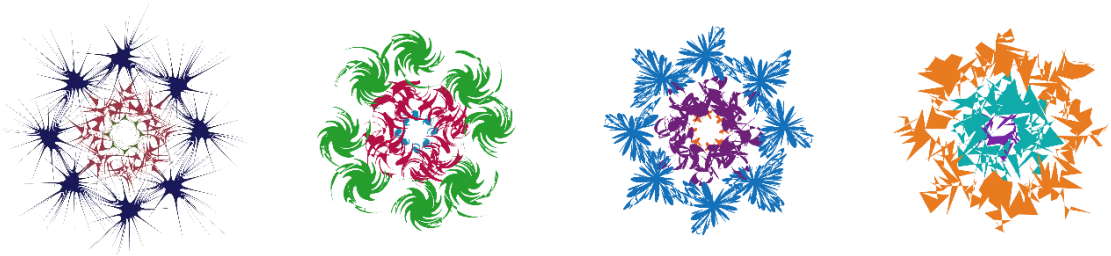


Table of Contents

0.1. ACKNOWLEDGEMENTS 4
0.2. PUBLISHED ARTICLES 6
0.3. ABSTRACT 8
0.4. LONG ABSTRACT 9
1. CHAPTER 1: Introduction 19
1.1 The basic tastes, evolution, and facial expressions 22
1.1.1. Physiological and evolutionary aspects of taste receptors 25
1.1.2. Taste and facial expressions 33
1.2. Aesthetic features, emotional valence, and basic taste 35
1.3. Anthropomorphic features, valence, emotion, and basic tastes 42
1.4. Embodied cognition 45
2.CHAPTER 2: Symmetry, curvature, and the number of elements and their relation to emotional valence and gustatory taste 47
2.1. Introduction 47
2.2. Matching shapes to approach and avoidance words 48
2.2.1. Methods and materials 49
2.2.2. Results and discussion 51
2.3. The influence of curvature, symmetry, and the number of elements on shape-valence and shape-taste matching 52
2.3.1. Methods 53
2.3.2. Results and discussion 56
2.4. General discussion 71
3.CHAPTER 3: Anthropomorphism, valence, and taste 73
3.1. Introduction 73
3.2. The implicit association test and lines that resemble sad and happy mouths 75
3.2.1. Methods and materials 75
3.2.2 Results 78
3.2.3. Discussion 80
3.3. Eye-like dots can convey a specific valence 82
3.3.1. Method and materials 83
3.3.2. Results 86
3.3.3. Discussion 90

3.4. Dots that resemble eyes can be associated with distinct emotions 92
3.4.1. Methods and materials.....93
3.4.2. Results 94
3.4.3. Discussion.....95
3.5. Lines that resemble a smile/frown can influence product preferences 96
3.5.1. Methods and materials.....100
3.5.2. Results 103
3.5.3. Discussion.....108
3.6. Shapes associated with emotion can influence product taste expectations.....113
3.6.1. Methods and materials.....114
3.6.2. Results 116
3.6.3. Discussion.....121
3.7. General Discussion.....122
4.CHAPTER 4: The role of facial expressions in shape-taste correspondences 127
4.1. Introduction.....127
4.2. Facial expressions influence the perceived intensity of basic tastes.....130
4.2.1. Methods and materials.....130
4.2.2. Results 134
4.2.3. Discussion.....138
5. CHAPTER 5: Concluding remarks: Bringing vision and taste together 141
5.1. A closer look at how specific visual features are matched to tastes 142
5.2. Embodied cognition and shape-taste correspondences.....144
REFERENCES 148
Appendix A Drawing sounds: Representing tones and chords spatially.....180
ABSTRACT.....181
A.2. STUDY A1.....188
A.3. STUDY A2.....201
A.4. General Discussion.....205
REFERENCES.....210

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The following articles were used in the introduction of the thesis:

Salgado-Montejo, A., Alvarado, J. A., Salgado, C. J., & Spence, C. (2016). Simple lines and shapes are associated with, and communicate, distinct emotions. *Cognition and Emotion, 31,* 511-525.

Salgado-Montejo, A., Alvarado, J., Velasco, C., Salgado, C. J., Hasse, K., & Spence, C. (2015). The sweetest thing: The influence of angularity, symmetry, and the number of elements, on shape-valence and shape-taste matches. *Frontiers in Psychology*, *6,* 1382.

The articles included in Chapter 3:

Salgado-Montejo, A., Alvarado, J., Velasco, C., Salgado, C. J., Hasse, K., & Spence, C. (2015). The sweetest thing: The influence of angularity, symmetry, and the number of elements, on shape-valence and shape-taste matches. *Frontiers in Psychology*, *6,* 1382.

Velasco, C., **Salgado-Montejo, A.**, Elliot, A. J., Woods, A. T., Alvarado, J., & Spence, C. (2016). The shapes associated with approach/avoidance words. *Motivation and Emotion, 40,* 689-702.

The articles used in Chapter 4:

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Salgado-Montejo, A., Tapia Leon, I., Elliot, A. J., Salgado, C. J., & Spence, C. (2015). Smiles over frowns: When curved lines influence product preference. *Psychology & Marketing, 32,* 771-781.

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Salgado-Montejo, A., Marmolejo-Ramos, F., Alvarado, J., Arboleda, J. C., & Spence, C. (2016). Drawing sounds: Representing tones and chords spatially. *Experimental Brain Research, 234,* 3509-3522.

0.2. PUBLISHED ARTICLES

Peer-reviewed

1) Velasco, C., Woods, A. T., Wan, X., **Salgado-Montejo, A**., Bernal-Torres, C. A., Cheok, A. D., Spence, C. (2017). The taste of typefaces in different countries and languages. *Journal of Aesthetics Creativity and the Arts*.

2) **Salgado-Montejo, A.**, Marmolejo-Ramos, F., Alvarado, J., Arboleda, J. C., & Spence, C. (2016). Drawing sounds: Representing tones and chords spatially. *Experimental Brain Research*, *234*, 3509-3522. http://link.springer.com/article/10.1007%2Fs00221-016-4747-9

3) Velasco, C., **Salgado-Montejo, A.**, Elliot, A. J., Woods, A. T., Alvarado, J., & Spence, C. (2016). The shapes associated with approach/avoidance words. *Motivation and Emotion*, *40*, 689-702. http://link.springer.com/article/10.1007/s11031-016-9559-5

4) **Salgado-Montejo, A.**, Alvarado, J. A., Salgado, C. J., & Spence, C. (2016). Simple lines and shapes are associated with, and communicate, distinct emotions. *Cognition and Emotion*, *31*, 511-525. http://www.tandfonline.com/doi/abs/10.1080/02699931.2015.1133401?journalCode=pcem20

5) **Salgado-Montejo, A.**, Alvarado, J., Velasco, C., Salgado, C. J., Hasse, K., & Spence, C. (2015). The sweetest thing: The influence of angularity, symmetry, and the number of elements, on shape-valence and shape-taste matches. *Frontiers in Psychology*, *6*, 1382. http://journal.frontiersin.org/article/10.3389/fpsyg.2015.01382/abstract

6) Wan, C., Woods, A. T., **Salgado-Montejo, A.**, Velasco, C., & Spence, C. (2015). Assessing the expectations associated with pharmaceutical pill colour and shape. *Food Quality and Preference*, *45*, 171-182. http://www.sciencedirect.com/science/article/pii/S095032931500138X

7) **Salgado-Montejo, A.**, Tapia Leon, I., Elliot, A. J., Salgado, C. J., & Spence, C. (2015). Smiles over frowns: When curved lines influence product preference. *Psychology & Marketing*, *32*, 771-781. http://onlinelibrary.wiley.com/doi/10.1002/mar.20817/abstract

8) Juravle, G., Velasco, C., **Salgado-Montejo, A.**, & Spence, C. (2015). The hand grasps the centre, while the eyes saccade to the top of novel objects. *Frontiers in Psychology*, *6*, 663. http://journal.frontiersin.org/article/10.3389/fpsyg.2015.00633/abstract

9) Velasco, C., Wan, C., Knoeferle, K., Zhou, X., **Salgado-Montejo, A.**, & Spence, C. (2015). Searching for flavor labels in food products: The influence of color-flavor congruence and association strength. *Frontiers in Psychology, 6,* 301.

http://journal.frontiersin.org/article/10.3389/fpsyg.2015.00301/abstract

10) **Salgado-Montejo, A.**, Velasco, C., Olier, S., Alvarado, J., & Spence, C. (2014). Love for logos: Evaluating the congruency between brand symbols and typefaces and their relation to emotional words. *Journal of Brand Management*, *21*, 635-649. https://link.springer.com/article/10.1057/bm.2014.29

11) Michel, C., Velasco, C., **Salgado-Montejo, A.**, & Spence, C. (2014). The butcher's tongue illusion. *Perception*, *43*, 818-824. http://www.perceptionweb.com/abstract.cgi?id=p7733

12) Velasco, C., Wan, X., **Salgado-Montejo, A.**, Woods, A., Onate, G., & Spence, C. (2014). The context of colour-flavour associations in crisps packaging: A cross-cultural study between China, Colombia, and the UK. *Food Quality and Preference*, *38*, 49-67. http://www.sciencedirect.com/science/article/pii/S0950329314001001

13) Velasco, C., **Salgado-Montejo, A.**, Marmolejo-Ramos, F., & Spence, C. (2014). Predictive packaging design: Tasting shapes, typefaces, names, and sounds. *Food Quality and Preference*, *34*, 88-95. http://www.sciencedirect.com/science/article/pii/S0950329313002310

Industry commentary

1) **Salgado-Montejo, A.**, Velasco, C., Ariza, L., Salgado, R., Moreno, A. M. (2017). The four moments of experience: Streamlining the process of packaging development. ESOMAR World Congress 70th Anniversary.

2) **Salgado-Montejo, A.**, Velasco, C., Maya, C., Woods, A. T., & Spence, C. (2016). Consumer understanding in the age of entrepreneurship: Using experimental psychology and online testing to massify research. ESOMAR Latam Congress 2016 – Research Renovation.

3) **Salgado-Montejo, A.**, Velasco, C., Maya, C., & Spence, C. (2015). Diseño sinestésico de envases: El envase multisensorial y los cuatro momentos de experiencia [Synesthetic packaging design: Multisensory packaging and the four moments of experience]. *El Empaque + Conversión*, *21*(3), 22-28.

4) **Salgado-Montejo, A.**, Maya, C., Velasco, C., & Spence, C. (2014). Construya experiencias a partir del sonido del envase. [Create experiences via the sound of the packaging]. *El Empaque + Conversión*, *20*(4), C8-C11. ISSN 1067-4586.

5) **Salgado-Montejo, A.**, Velasco, C., Maya, C., & Spence, C. (2014). La ciencia del color y cómo se puede aplicar a envases y etiquetas [The science of colour and how it can be applied to packaging and labels]. *El Empaque + Conversión*, *20*(2), 46-48. ISSN 1067-4586.

6) **Salgado-Montejo, A.**, Velasco, C., & Spence, C. (2014). Potenciando el sabor del producto a través de la forma del envase. [Enhancing the flavour of the product through the shape of its packaging]. *El Empaque + Conversión*, *20*(1), Febrero-Marzo, 14-18. ISSN 1067-4586.

0.3. ABSTRACT

Exploring the mechanisms that underlie the crossmodal correspondences between shapes and tastes: Assessing the role of aesthetics, anthropomorphism, emotional valence, and embodied cognition.

Alejandro Salgado Montejo, Oriel College and Crossmodal Research Laboratory, University of Oxford

DPhil in Experimental Psychology, Michaelmas Term, 2017

This thesis consists of one theoretical chapter, three experimental chapters, and a final concluding chapter. Eight studies were conducted in total, two of these studies (studies 1-2, Chapter 2) evaluated whether visual aesthetic features (i.e., symmetry, curvature, and the number of elements) influenced how shapes and objects are matched to a valence and to a taste word (i.e., sweet or sour). The evidence reported in Chapter 2 demonstrates that symmetrical / asymmetrical, rounded / angular, and shapes with fewer / more elements are more likely to be matched with a positive / negative valance and to sweetness / sourness. The relationship between valence and shape-taste matching is discussed and challenged. Three different studies (studies 3-7, Chapter 3) analysed whether simple dots and lines that resemble facial features (i.e., eyes and mouth) could be associated with an emotional valence and an emotion, as well as to a specific taste word (i.e., sweet, sour, or bitter). The results reported in Chapter 3 confirm that it is possible to reduce a facial feature to its simplest form (i.e., a line and a dot) and still be associated with a specific valence and emotion. Furthermore, Study 7 demonstrates that dots and lines that resemble eyes and mouths can influence taste expectations (i.e., how sweet, sour, or bitter they predict a product will be). Chapter 4, comprises a short study that provides initial evidence that facial expressions of joy, disgust and anger can influence the perceived intensity of a taste (i.e., sweet, sour, and bitter). The role of embodied cognition in the crossmodal correspondences between shapes and tastes is discussed. Finally, in Chapter 5, the importance of associative learning, the role of evolution in our ability to detect patterns, and embodied cognition are presented as potential mechanisms that explain how it is that shapes are matched to tastes.

0.4. LONG ABSTRACT

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Chapter 1

This chapter begins showing the diverse and growing interest in understanding how visual information can be associated with an emotional valence and with information derived from other senses (e.g., from evolutionary biology and ethology, aesthetic science, neuroscience, and experimental psychology). I am particularly interested in how visual information can be associated with a specific gustatory taste (i.e., sweet, sour, or bitter). It has been suggested that shape-taste matches are facilitated by an underlying shared emotional valence. However, recent evidence has established that the emotional valence of the stimulus cannot fully account for these associations. The need to further understand the mechanisms facilitating shape-valence and shape-taste matches is underscored. I posit that both aesthetic (i.e., symmetry, curvature, and the number of elements) and anthropomorphic features (i.e., lines and dots that resemble eyes and mouths) influence how shapes are matched to a valence and to basic tastes. I propose that embodied cognition may be involved in shape-taste matches and that there is a need for further research to address this link.

Chapter 1 reviews four key topics. First the physiological and behavioural bases of gustation, showing that gustatory perception is inherently categorized in terms of appetitive (e.g., sweet) and aversive (e.g., sour and bitter) responses. These motivational stances that are derived from our gustatory experience are generally accompanied by a

facial expression. Afterwards, the literature on aesthetic features is reviewed, specifically those studies looking at symmetry, curvature, and the number of elements. Symmetry, roundness, and stimuli with fewer elements are preferred. Asymmetry, angularity, and stimuli with a greater number of elements tend to be rated as unpleasant. There is evidence that roundness / angularity is associated with sweetness / sourness and with the word sweet / sour. Thereafter, studies concerned with how simple lines and shapes can be associated with a specific valence or motivational stance are reviewed. The evidence points to the idea that facial expressions and facial features can be reduced to their simplest expression, a line or dot, and still retain their "meaning" (i.e., the valence or emotion that they are associated with). Finally, I include a brief review of the concept of embodied cognition and its importance in understanding the world around us and potentially (at least) some of the crossmodal correspondences. Embodied cognition alludes to the fact that the body and the brain make cognition possible. Motor, visceral, physiological, responses are used as scaffolding to construct our cognitive experience. Bodily experiences, then, facilitate and define the cognitive experience of an organism.

Chapter 2

This chapter is comprised of two studies (Studies 1-2) and focuses on evaluating the influence of symmetry, curvature, and the number of elements in terms of approach/avoidance stances, valence, and two basic tastes (i.e., sweet and sour).

Study 1

The influence of symmetry and curvature on approach and avoidance stances was evaluated. The participants had to match five pairs of approach/avoidance words with eight shapes varying in both symmetry and curvature. The results show that symmetrical

shapes and symmetrical and rounded shapes were more easily matched to an approach word. Shapes that were asymmetrical and angular were associated with an avoidance word. This study constitutes a first step in furthering our understanding of shape-taste matches as there is evidence showing that basic tastes are inherently associated with a motivational stance.

Study 2

The objective of this study was to evaluate the influence of symmetry, curvature, and the number of elements in shape-valence and shape-taste matches. Two tasks were presented to the participants. In the first task, they had to match eight different shapes to the words pleasant or unpleasant using mouse tracker software. The second task consisted on the same procedure, but the participants now had to match the shapes to the words sweet and sour.

The results of Study 2 suggest that symmetry and the number of elements had the strongest influence on the shape-valence task for both countries. Symmetry/asymmetry presented the highest influence on the likelihood of matching a shape to a specific valence in both countries. Shapes that were symmetrical and presented fewer elements were deemed more pleasant when compared to those that were asymmetrical and had a greater number of elements. For the shape-taste task, no differences were found for the two countries in terms of the direction of the main effects.

Rounded, symmetrical, and shapes with fewer elements were more likely to be matched to the word sweet. Angular, asymmetrical, and shapes with a greater number of elements were matched to the word sour. A correlation between the results of the first and second task revealed that the valence of the stimulus is a significant, but weak predictor, of shape-

taste matches. The latter evidence underscores the importance of conducting further studies aimed at identifying potential mechanisms that explain the correspondences.

Chapter 3

The research presented in this chapter sought to study whether dots and lines that resemble facial features (i.e., mouths and eyes) could be associated with an emotional valence, specific emotions (i.e., joy, surprise, anger, and sadness), and whether they would influence taste expectations. This chapter consists of five studies (3-7).

Study 3

This study evaluated whether a concave, convex, and a flat line that resembled a mouth could be associated with the words happy and sad. The participants were presented with six implicit association tests (IAT) to evaluate the association strength of a concave, convex, and flat line with the words happy and sad.

It was easier for the participants to associate the concave line with the word happy as compared to the convex line, and straight line, and to associate the word sad with the convex line. The results of this study suggest that simple lines that resemble a smile or frown can be associated with the words happy and sad, respectively. Study 4 was carried out to determine whether dots that resemble eyes influence the perceived valence of the stimulus.

Study 4

In order to evaluate whether different dots that resembled eyes could influence the perceived valence of a concave (happy) and convex (sad) line, the participants were presented with a total of 12 emoticons. The emoticons presented either a concave or

convex line, and one of six pairs of dots. The dots corresponded to the movement of the parpebralis, procerus, zygomaticus, and frontalis muscles. Visual analogue (VA) scales were used to evaluate the emotion (i.e., happy / sad), valence (pleasant / unpleasant), liking, and perceived tension (i.e., relaxed / tense) of each of the emoticons. The participants categorized the emoticons in terms of a valence and the words happy and sad using a forced-choice task.

The results of Study 4 replicate the findings of Study 3 and confirm that simple lines are consistently associated with an emotional valence and with the words happy and sad. Overall, those eyes that were paired with the concave line were rated as more positive on all the scales (i.e., happier, more pleasant, more liked, and relaxed), with the opposite being true for those eyes paired with the convex line.

A significant interaction was found between the lines and the dots in the choices made by the participants in the forced-choice task, suggesting that the eyes aid in defining the valence of the emoticon. The results in the forced-choice task demonstrate that the dots that resemble eyes influence categorization speed. These results suggest that the lines can determine the overall valence of the emotion (as shown by the IATs, VA scale scores, and the participants' choices in the mouse tracking task) and that it is possible that the eyes of the emoticons influence the relative valence (and perhaps also the intensity) of the emotion perceived. The findings of Study 4 are consistent with research on facial expressions of emotion showing that different parts of the face can convey specific emotions.

Study 5

After demonstrating that the dots that resemble eyes influence the perceived valence of an emoticon, it was important to determine whether the dots could be associated with

specific emotions. Understanding whether simple visual stimuli can convey emotions sheds light on how the brain processes information such as facial expressions. Four emotions were selected for the study (i.e., joy, surprise, anger, and sadness) as well as the dots from Study 4. The participants had to classify each of the six dots by clicking on one of the four emotions presented on each corner of the screen. Of the six eyes, four presented consistent matches with an emotion: the concave eyes with sadness, the convex eyes with joy, the oblique eyes with anger, and the vertical eyes with surprise.

The results of Study 5 are consistent with previous research on facial expressions and specifically with research showing that certain muscles correspond to specific emotions. The findings of this study are consistent with previous research showing that a "V" is matched to anger or threat, and that simple visual stimuli can be consistently associated with a valence and with specific emotions. Study 5 contributes to research on perception and emotion by showing that simple visual stimuli can be associated with positively valenced emotions.

Study 6

The objective of Study 6 was to validate the effect of the lines that resemble a smile or frown in a more applied context. Particularly that of product packaging which facilitates the embedding the lines into a more complex design. By presenting the lines as part of more complex stimuli, it is possible to validate whether the effect of lines is present in more ecologically valid stimuli and therefore if it has any real-world validity. VA scales were used in conjunction with a forced-choice task in the present research. VA scales provide explicit ratings of reward estimation and purchase intent toward the products used; the forced-choice task was designed to complement the VA data by assessing

whether there would be a change in people's preferences when pairs of products were tested against each other.

Participants from the UK and Colombia took part in the study. The products were chosen to cover a diversity of design features (i.e., shape, colour) and categories (tea, shampoo, and juice); this minimized the likelihood that any findings would be a mere function of idiosyncratic aspects of the stimuli presented. There were four conditions (i.e., concave, convex, flat, and absent) for each product category giving rise to a total of 12 designs.

Overall, the concave (smiling) and flat lines yielded the highest scores in all scales in both countries, suggesting that products with these features can positively bias liking, wanting, and purchase intent. The convex (frowning) line presented the lowest scores. The forced-choice task confirmed the results obtained via the VA scales and demonstrate the there is a preference for products presenting a smiling line and even more so when compared to product displaying the frowning line.

The results of Study 6 reveal that simple lines that resemble a mouth can be associated with a specific valence and can influence choices in an applied context. Moreover, the results from this study replicate the findings presented in Studies 3 and 4.

Study 7

After demonstrating that simple lines and dots that resemble facial features can be associated with a valence and with specific emotions, the question that remains was whether these same features could also influence taste expectations. It is important to bear in mind that gustatory experiences are generally accompanied by a facial expression that activates muscles that are also involved in joy, anger, and disgust. Therefore, it is viable to expect that simple lines and dots that are associated with specific emotions will also be associated with a specific basic taste.

In this study, the participants were presented with four product categories (i.e., ice cream, crisps, juice, and beer) and had to rate each stimulus along three VA scales. The VA scales asked the participants how sweet, sour, or bitter they expected the product to be. The eyes from Study 5 and the lines from Study 6 were embedded into the design of each of the packages giving rise to a total of 28 different products. The results revealed that the ratings made by the participants of each of the products in terms of how sweet, sour, or bitter varied depending on which of the lines or dots were present in the packaging. Products with dots and lines associated with joy were rated as sweeter, while those features that are more easily matched to a negative valence and to emotions such as sadness or anger yielded higher ratings in terms of sour and bitter. The results suggest that lines and dots that resemble mouths and eyes can influence taste expectations in four product categories.

Chapter 4

The previous chapters demonstrated that features such as symmetry, curvature and the number of elements, as well as anthropomorphic features can be associated with a valence and with a basic taste. What remains now is to explore a mechanism that might explain how these visual features are associated with a valence and a basic taste. In this chapter, embodied cognition is put forward as a good candidate mechanism with which to explain this phenomenon. This chapter explores whether facial expressions can influence the perceived intensity of a basic taste.

Study 8

Water-based solutions of caffeine (bitter), critic acid (sour), and sucrose (sweet) were presented to participants. Three different concentrations of each of the basic tastes were

produced, giving rise to a total of 12 basic taste solutions. The participants had to drink each the solutions from a small plastic cup and afterwards do one of the following on each trial; to maintain a neutral expression, to produce am angry face, or to smile. Afterwards, the participants had to rate the intensity and valence of the taste, as well as the roundness/angularity of both the taste and their own facial expression.

The facial expression produced after trying each solution had an influence on the perceived intensity of the tastes. There was a correlation between the taste and face roundness/angularity scores, suggesting that more angular faces were associated with more angular tastes (i.e., bitter and sour). The smile influenced the perceived intensity of the sweet solution, while the frowning expression had the same effect for the bitter and sour solutions. The interaction between the face and the taste reveals that the facial expression is involved in encoding the valence of a gustatory experience. With the results from Study 8 in mind, it is proposed that affective matching may be a by-product of the relationship between tastes and facial expressions, given that facial expressions (which convey a specific shape) tend to be associated with an emotional valence.

Chapter 5

The concluding chapter of this thesis explores the possible mechanisms involved in shape-taste matches considering the results presented in the previous chapters. Throughout this thesis, I have repeatedly raised three fundamental points: First, that taste evolved to sort noxious substances from those that are nutritious. This automatic categorization of tastes, in turn, enables the encoding of gustatory experiences in terms of approach and avoidance.

The second point to note is that specific visual features can influence how tastes are matched to visual information (e.g., as conveyed by shapes, lines, dots, and product

packaging). Specifically, the experiments reported in this thesis have demonstrated that features such as symmetry, curvature, and the number of elements can influence how participants match shapes to taste words. Furthermore, anthropomorphic features that resemble eyes and mouths (i.e., dots and lines) also influence how shapes are matched to tastes. Dots and lines that presented a positive valence, swayed responses towards expectations of sweetness, whereas negatively-valenced dots and lines were more easily matched to bitterness and sourness instead. The main contribution of this thesis, then, in that respect, is that it demonstrates that specific visual features mediate these matches.

The third and final point is that facial expressions can influence the perceived intensity of a basic taste. Overall, incongruent facial expressions to those that generally accompany a gustatory experience reduced the perceived intensity of each taste (e.g., smiling when tasting a bitter solution or frowning when tasting a sweet solution). The aforementioned evidence therefore helps connect research on the crossmodal correspondences between shapes and tastes with that on embodied cognition. The results presented throughout this thesis, highlight the importance of associative learning and the ability of organisms to detect patterns to explain shape-taste correspondences. The conclusions derived from this thesis research may be relevant for the designers seeking to communicate different sensory experiences and for the development of product packaging.

1. CHAPTER 1: Introduction

"Our obsession with the senses has been driven as much by a need to understand how we apprehend the physical world as it has by the need to understand how we become who we are, based on those sensory experiences."

Stein (2012, p. xi)

Over the last hundred years or so, there has been a steady stream of interest in understanding how visual information can be associated with both an emotional valence (Aronoff, Barclay, & Stevenson, 1988; Gordon, 1909; Larson, Aronoff, & Steuer, 2012; Poffengerger & Barrows, 1924; Salgado-Montejo, Velasco, Olier, Alvarado, & Spence, 2014) and with information derived from the other senses (Ngo et al., 2013; Ngo, Misra, & Spence, 2011; Ngo, Piqueras-Fiszman, & Spence, 2012; Spence & Gallace, 2011; Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014). A wide range of fields of research have slowly begun to explore how visual information is matched to an emotional valence and to a gustatory taste.

For instance, evolutionary biology and ethology have both addressed how it is that visual signals can be associated with relevant information for survival (e.g., resources, quality, or danger, see Apthorp & Bell, 2015; Enquist & Johnstone, 1997; Enquist & Arak, 1994; Perrett et al., 1999; Rhodes, 2006; Rodríguez, Gumbert, De Ibarra, Kunze, & Giurfa, 2004). Aesthetic science has looked at how canons of beauty are formed and why certain visual patterns are preferred by the general population (e.g., Makin, Pecchinenda, & Bertamini, 2012; Palmer, Schloss, & Sammartino, 2013; Shepherd & Bar, 2011; Shimamura & Palmer, 2014; Tinio & Leder, 2009). Neuroscience (and particularly neuroaesthetics) has sought to identify the neural mechanisms that are involved in aesthetic experience (e.g., Brown, Gao, Tisdelle, Eickhoff, & Liotti, 2011; Cela-Conde, Agnati, Huston, Mora, & Nadal, 2011; Chatterjee, 2011; Cinzia & Vittorio, 2009; Höfel

& Jacobsen, 2007; Jacobsen, Schubotz, Höfel, & Cramon, 2006; Kirk, Skov, Christensen, & Nygaard, 2009; Nadal & Pearce, 2011).

The study of crossmodal correspondences, within the field of experimental psychology, has focused on how the brain associates seemingly unrelated information from different senses (Spence, 2011). The initial interest in these sensory associations (e.g., a rounded shape with a sweet taste) was in documenting their very existence. However, more recent research has focused on three key points: 1) Understanding how sensory information in one sense can produce expectations in other senses (e.g., seeing rounded typeface and expecting a product to taste sweet); 2) Determining whether these expectations can affect our sensory experience (e.g., influencing the taste of a product via the colour of its packaging); and 3) Suggesting potential mechanisms to explain how the brain formed these associations in the first place (Spence, 2011, see also Deroy & Spence, 2013; Martino & Marks, 2001).

The relationship between shapes and tastes has steadily caught the attention of researchers interested in the study of the crossmodal correspondences. There is already evidence to demonstrate that, for example, shapes can be consistently associated with basic tastes (i.e., sweet and sour, see Ngo et al., 2013; Velasco, Woods, Deroy, & Spence, 2015, for examples). Following earlier work (Collier, 1996; Kenneth, 1923; Lyman, 1979), Spence and Deroy (2013) suggested that the crossmodal correspondences between shapes and tastes may be mediated, at least in part, by a shared underlying emotional valence. Emotional valence can be understood as the assessment of whether a situation/object is perceived as helpful/harmful or rewarding/threatening (Feldman, 2006; Lane, Chua, & Dolan, 1999). The prediction is that if a taste and shape are both deemed pleasant/unpleasant then they will be matched to each other. Velasco et al. (2015) have provided evidence that the valence of tastes and shapes does indeed appear to be

involved in shape-taste matches, however they do not seem to fully account for the phenomenon (see also Section 2.7 of this thesis).

The challenge, then, is to further demonstrate that valence cannot fully explain shape-taste matches and provide an alternative mechanism. To accomplish the latter, it is necessary to address three key issues. The first is to determine what the mechanisms are that explain how simple visual forms (e.g., a downward-pointing triangle or a concave line) can be associated with a valence and a motivational stance (e.g., approach or avoidance). It is of particular interest here to expand the existing research that has studied how downward-pointing triangles, a "V", and simple lines that resemble a frown can be associated with threat and anger (e.g., Larson, Aronoff, & Stearns, 2007; Larson et al., 2012; Watson, Blagrove, Evans, & Moore, 2012). Specifically, there is a need to determine whether simple visual patterns can also be matched to positively valenced emotions and approach behaviours.

The second challenge is to explore whether specific visual features (e.g., curvature and symmetry) facilitate shape-taste associations and whether emotional valence is involved. In this case, I am interested in determining if the (mostly theoretical) claim that emotional valence mediates the crossmodal correspondences between shapes and tastes is actually correct. Is valence the mechanism that facilitates these unexpected matches or is there more to the story of shape-taste correspondences? The third and last challenge is a sort of unifying question: Does embodied cognition play a role in the matching of visual information to a valence and to gustatory tastes? I am particularly interested in determining whether facial expressions provide the "missing link" in terms of explaining how it is that shapes and tastes are matched to a valence and to each other.

This introductory chapter (Chapter 1) has four sections, the first reviews the literature on gustation and facial expression (Section 1.1). The second focuses on aesthetic visual

features, emotional valence, and taste (Section 1.2). The third section looks at the concept of anthropomorphism (Section 1.3), and finally, in the last section, I concentrate on the concept of embodied cognition (Section 1.4).

1.1 The basic tastes, evolution, and facial expressions

Even though each organism may have its own "tasting" system (just imagine tasting through hairs in your body, like a fruit fly! See Clyne, Warr, & Carlson, 2000), most of these systems use chemosensory receptors to transduce molecules into taste[1] experiences. Most, if not all organisms, from bacteria through to humans, have some sort of system in place with which to evaluate a potential food source before ingesting it. Gustation (i.e., taste), like pleasure, evolved to help organisms discriminate between options, learn, and ultimately, stand a better chance of survival. Taste receptors[2], the basic unit of gustation, detect specific substances that reveal two key aspects concerning a potential food, the safety/danger level and the nutritional value. Understanding why and how we choose what to eat stands at the centre of human behaviour and touches on a wide range of issues that are of interest to experimental psychology (i.e., the mechanisms of perceptual experience).

[1] Here it is important to differentiate taste from flavour. The widely-accepted view is that all sensations that are directly caused by receptors in the mouth except for tactile, trigeminal, and thermal sensations are part of taste (i.e., gustation or gustatory perception). Flavour, on the other hand, has been described as a *"Complex combination of the olfactory, gustatory and trigeminal sensations perceived during tasting. The flavour may be influenced by tactile, thermal, painful and/ or kinaesthetic effects."* (ISO standard for sensory analysis 5492, in Spence, 2012a, p. 505). Sound may be the "forgotten" sense when it comes to defining flavour further demonstrating that a wide variety of senses are involved in modulating flavour perception (Spence, 2012a).

[2] Taste receptors are specialized epithelial cells that act as chemical detectors and are usually concentrated in the rostral region of the gastrointestinal system (i.e., the mouth). These receptors are generally clustered together in what are known as taste buds (Bigiani et al., 2003; Stone, Finger, Tam, & Tan, 1995). All vertebrates, except for hagfish, have taste buds innervated by the VIIth, IXth, and Xth cranial nerves (Northcutt, 2004).

Notwithstanding the significant progress that has been made in the understanding of olfactory experiences over the last two decades, some of the mechanisms of gustatory perception remain somewhat elusive (Mouritsen, 2015). More importantly, there is still a need to understand what can be considered a "basic" taste, to clarify the link between the physiology of taste and its perception, and to understand how gustatory taste influences behaviour. It has been suggested that a greater understanding of how we experience taste could impact the design of healthier food, which, in turn, might help facilitate the development of strategies to help tackle obesity and diabetes (e.g., Breslin, 2013; Mennella, 2014). There is also an important potential in the development of medications that produce a less unpleasant gustatory experience and hence can increase treatment compliancy, especially in children (Jubb & Bensing, 2013; Mennella, Spector, Reed, & Coldwell, 2013; Wan, Woods, Salgado-Montejo, Velasco, & Spence, 2015).

Given that we rarely taste in the absence of other sensory inputs, an understanding of how taste and the other senses (e.g., vision and sound) come together can contribute to the design of better human experiences. For example, a greater understanding of the influence of different senses in our eating experiences could aid in the development of healthier foods that are more attractive (e.g., Michel, Velasco, Gatti, & Spence, 2014) or rewarding (e.g., airplane food, see Spence, 2017; Spence, Michel, & Smith, 2014). A more in-depth understanding of how different tastes are matched to simple visual stimuli (e.g., shapes, lines, and dots) can facilitate the development of guidelines for the design of food products that communicate their taste attributes more effectively (Becker, van Rompay, Schifferstein, & Galetzka, 2011; Ngo et al., 2013; Parise & Spence, 2012; Spence, 2012b; Spence & Piqueras-Fiszman, 2012).

In this section, I review previous research that has addressed the physiological and behavioural components of gustation to demonstrate that taste can fundamentally be

classified in terms of approach and avoidance motivation. The physiological mechanisms involved in taste perception are reviewed to demonstrate that we have evolved different receptors in order to maximize the intake of nutritious foods and reduce the potential risk of contamination (e.g., with poisonous or toxic substances). I will then look at studies of facial expression and show that they also support the notion that gustation can be encoded in terms of approach and avoidance motivation. Clarifying the role of approach and avoidance motivation in gustatory experiences is of key importance to my thesis research as it lays the foundations for what comes in the following chapters.

Linking motivation with gustation provides initial evidence that tastes are inherently associated with a motivational stance and furthermore, with a positive or negative emotional valence. Recent studies have suggested that a concordant valence (i.e., positive or negative) may explain why shapes and tastes are matched to each other (Spence & Deroy, 2013; Velasco, Woods, Deroy, et al., 2015). However, the "affective matching" hypothesis seems to be only part of the story (Velasco et al., 2015, see also Chapter 3, Study 2). So far, Velasco et al. (2015) have demonstrated that emotional valence has an influence on how tastes and shapes are matched to each other. These authors also show that emotional valence is not sufficient to wholly account for shape-taste matches. One possible explanation for the (incomplete) influence of emotional valence on shape-taste associations could be facial expressions. Facial expressions, which inherently produce a shape that is represented in the frontal lobe and cingulate cortex (see Morecraft, Stilwell-Morecraft, & Rossing, 2004, for a review on the production of facial expressions), are a common denominator for both tastes and emotional experiences. Hence, an important focus of this chapter is on demonstrating the similarities between certain facial expressions of emotion and facial expressions of taste.

1.1.1. Physiological and evolutionary aspects of taste receptors

Food, together with sex, constitute some of the first rewards to appear, from which all other rewards stem (Kelley & Berridge, 2002). The ability to taste evolved because it is an efficient method to sort what is nutritious from what is dangerous. However, it is not sufficient to know that something is "good" or "bad" it is necessary for an organism to remember and develop behavioural responses accordingly. It is also possible to say that what is "good" varies depending on our physiological needs (e.g., whether we are hungry or satiated), what is beneficial at some point in time may not always be so later on (see Sternini, 2013). This intimate and ancient relationship between taste and reward, underscores the importance of studying the mechanisms underpinning taste. From obesity and addiction, through diabetes and the development of healthier foods, taste seems to be at the centre of many of the current issues faced by the medical sciences. Healthier living largely seems to be associated with the way we eat, for this reason, a better understanding of gustatory experience may help develop policies that are more impactful.

The Greek philosopher Democritus suggested that "atoms" located in the tongue mediated gustatory experience. Current evidence suggests that the surface of the tongue is covered with chemosensory receptors sensitive to different substances (Yarmolinsky, Zuker, & Ryba, 2009). G-protein coupled receptors[3], ionotropic receptors[4], and ion channels seem to be the main sensors for the so-called "basic tastes" (i.e., sweet, umami, salty, sour, and bitter, see Lindemann, 2001).

[3] G-protein coupled receptors, a type of metabotropic receptor, act via second messengers (i.e., G-proteins) that indirectly influence the closing and aperture of ion channels.

[4] Ionotropic receptors are activated by a ligand (i.e., a chemical substance) and contain a transmembrane domain that forms an ion pore. When the ligand binds to the receptor, it influences the aperture or closing of the ion pore allowing or restricting the flow of ions inside the cell.

Currently there is great debate as to what is and is not a basic taste. Specific receptors have been characterized for salts (Lim & Lawless, 2006; Riera, Vogel, Simon, Damak, & le Coutre, 2009), sour (DeSimone & Lyall, 2006; Ishimaru, 2015), bitter (Behrens & Meyerhof, 2013; Chandrashekar, Hoon, Ryba, & Zuker, 2006), sweet (Nelson et al., 2001; Treesukosol, Smith, & Spector, 2011), and umami (Temussi, 2009; Zhang et al., 2003; Zhao et al., 2003), suggesting that there are at least this many basic tastes (see also Feng, Zhang, Zhuang, Zhou, & Xu, 2016; Keast & Costanzo, 2015; Kuroda & Miyamura, 2015; Mattes, 2011). In this chapter, I focus on the physiology and facial expressions associated with the perception of salt, sour, bitter, sweet, and umami. These five tastes account for the entire spectrum of approach and avoidance motivation and some these tastes are used in different experiments throughout the thesis.

The following sections, dealing with the physiology of taste, have the purpose of demonstrating that the five basic tastes (i.e., bitter, sour, salty, sweet, and umami) are coded in terms approach and avoidance stances. Be it because they signal nutritional density (e.g., sweetness), threat (e.g., bitter), or due to the metabolic state of the organism (e.g., rejecting salt when thirsty or feeling more pleasure when ingesting umami rich foods when hungry). I will begin by addressing sweet and umami, which are generally associated with nutritious substances and work towards bitter compounds that are generally considered potentially threatening.

1.1.1.1. Sweet and umami

If the experience of taste is mediated by the nutritional value/potential threat of a substance, then that would mean that the substances that we are able to taste have some special value (positive or negative) that is relevant to our survival. For instance, “sweet” and “umami” are generally associated with foods that provide energy and the necessary

materials for protein synthesis (i.e., amino acids). The receptors that detect the wide range of sweet carbohydrates, amino acids, peptides, proteins, and artificial sweeteners as well as the amino acids that give rise to our experience of umami are actually related. Sweet and umami receptors come from the same family of G-protein coupled receptors, with different subunits facilitating the perception of these two tastes.

Interestingly, there are differences in how sensitive these receptors are to specific substances, suggesting a link between receptor configuration and the dietary preferences of each species. Humans, for example, can only sense one of the isomers of glutamate and aspartate whereas mice are sensitive to a wide range of amino acids (Iwasaki, Kasahara, & Sato, 1985; Nelson et al., 2002; Yarmolinsky, Zuker, & Ryba, 2009; Zhao et al., 2003). There are also differences in sweet perception amongst monkeys and non-human primate species (see Guevara et al., 2016; Li et al., 2011, for examples) and among individuals who can be classified as sweet-likers/dislikers (Hayes & Duffy, 2008; Looy & Weingarten, 1991; Yeomans, Tepper, Rietzschel, & Prescott, 2007).

The unique experience that each species has had with the environment over the course of evolution shapes their gustatory perception, which, in turn, facilitates and restricts the development of preferences of potential food sources (Li et al., 2011; Liu et al., 2012, see also Wintjens, Viet, Mbosso, & Huet, 2011). Our ability to taste sweet and umami is clearly linked to our need to identify the building blocks that facilitate survival. However, if L-Glutamate is isolated and presented in a water-based solution, most people do not find it pleasant (McCabe & Rolls, 2007; Weiland, Ellgring, & Macht, 2010).

McCabe and Rolls (2007) argue that umami is, in fact, a flavour rather than a taste and is produced by the convergence of glutamate and a congruent savoury odour (i.e., vegetable odour). They argue that without the odour the experience of glutamate is not pleasant.

There is also the possibility that, by itself, glutamate is simply too salient and intense and that when it is presented in conjunction with other substances the overwhelming feeling that is experienced in the mouth is masked or suppressed by other tastes and smells (see Keast & Costanzo, 2015; Suwankanit, Dermiki, Kennedy, & Methven, 2013).

Breast milk, which is essentially made-up of amino acids, carbohydrates (including sugars), electrolytes, fats, and vitamins (Ballard & Morrow, 2013; Praticò et al., 2014), produces a pleasant gustatory experience (at least for babies). For amino acids to be perceived as pleasant it is possible that other tastes and (but not only) odours need to be present. After all, taste cells can interact with one another and influence gustatory perception. For instance, there is evidence that tastes can mask/enhance each other (e.g., umami is suppressed by other tastes but can enhance salt and sweet sensations) and influence the overall tasting experience (Suwankanit et al., 2013).

It is also important to note that taste perception changes over the course of development with, for example, babies liking milk but rejecting it as adults it if they become lactose intolerant. Linking or disliking a specific substance or food may be caused by oral or extraoral processing, for example, an adult may like milk for its taste bur reject it because of the visceral feelings it causes (i.e., those associated with lactose intolerance). There are receptors in the mouth that help us immediately codify substances it terms of them being nutritious or dangerous, however, receptors in the gut also detect potentially nutritious and harmful substances (Behrens & Meyerhof, 2011; Yamamoto & Ishimaru, 2013). That is why something that may initially be accepted because of its taste may be rejected or avoided afterwards. Hence, it is possible to like something and yet have an avoidance response towards it.

Substances rich in molecules that activate sweet and umami receptors tend to be coded as appetitive by many species. One would expect that foods rich in molecules that activate receptors linked to these families would be associated with a positive emotional valence.

1.1.1.2. Electrolytes (salts)

Another important element to our survival is ingesting the correct quantity of electrolytes. That is, ingesting the correct amount of salts to help maintain homeostasis and a wide range of other cellular processes (from action potentials, to heartbeats, to muscle function, see Joung & Cheatham, 2008). The epithelial sodium channel has been identified as the receptor responsible for salt perception, ending several years of probing for a potential candidate (Chandrashekar et al., 2010). This receptor serves as a transducer for the salty taste and seems to show that ion diffusion may serve an important role in the transduction of at least some of the so-called basic tastes (Bigiani, Ghiaroni, & Fieni, 2003). The acceptance or rejection of salty substances seems to be intimately tied to the physiological needs of the organism (e.g., when we are thirsty, salt is aversive, see Yarmolinsky, Zuker, & Ryba, 2009). In general, low salt tastes are preferred over high salt tastes[5], suggesting that even though homeostasis plays an important role in its preference, excessive salt is aversive (Sternini, 2013).

Given that the preference for salt is mediated by the physiological state of the organism, it is likely that in an experimental setting where satiety/hunger is not controlled, many participants will find salty solutions unpleasant.

[5] There seems to be an inverted U-shape for pleasantness for most (if not all) taste, with low and high concentrations rated as unpleasant.

1.1.1.3. Acidic compounds (sour) and carbonation

Sour receptors may have evolved as part of our threat detection system[6]. These receptors facilitate the detection of acidity and can signal unripe fruit or fermented food, especially when the taste is very strong (Ishimaru, 2015; Lindemann, 2001). There is evidence that sour-sensing receptors are also capable of transducing carbonation, a frequent by-product of fermentation. What is more, it seems that the detection of sourness and carbonation can be functionally segregated suggesting that they are two different sensing systems within the same receptor.

The fact that sourness and carbonation share a receptor is further appreciated when one realises that carbonation also produces a slight acidic taste in the mouth (Chandrashekar et al., 2009). This intimate relationship between sourness and carbonation is particularly interesting for those experimental psychologists studying how information from one sense is matched to information in a different sense. For example, there is evidence that both sourness and carbonation are matched to angular shapes (Ngo, Piqueras-Fiszman, & Spence, 2012; Spence & Gallace, 2011, but see Bremner et al., 2013; Wan et al., 2014). These associations between visual stimuli and tastes have an important potential to aid in the design visual communication (e.g., advertisement and product labels) that can convey (and perhaps modify) the taste properties of different foods and products (Spence, 2012b).

1.1.1.4. Bitter

Initially, it was thought that bitter and sweet receptors were related given the wide range of substances (e.g., saccharines) that elicit both bitter and sweet perception. However, we now know that molecules with isomers that are capable of stimulating either sweet or

[6] Sour receptors may also play a role in separating unripe fruits from sources rich in vitamins.

bitter receptors cause this confusion (Schiffman, Reilly, & Clark, 1979; Temussi, Lelj, & Tancredi, 1978; Verkade, 1968). While bitter receptors are also G-protein coupled receptors, they do not seem to share the same genetic lineage as sweet and umami receptors.

In general, bitter compounds are rejected and are perceived as potentially harmful (Behrens & Meyerhof, 2011; Piero Andrea Temussi, 2009). If one looks at the *Handbook of poisonous and injurious plants* (Nelson, Shih, & Balick, 2007) there are entries showing that potentially dangerous plants have a distinct bitter taste and that, on occasion, the taste can be so strong that it can limit the amount that is ingested (p. 115). The bitterness of a plant signals how poisonous it is:

"…The so-called 'sweet' variety with a lower cyanide content is most commonly found in commerce [i.e., in markets and stores]; the so-called 'bitter' variety contains far more cyanide and requires extensive preparation and processing before eating." (p. 213).

There is now evidence showing that the response strength of the bitter receptor is directly linked to the toxicity of the substance. For example, there is a greater response for picrotoxinin (more toxic and bitter) than picrotin and to strychnine (more toxic and bitter) when compared to brucine (the least toxic and bitter of the four substances, see Behrens & Meyerhof, 2013, for a review on the molecular basis of the bitter receptor). Given the diversity of bitter-tasting substances, it is not surprising that bitter receptors are the most structurally diverse, to this day, 25 different bitter receptors have been identified (see Breslin, 2013). There is a direct link between the physiological response generated by the bitter receptor and avoidance motivation.

Different receptor families are needed to be able to differentiate nutritious from harmful substances in the environment. These receptors, in turn, are specifically sensitive to families of substances, which facilitate the acceptance or rejection of different foods even

if the organism has not tasted that specific food source before. It is clear, then, that one of the main functions of gustation is to classify potential food sources in terms of "acceptable"/"unacceptable" (Breslin, 2013). The latter classification already implies that there is a motivational stance associated with each taste; we approach (i.e., ingest) those substances that are nutritious while avoiding those that are potentially harmful. Furthermore, gustation involves reward systems and therefore implies that taste experiences are matched to an emotional valence. There is now considerable evidence that the relationship between motivation and emotional valence is ancient and that they possess shared neural circuits (Nieh, Kim, Namburi, & Tye, 2013).

1.1.1.5. Conclusions concerning the physiology of taste and motivation

Almost all (if not all) digestive systems seem to have a biological machinery dedicated exclusively to the classification of potential food sources in terms of approach and avoidance motivation. That alone should tell us the importance of studying taste bearing in mind the concepts of emotional valence and motivation. We evolved to taste, which inherently suggests that we evolved to like/dislike, accept / reject certain foods. Gustatory perception cannot be separated from the motivational and emotional experience that it elicits. The design of healthier food that is appealing, the reduction of obesity and diabetes, and the overall enhancement of well-being through food is intimately tied to how the physiology of taste drives our cognitive experience of food.

The evidence presented in this chapter is the basis to begin understanding how is it that motivation and emotional valence are involved in the matching of shapes to tastes. The association of different basic tastes with a motivational stance and a valence supports the possibility that shape-taste matches are formed (at least in part) because they share an underlying valence. However, another interesting mechanism that may be involved in

shape-taste matches is embodied cognition and specifically facial expressions. Facial expressions are both produced when we experience an emotion and when we taste.

1.1.2. Taste and facial expressions

So far, I have looked at the physiological mechanisms of taste and how our perception towards the different tastes is guided by how nutritious/harmful each substance is. Not surprisingly, the valence of the facial expressions that are often associated with some of the aforementioned tastes (i.e., sweet, sour, bitter) are consistent with the nutritional/potential danger of a substance. In general, those tastes that contribute to an organism's survival tend to produce positively-valenced emotions. In contrast, those tastes that are potentially harmful tend to elicit negatively-valenced emotions instead.

There is robust evidence that facial expressions appear early in life in response to tastes (newborns produce facial expressions associated with the acceptance and rejection of different tastants) and extend to many primate species and monkeys (Steiner, Glaser, Hawilo, & Berridge, 2001). The literature on facial expressions and basic tastes shows that participants tend to produce expressions of disgust while trying a sour (or bitter) taste. Moreover, sweet tastes have been reported to produce expressions associated with pleasantness (Birch, 1999; Ganchrow, Steiner, & Daher, 1983; Mennella, Forestell, Morgan, & Beauchamp, 2009; Rosenstein & Oster, 1988; Steiner, 1979; Weiland et al., 2010).

Different studies have demonstrated that negatively-valenced facial expressions can be reduced to simpler stimuli such as an angular shape. These schematic facial-features continue to retain their emotional and motivational value even in the absence of other contextual cues (Aronoff, Barclay, & Stevenson, 1988; Bassili, 1978, 1979; Larson,

Aronoff, Sarinopoulos, & Zhu, 2009; Larson, Aronoff, & Steuer, 2012). Less research has been conducted to match specific shapes to positively-valenced facial expressions (e.g., Aronoff, Woike, & Hyman, 1992, see also Chapters 3 and 4). Further exploring the relationship between tastes and visual features can help in the development of guidelines for food and product design. For example, understanding how visual features influence taste expectations and preferences (and perhaps the taste of food itself) sheds light on the decisions made by consumers and on eating habits and ultimately on how to develop policies that strengthen well-being (see Chapter 4 on this theme).

The intriguing relationship between facial expressions of emotion and basic tastes also raises the question of how the link was forged in the first place. Did some taste experiences contribute to the development of, not only facial expressions, but also emotions? According to Berridge (2000) there is a phylogenetic consistency in how taste elicits emotional reactions in humans, primates, and rats (see Steiner, 1973, 1974, for the seminal papers on this topic). Indeed, if several mammalian species share a common taste-emotion response then it is possible to assume that this link is quite ancient. In fact, a study conducted by Bredie, Tan, and Wendin (2014) validates the work of Berridge in showing consistency in the emotions expressed by different mammalian species when exposed to sweet, sour, and bitter tastants.

Evidence collected over the last two decades has demonstrated that, at least in humans, disgust seemed to originate first in response to taste and afterwards also became a moral emotion (Chapman, Kim, Susskind, & Anderson, 2009; Rozin, Lowery, & Ebert, 1994). There are even specific brain areas that facilitate the identification of disgust and involve circuits associated with the judging of offensive stimuli (Phillips et al., 1997). It is very likely, then, that the underlying valence that is shared by the basic tastes and different shapes is the result of a bodily response (i.e., facial expression) that both denotes taste

and valence. In the following two chapters, I revise whether emotional valence can account for the associations between shapes and tastes.

1.2. Aesthetic features, emotional valence, and basic taste

Organisms survive because they can detect patterns in the sensory information available in the environment that surrounds them. The detection of patterns can help an organism to determine whether they should approach or avoid a stimulus and make an appropriate behavioural response. For instance, bees select flowers that are more symmetrical as they tend have more nectar (Rodríguez et al., 2004). A toad is capable of identifying the pattern of flight of an insect and respond by launching its tongue towards it (Ewert, 1987; Ingle, 1983). While rats and mice produce a flight response when a shadow is suddenly cast above them, as it may signal the attack of a bird of prey (Wallace et al., 2013). Hence, a pattern is formed when a sensory signal is systematically associated with specific consequences, qualities, or attributes. The strength of the association between a given signal and specific attributes or consequences (as well as the consistency of the subsequent behavioural response) is dependent on statistical regularity in the environment. If a stimulus is generally associated with a specific consequence, then the association between the stimulus and the consequence will be strong. If, however, there are contradictory signals that confuse the organism, the association may be weak to the degree that the pattern may disappear, as it does not allow for a reliable prediction.

For more than eighty-years now, the question as to how patterns are formed and recognized has been of interest to the fields of both physiology and psychology. For instance, Metzger (1936/2009) suggested that perception was the result of the brain interpreting objects according to the laws of nature. The patterns we are able to perceive,

then, are an interpretation of the physical and chemical phenomenon around us. Metzger provides a beautiful example:

> *"In every boundary surface (not just between fluids) a surface tension force exists that seeks to shrink that surface. It is the force to which soap bubbles owe their spherical form. The strength of that force increases as the size of the bubble is reduced. In microscopically small bubbles surface tension finally overpowers all other shaping forces. That is why even crystals below a certain very small size always have rounded-off corners, and still smaller ones are rounded like a droplet. A very similar phenomenon is observed when visible objects become sufficiently small: their shape becomes ever more rounded. Finally they become rounded dots, often long before their image becomes as small as a retinal cone, and when they are not sufficiently enclosed they decompose into groups of little dots."* (Metzger, 2009, p. 193).

It would seem that roundness results from applying a homogenous force to an object or fluid, which suggests some level of order. It may also be the product of how the eye is constructed and as Metzger suggested when the distance between the object and the observer increases, the object appears more rounded. Our affinity towards roundness and other properties such as symmetry may very well be the result of our ability to recognize how forces have been applied to an object. What is more, the kind of forces needed to create a more rounded or symmetrical object may imply that these objects are more complete or terminated, in contrast to angular or asymmetrical objects, which may have been submitted to inconstant or irregular forces. Take, for instance, a fruit; if the climate and water supply are favourable, the force that tenses and expands the surface of the fruit will remain more or less constant. If, however, climate and water change constantly, the skin of fruit will be stretched and contracted and the shape of the fruit will be irregular and the surface rugged.

Berlyne (1960, p. 244) suggested that objects in a state of transition, or lacking resolution (e.g., a leaning tower), produced tension. It is possible that roundness, symmetry, and other visual features that are of interest to psychology and aesthetics convey a finished

state. If the aforementioned features inherently convey some properties about objects (e.g., its quality or nutritional density), it is not surprising that they can be associated with features in other sensory modalities that also convey similar properties or attributes (see Spence, 2011, for a review on sensory matches across the senses).

It is key, then, to identify those sensory signals that provide the most reliable associations with specific outcomes or attributes. There is convincing evidence to show that symmetry, curvature, and the number of elements are visual features that seem to be consistently associated with approach or avoidance motives in several species (e.g., Bar & Neta, 2006; Brain, 2008; Enquist & Johnstone, 1997; Enquist & Arak, 1994; Jansson, Forkman, & Enquist, 2002; Leder, Tinio, & Bar, 2011; Palmer, Schloss, & Sammartino, 2013; Palumbo, Ruta, & Bertamini, 2015; Roca, Gómez-Puerto, Nadal, & Call, 2015; Rodríguez et al., 2004; Shimamura & Palmer, 2014; Tinio & Leder, 2009).

In Köhler's (1929, pp. 224-225) seminal early work, participants were asked to match two shapes (i.e., one round and one angular) with one of two nonsense words "Baluma" and Takete". The participants found it easier to match "Baluma" to the round shape and "Takete" to the angular shape and revealed that people do indeed match speech sounds to shapes. Köhler's results can further be taken to demonstrate that shapes could be matched to information in other modalities. In the intervening years, there has been a growth in the interest to understand how shapes are matched to tastes[7]. However, shape-taste-matching research has tended to focus primarily on the influence of one polar[8] shape property; curvature (Bremner et al., 2013; Gallace, Boschin, & Spence, 2011; Maurer,

[7] Taste here is used to mean the sensation that arises from the stimulation of gustatory receptors on the tongue rather than the broader concept of flavour which also includes olfactory and trigeminal information (see Spence, Auvray, & Smith, 2014).

[8] Presenting the participants with two opposing features on each side of a visual analogue scale (i.e., roundness and angularity).

Pathman, & Mondloch, 2006; Ngo et al., 2013; Spence & Gallace, 2011, but see also Cytowic & Wood, 1982, and see Spence & Deroy, 2013, for a review), leaving aside other shape aesthetic properties that may also be relevant to explaining shape-taste matches. Moreover, while many studies have provided interesting evidence on the phenomenon of shape-taste matches, the mechanisms that explain how it is that shapes are matched to tastes remains elusive.

Emotional valence (see Kenneth, 1923, for an early example; see also Collier, 1996; Lyman, 1979) has been put forward as a plausible mechanism with which to explain shape-taste correspondences (Spence & Deroy, 2013). Velasco, Woods, Deroy, and Spence (2015) demonstrated that taste hedonics (as assessed by liking ratings) were correlated with the crossmodal associations that people made between tastes and the roundness/angularity of shapes. These researchers also underline that emotional valence does not seem to be sufficient to explain how shapes are matched to tastes. Hence, it is possible that other factors play a role in defining how gustatory and visual information are associated. The aforementioned authors also suggest that other shape attributes might be involved in these matches (see also Velasco, Woods, Hyndman, & Spence, 2015; Wan et al., 2014). Furthermore, given that crossmodal correspondences are thought to be bidirectional (Deroy, Crisinel, & Spence, 2013; Parise & Spence, 2013; Spence, 2011a), the suggestion is that both gustatory taste and shape properties may influence shape-taste matching.

Evidence from the fields of psychology (Berlyne, 1960, p. 244; Reber, Schwarz, & Winkielman, 2004), neuroscience (Chatterjee, 2011, 2014, for a review), evolutionary biology (Enquist & Arak, 1994; Enquist & Johnstone, 1997; Jansson, Forkman, & Enquist, 2002), and art theory (Collingwood, 1958; Hobbs & Salome, 1991), demonstrates that a variety of visual properties influence the perceived valence of a

stimulus. For example, several studies have demonstrated that symmetry is associated with a positive valence (Makin, Pecchinenda, & Bertamini, 2012). According to aesthetics theory, the number of elements that a shape possesses can also influence people's expressed preference, with shapes having fewer elements being preferred over those with more (e.g., Jacobsen, Schubotz, Höfel, & Cramon, 2006). Nevertheless, subsequent attempts to confirm this claim have tended to yield somewhat mixed findings (see Palmer, Schloss, & Sammartino, 2013, for a review on visual aesthetics and preference).

Symmetry is probably the visual feature that produces one of the most stable and pervasive influences on behaviour (Enquist & Arak, 1994). Its effects are ubiquitous across contexts and species and it seems to be a universal indicator of quality and resources (Enquist & Johnstone, 1997; Wagemans, 1995). From religious symbols (i.e. the Christian cross, the Judaic star, and the Islamic moon and star) to brand logos such as Mercedes-Benz, Toyota, BMW, Chanel, and Givenchy, symmetry seems to be a pervasive element in human life (see Stewart, 2013, pp. 23-25). There is also evidence showing that humans consider symmetrical faces to be more attractive and healthier (Jones et al., 2001; Little, Apicella, & Marlowe, 2007; Little, Jones, & DeBruine, 2011; Perrett et al., 1999) and that there is a relationship between body odour, symmetry, and attractiveness (Martín & López, 2000; Rikowski & Grammer, 1999; Thornhill, 1999).

A recent study, however, suggests that symmetry has no predictive value for health in humans (Pound et al., 2014, see also Henderson, Holzleitner, Talamas, & Perrett, 2016, for a review on facial cues and health perception). Pound et al.'s study is the largest of its kind to date, but note that the sample was entirely from the UK. The chosen sample may add limits to the conclusions of the study as this country has free healthcare and a low exposure to parasites and tropical illnesses. Furthermore, the study was conducted

exclusively in children up to age 15 years and there is no reason to assume that symmetry cannot vary later in life (cf. Fink, Neave, Manning, & Grammer, 2006; Jones et al., 2004). It is not clear whether symmetry cues for specific detriments to health that may not have been part of the study.

Strictly speaking, symmetry refers to the reflective, translational, and rotational regularity present in an object. Reflective symmetry, which is one of the factors of interest to the present study, is a type of symmetry to which the visual system is distinctively responsive and refers to symmetry of an object over its vertical or horizontal axis (Bertamini, Friedenberg, & Argyle, 2002; Bruce & Morgan, 1975; Mach, 1886/1959). Research shows that vertical symmetry is more salient than horizontal symmetry (Makin et al., 2012) and that the preference for symmetry is directly proportional to the number of axes of symmetry present in the object, shape, or organism (Tinio & Leder, 2009).

The association of symmetry with positive attributes or qualities of objects and organisms could explain why it is one of the central feature in aesthetics research (Jacobsen & Höfel, 2003; Palmer, Schloss, Xu, & Prado-León, 2013). What is more, there is evidence that there are specific brain areas (i.e., the intraparietal sulcus) that respond specifically to symmetry as compared to stimuli that are deemed beautiful (see Jacobsen et al., 2006; Sasaki, Vanduffel, Knutsen, Tyler, & Tootell, 2005; see also Chatterjee, 2011, for a review).

The prevailing influence of symmetry over behaviour is present not only in humans but in many other species as well. Take, for example, how fowl display a receiver bias for symmetry and prefer the latter over asymmetry without any external reinforcement (Jansson, Forkman, & Enquist, 2002, see also Swaddle, 1996, for the effect of symmetry on zebrafish mate selection). Perhaps one of the most striking examples of how symmetry can influence even the most automatic of judgements can be seen in the courtship ritual

of the male pufferfish. To attract a female, the male pufferfish creates a complex design on the seabed which resembles a mandala; the more complete and well executed the design the more likely that a female will become interested (Kawase, Okata, & Ito, 2013).

One explanation for the preference for symmetry (Enquist & Arak, 1994; Rodríguez, Gumbert, De Ibarra, Kunze, & Giurfa, 2004, but see Shepherd & Bar, 2011) is that the development of this trait requires a high investment of resources. For this reason, the presence (or lack) of symmetry in an object or organism can reflect some of its qualities (e.g., Fink, Neave, Manning, & Grammer, 2005, 2006; Gangestad, Thornhill, & Yeo, 1994; Møller & Thornhill, 1998; Møller, 1990; Noor & Evans, 2003; Rhodes, 2006; Rhodes, Proffitt, Grady, & Sumich, 1998; Scheib, Gangestad, & Thornhill, 1999; Thornhill & Gangestad, 1999). An alternative explanation to the resource investment hypothesis, is that symmetry may facilitate the processing of visual information (Apthorp & Bell, 2015; Koffka, 1953; Leeuwenberg, 1971; van der Helm & Leeuwenberg, 1996). Other studies have suggested that it is not a preference for symmetry *per se* but for 'efficient' signals. The preference for symmetry, then, would reflect, in many cases (but not all, see Morris, Rios-Cardenas, Lyons, Scarlett Tudor, & Bono, 2012; Oakes & Barnard, 1994), a preference for a signal that is easier to identify among a wide array of signals (Johnstone, 1994).

There is already a substantial body of evidence to support the idea that angular geometric shapes tend to be associated with threat (e.g., Larson, Aronoff, Sarinopoulos, & Zhu, 2009; Larson, Aronoff, & Steuer, 2012; Watson, Blagrove, & Selwood, 2011), while rounded shapes tend to be linked to more positive emotions and are generally preferred (Bar & Neta, 2006; Dazkir & Read, 2011; Jadva, Hines, & Golombok, 2010; Leder & Carbon, 2005; Silvia & Barona, 2008; Vartanian et al., 2013; Westerman et al., 2013). A

study by Westerman et al. (2012) found that participants preferred rounder packaging contours and designs as part of the product's label in two product categories (i.e., chocolate and bleach, see also Cheskin, 1981). Rounder elements were also deemed more beautiful and were rated higher in purchase intent as compared to the angular elements.

A study by Bar and Neta (2006, see also Silvia & Barona, 2008) presented participants with a wide variety of objects varying in their angularity and roundness, these researchers documented an overall preference for roundness. Roca, Gómez-Puerto, Nadal, and Call (2015) have provided evidence that the preference for rounder visual objects extends to other primate species as well. Intriguingly, Bertamini, Palumbo, Gheorghes, and Galatsidas (2015) have argued that the effect may perhaps be mediated by a dislike for angularity. The authors demonstrate that it is possible that the preference for roundness that has been reported thus far is the by-product of rejecting angular stimuli, that is, participants prefer rounder stimuli only when presented against angular stimuli.

1.3. Anthropomorphic features, valence, emotion, and basic tastes

Anthropomorphism, understood as the propensity to see the human form in an object contour, or shape (Epley, Akalis, Waytz, & Cacioppo, 2008; Epley, Waytz, Akalis, & Cacioppo, 2008; Epley, Waytz, & Cacioppo, 2007; Waytz, Cacioppo, & Epley, 2010) seems ubiquitous and can engage attention and influence human behaviour. From cars (Aggarwal & McGill, 2007) to slot machines (Kim & McGill, 2011), and space/architecture (Osawa & Imai, 2008; Osawa, Ishii, Osumi, Ohmura, & Imai, 2009), anthropomorphism seems to affect how we perceive and interact with the world around us. But why does this happen? And how is it that simple visual features come to be construed as, for example, a face and thus convey a specific emotional valence? It would seem that the human brain is capable of associating simple visual stimuli with emotions,

perhaps because they resemble facial gestures, or else because they resemble movements similar to those made by our own bodies.

For more than a century now, psychologists have been interested in trying to understand the ways in which simple lines communicate emotion. For instance, Gordon (1909) studied the link between lines and emotions.

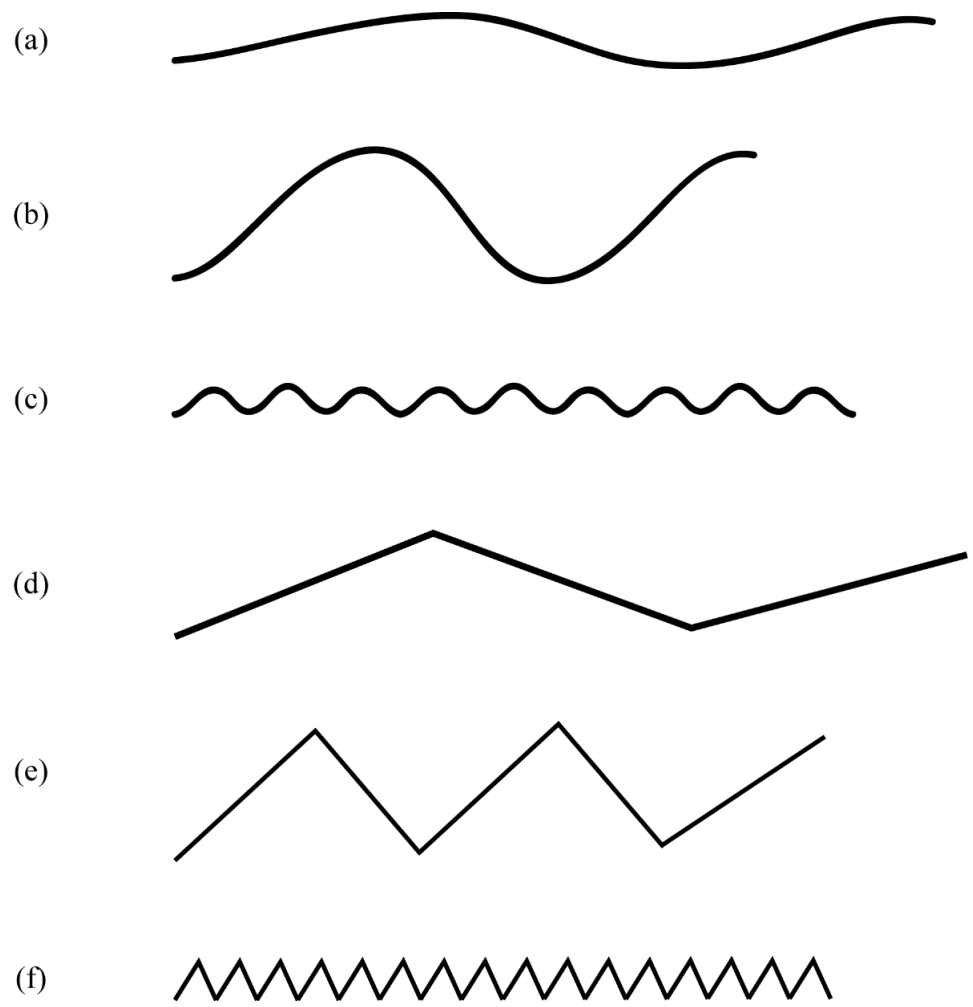


Figure 1.1. Figure inspired by Lundholm (1921) and Poffengerger and Barrows (1924) showing lines that communicate emotion.

Thereafter, Lundholm (1921), and Poffengerger and Barrows (1924), also demonstrated, for example, that words such as quiet and gentle were paired with a line such as that shown in Figure 1.1a, and that words like sad, lazy, and weak were paired to the same

type of line but with a downward slope instead. A line such as that depicted in Figure 1.1b, was related to the words merry and playful while the line displayed in Figure 1.1e which also has an upward slope, was reported to be related to agitation, furious, and powerful (Hair, 1995; Hevner, 1935; Lyman, 1979).

Since the research carried out by Bassili (1978) in which point-light sources were used to study the geometric patterns of facial expressions of emotion (see also Johansson, 1973), there has been a steady interest amongst researchers in trying to link simple visual stimuli, such as shapes, with emotionally expressive facial gestures. For instance, Aronoff, Barclay, and Stevenson (1988) conducted a cross-cultural study in which they demonstrated that those expressions that were associated with happiness were linked to rounder shapes, whereas angry faces were coupled with angular/diagonal shapes such as a downward-pointing "V" instead. The previously-mentioned research regarding the facial expression of emotion and shapes is consistent with those results demonstrating that certain facial expressions can be classified as more angular or rounded, and that this is consistent with their emotional valence (Aronoff, 2006; Marsh, Adams, & Kleck, 2005; see also Aronoff, Woike, & Hyman, 1992). Several studies have also reported that simple visual features (i.e., a "V" or downward-pointing triangle), that emulate the eyebrows of an angry facial expression, can communicate valence without the presence of other cues (Larson, Aronoff, Sarinopoulos, & Zhu, 2009; Larson, Aronoff, & Stearns, 2007; Watson, Blagrove, Evans, & Moore, 2012; Watson, Blagrove, & Selwood, 2011; but see Tipples, Atkinson, & Young, 2002). Moreover, the "V" and downward-pointing triangle could be related with the bared-teeth display (i.e., showing the canine teeth), displayed by canids and primates as a sign of dominance and aggression (Maestripieri & Call, 1996; Marsh, Ambady, & Kleck, 2005; Mignault & Chaudhuri, 2003; Waller & Micheletta, 2013).

Thus far, no studies have addressed whether simple visual features that resemble facial expressions can be associated with tastes or tastes words and bias taste expectations. A better understanding of which visual features may be associated with basic tastes put us closer to identifying the mechanisms involved in shape-taste correspondences. What is more, understanding the relationship between different visual features and tastes can be of interest to designers, brand managers, and in general to the field of product development.

1.4. Embodied cognition

According to Niedenthal et al. (2010), embodied cognition is the process of integrating the neural (i.e., motor, somatosensory, affective, and reward systems) and bodily responses (i.e., muscular and somatic states) to create our cognitive experience. Embodied cognition alludes to the fact that the body and the brain make cognition possible (Feinberg & Mallatt, 2016, p. 19). Motor, visceral, physiological, responses are used as scaffolding to construct our cognition. Bodily experiences, then, facilitate and define the cognitive experience of an organism (Eccleston, 2016, p. 35). For instance, producing a facial expression can provide motor feedback as to the intensity of an emotion (see Niedenthal et al., 2010; Zajonc & Markus, 1984). It took neuroscientists almost 20 years to demonstrate that embodied cognition is real (Eccleston, 2016; Minagawa-Kawai et al., 2009; Niedenthal et al., 2010; Niedenthal, Mermillod, Maringer, & Hess, 2010; Nitschke et al., 2004) and that the body itself is an interface involved in learning, understanding, and in forming associations. Cristopher Eccleston brilliantly summarizes the need for more research in, and the importance of, embodied cognition in the understanding of psychological phenomenon in the following passage:

> *"For the most part, the body has been neglected and ignored, thought merely as a taxi for the mind, dwarfed by the study of observable behavior, action and agency, motivation and performance, cognition and emotion. We take for granted the obvious truth that the objects of our study (personality, motivation, emotion, cognition, and behavior) are quite literally embodied."* (Eccleston, 2016, p. 1).

Eccleston suggests that many mental processes are accompanied by a bodily response. What is more, the passage also reveals an interesting relationship between bodily experience and sensory processing. An unanswered question, then, is what role does the body play in the encoding and understanding of tastes and shapes? Studying the connection between embodied experience and sensory processing is long overdue and may help shed light as to why it is possible to match tastes, shapes, and an emotional valence to each other.

2. CHAPTER 2: Symmetry, curvature, and the number of elements and their relation to emotional valence and gustatory taste

"It all hinged on the line. Henry's scientific aesthetics, including his work on color and sound, turned on the notion that all aesthetic perception relied on the principle of the line… It also served as the bearer of emotion or affect and the carrier of the artist's unique personal signature."

Brain (2008, p. 98)

2.1. Introduction

In Section 1.1 of the previous chapter, a framework in which to understand how the brain maps different basic tastes in terms of approach and avoidance stances was established. Based on this framework, it is possible to study how the liking or disliking of aesthetic features influences how visual information is matched to tastes. More specifically, how it is that we associate a shape with a basic taste.

The focus of this chapter is on determining the overall importance of symmetry, curvature, and the number of elements in shape-taste matches. To accomplish this, and bearing in mind that gustatory experiences are coded in terms of motivational stances, I first explore how visual features are matched to approach/avoidance motivation. Afterwards, a study is presented that seeks to determine the weight of each visual feature (i.e., symmetry, curvature, and the number of elements) in shape-valence and shape-taste matching. The conclusions of the research reported in this chapter are consistent with those reported by Velasco et al. (2015) in showing that emotional valence is in-and-of-itself insufficient to explain how shapes are matched to tastes. Furthermore, I underscore the importance of incorporating other visual features in order to understand how it is

possible to associate visual and gustatory information and provide more accurate stimuli to study how shapes are matched to tastes.

Two studies will be presented. The first study focuses on the relationship between shapes and motivational stances (i.e., approach and avoidance) and helps understand the influence of approach and avoidance on shape-taste matches. The second addresses an issue that has long been omitted in the literature on shape-taste correspondences. In general, the stimuli presented to participants to study shape-taste matches varies in terms of symmetry and curvature, however only curvature has been reported as having an influence in the crossmodal correspondences between shapes and tastes. The lack of interest by the research community in other aesthetic features may present important confounds and limit our understanding of the mechanisms involved in shape-taste matches. Furthermore, the study demonstrates that the emotional valence (and hence the motivational stance) attributed to the shape can influence how shapes are matched to tastes.

STUDY 1

2.2. Matching shapes to approach and avoidance words[9]

Bar and Neta (2006) presented participants with different objects varying in curvature. They demonstrated that there was a positive bias towards rounded objects when compared to angular objects. To continue this line of research and to evaluate the influence of another visual feature that has been reported with a specific motivational stance (i.e., approach), objects varying in both curvature and symmetry were created. The

[9] The findings presented in this section (Section 2.2) were published as Velasco et al. (2016). Please note that while I am not the first author of this study, as explained in the article, the first author and myself contributed equally to the development of these studies. I was involved in stimuli design, experimental design and programming, as well as in the write-up of the paper.

participants had to match the objects to different approach and avoidance words. It was expected that they would match rounder and more symmetrical objects to approach words and more angular and asymmetrical objects to avoidance words. The study presented here further links curvature and symmetry with the field of motivation and emotion and validates the idea that certain visual features are matched to positive or negative qualities.

2.2.1. Methods and materials

Participants. Thirty individuals (17 female, mean age = 26.03 years, SD = 5.44, ranging from 18 to 40) participated in the study. The study was reviewed and approved by the Central University Research Ethics Committee at the University of Oxford (MSD-IDREC-C1-2014-034). All the participants had normal or corrected-to-normal vision. Participants signed a standard consent form at the beginning of the study and were compensated with £5 cash for taking part in the study.

Apparatus and materials. The study was conducted at the Department of Experimental Psychology, University of Oxford, in a darkened, soundproof room. MouseTracker Software was used to run the study and record participants' responses (Version 2.82, Freeman & Ambady, 2010).

Five pairs of approach/avoidance words were selected from those used by Fetterman, Ode, and Robinson (2013): Approach – avoid, advance – retreat, seek – escape, pursue – evade, proceed – withdraw. The words were presented in Arial 28 in the upper part of the screen, one in the left corner and the other in the right corner; they were presented in white against a black background. Shape stimuli were also used, including four rounded shapes (two symmetrical and two asymmetrical), and four angular shapes (two

symmetrical and two asymmetrical). The shapes were presented in black on a white background.

Each of the five word-pairs was presented twice (with the position of each word in each pair counterbalanced) as response options to each shape. The participants' task consisted of matching each shape to one of the two words (the word most closely associated with the shape) by moving the mouse to either the upper-left or upper-right corner of the screen (where one approach word and one avoidance word were placed) and clicking on their chosen response. All combinations of shapes and pairs of words were presented in a random order. Each participant completed a total of 80 trials corresponding to 10 trials per shape, half of which corresponded to each pair of words in one position, and the other half in the opposite position.

Procedure. A 2 x 2 x 2 experimental design with the within-participants factors of shape curvature (round/angular), shape symmetry (symmetrical or asymmetrical), and approach/avoidance words was conducted. Participants were seated approximately 50cm from a 14" LED monitor. Each trial started with the presentation of the two words at the top of the screen and a "START" box at the bottom of the screen. As soon as the participant clicked on the "START" box, one of the shapes appeared in the middle of the screen and the participants had to click on the word that he or she associated most with the presented shape.

Analyses. A generalized estimating equations (GEE)[10] method was used to analyse the data (Liang & Zeger, 1986). The GEE method is a quasi-likelihood method that is an

[10] GEE is a quasi-likelihood method that extends from generalized linear modelling. Aside from the benefit of controlling for multiple responses, it can also control for data that is not independent (which is the case in many repeated measure designs). While a logistic regression could have been used to analyse the data, the risk of a Type-II error is higher than with a GEE, since it does not properly control for repeated as well as for dependent measures (increasing variance redundancy; see Hanley, Negassa, Edwardes, & Forrester, 2003, for a discussion on the suitability of GEE).

extension of generalized linear modelling. The GEE method is particularly suitable when the data is not independent (as often happens in repeated measures designs), is less sensitive to outliers, and overall reduces the chance of a Type-II error (see also Hanley, Negassa, Edwardes, & Forrester, 2003; Hardin & Hilbe, 2012). Given the nature of the data of this study, a binary logistic regression GEE with exchangeable covariance matrix, using a hybrid estimation method and a marginal model, were used to analyse the data. The analyses focused on the choices made by participants.

2.2.2. Results and discussion

Those trials in which the participants took more than 5000ms to respond were automatically removed by the mouse tracking software (this resulted in the removal of a total of 35 trials from 18 participants). All approach words (approach, advance, seek, pursue, proceed) and all avoidance words (avoid, retreat, escape, evade, withdraw) were pooled and tested as a function of shape curvature and shape symmetry.

Approach/avoidance words. A significant effect of shape symmetry was found, $\chi^2(1) = 22.35$, $p < .001$, with symmetrical shapes being more likely to be matched to an approach word (OR: 2.86). No significant effect was found for shape curvature, $\chi^2(1) = 1.95$, $p = .162$; however, the tendency was for round (relative to angular) shapes to be more likely to be matched to an approach word (Odds ratio – OR –: 1.35). The interaction between shape curvature and shape symmetry was significant, $\chi^2(1) = 6.12$, $p = .013$ (OR = 1.84). Bonferroni-corrected pairwise comparisons revealed that round and symmetrical shapes were more frequently associated with approach words than round and asymmetric shapes ($p < .001$), and angular and asymmetric shapes ($p < .001$). Moreover, angular and symmetric shapes were more frequently associated with approach words than were angular and asymmetric shapes ($p < .001$).

The results of this study demonstrated that the curvature and symmetry of shapes can influence the way in which people match shapes to approach and avoidance words, that is, with words that are associated with a specific motivational tendency. While it is known that symmetry affect visual preference (e.g., Palmer, Schloss, & Sammartino, 2013), these results show that this effect may be influenced by approach and avoidance motivation. The results also link research on shape curvature with that on shape symmetry. What is more, this is a first step to further explain the mechanisms that explain shape-taste correspondences, as it shows that both basic tastes (see Chapter 1, Section 1.1.1) and shape features can be associated with approach or avoidance motivation. In order to further understand how aesthetic features are involved in affective matching and how they may influence shape-taste matches it is important to determine the influence of each of these features in shape-valence and shape-taste matching.

STUDY 2

2.3. The influence of curvature, symmetry, and the number of elements on shape-valence and shape-taste matching[11]

The present study has two main objectives: First, to determine the influence of visual features such as roundness/angularity, symmetry/asymmetry, and the number of elements in how shapes are matched to a valence (i.e., pleasant/unpleasant) and to a taste word (i.e., sweet/sour). Henrich, Heine, and Norenzayan (2010) have argued that most of the samples of behavioural studies have come from Western, educated, industrialized, rich, and democratic societies (WEIRD). These authors point-out that this particular choice of

[11] The findings of this study were initially presented at the British Psychological Society Cognitive Psychology Annual Conference (2015) where it was awarded the best postgraduate poster award. It was subsequently published as Salgado-Montejo et al. (2015).

sample may not represent the general population (but see Machery, 2010). Hence, I was interested in determining whether any effects found in terms of shape-valence and shape-taste matching would be similar in two different countries, namely the United Kingdom and Colombia. What is more, it is important to note that different studies have reported cultural differences in the valence attributed to different visual features (e.g., such as the number of elements, see Jacobsen, 2010; Masuda, Gonzalez, Kwan, & Nisbett, 2008; Tinio & Leder, 2009). Such results therefore emphasize the need to explore how different countries match specific shape properties with emotional valence and whether this influences the shape-taste matches that they exhibit. Moreover, it is also interesting to study the effects so far reported in countries that have received less attention from researchers, as this helps to strengthen any generalization derived from experimental research (see Henrich et al., 2010).

2.3.1. Methods

UK participants. Twenty-six participants (15 male, mean age = 29.05 years, SD = 9.03, ranging from 18 to 55), recruited via the database of the Crossmodal Research Laboratory at the University of Oxford took, part in the study. The study was reviewed and approved by the Central University Research Ethics Committee at the University of Oxford (MS-IDREC-C1-2014-056). All of the participants had normal or corrected-to-normal vision. The participants signed a standard consent form at the start of their session and were compensated with £5 for taking part in the study.

Colombian participants. Thirty-seven participants (18 female, mean age = 20.7 years, SD = 2.29, ranging from 18 to 28) were invited to take part in the study via the database of the International School of Economics and Administrative Science at Universidad de La Sabana in Colombia. The study was reviewed and approved by the Research Committee

of the International School of Economics and Administrative Science at Universidad de La Sabana. The participants were compensated with academic credit for taking part.

Apparatus and materials. The participants sat approximately 50 cm in front of a 14" LED monitor, with a screen resolution of 1024x768 pixels, and a screen refresh rate of 60 Hz. Adobe Illustrator CS6 was used to create eight different shapes (see Figure 2.1). The stimuli were developed based on the shapes first introduced by Köhler (1929, see also Ramachandran & Hubbard, 2001). The original shapes presented by Köhler (see shapes on the top right corner of Figure 2.1) were taken as a reference point and they were modified by making them symmetrical or by increasing the number of elements that make-up each shape.

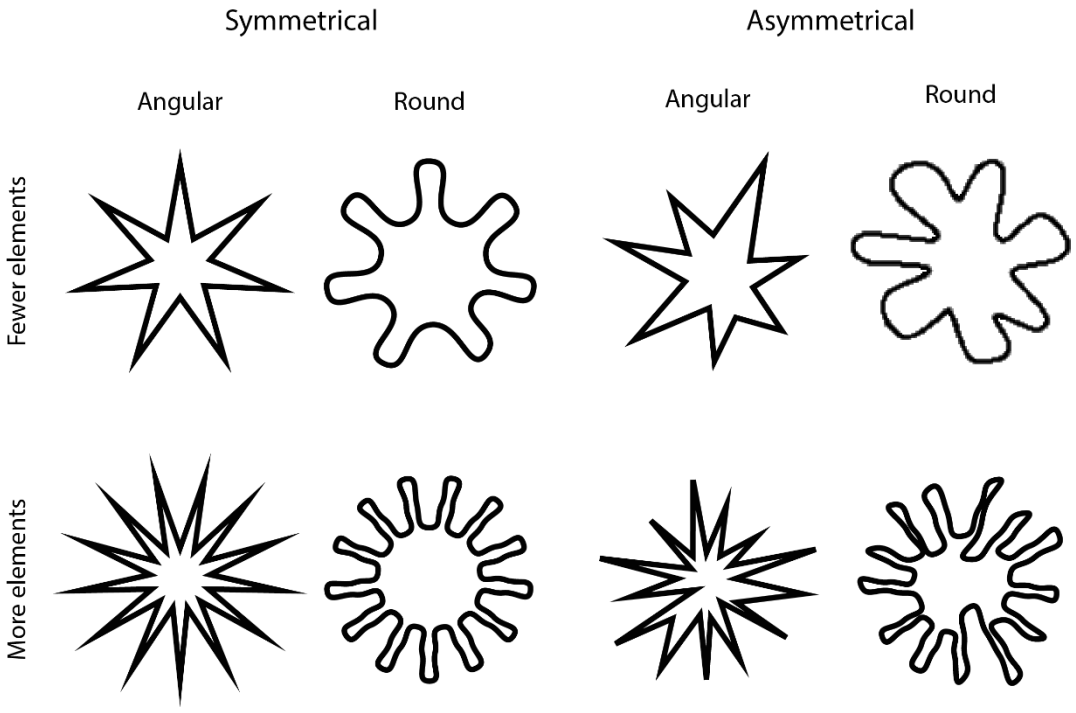


Figure 2.1. The visual stimuli that were presented to the participants in the two tasks in Study 2.

The different shapes were presented to the participants using MouseTracker Software (Version 2.82., Freeman & Ambady, 2010). For the Colombian sample, all words in the

study were presented in Spanish (Sweet = Dulce; Sour = Ácido; Pleasant = Agradable; Unpleasant = Desagradable).

Procedure. Two 2 x 2 x 2 experimental designs with factors shape roundness/angularity, shape symmetry/asymmetry, and the number of elements (7 vs. 12), were conducted. The participants were informed that they would be presented with different shapes (see Figure 2.1) and two words (i.e., sweet and sour or pleasant and unpleasant) located at the top-left and top-right of the screen.

The study comprised two tasks; in each task, the participants were first presented with written instructions on the screen. They then had to decide which of two words best matched the shape presented on the screen. During one of these tasks, they had to match each shape to either the words "pleasant" or "unpleasant". In the other task, the participants had to match the shapes to the words "sweet" or "sour" (in Spanish) instead. The order of presentation of the two tasks was counterbalanced across participants.

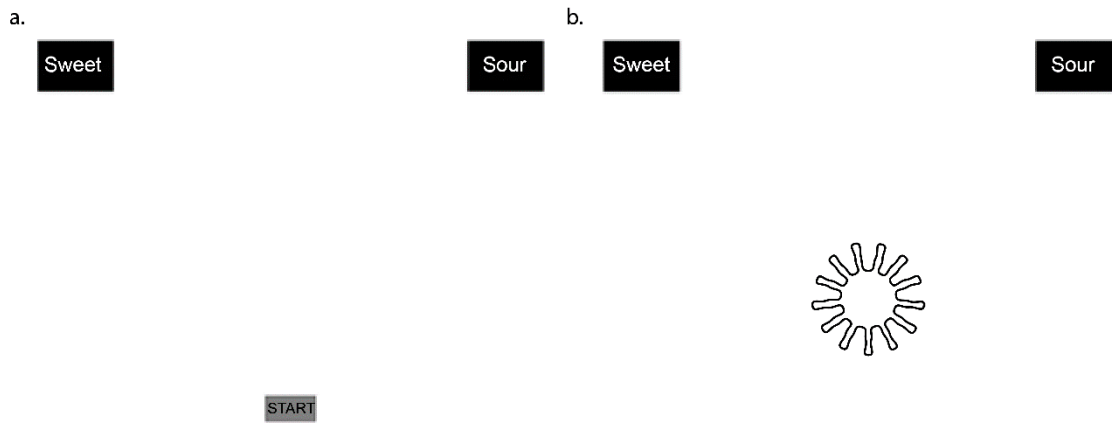


Figure 2.2. Schematic visualization of the task presented to participants in Study 2 showing the screen before (A) and after (B) the participants had clicked the start button on the screen.

In both tasks, the shapes were presented on the lower centre of the screen and afterwards the participants had to move the mouse and click on one of two possible words (see Figure

2.2). Each of the eight shapes was presented four times (32 trials) and the position of the words presented on the screen (either unpleasant and pleasant or sweet and sour) was counterbalanced.

Analyses. A GEE was used to analyse the data (see Liang & Zeger, 1986). Given the nature of the data from this study, a binary logistic regression GEE was used to analyse the choices that were made by the participants. RTs were analysed with a scalar logistic regression GEE and, for the motor complexity indexes, a Poisson logistic regression GEE was used. All GEE used a hybrid estimation method and a marginal model. Participants' choices, as well as RTs, and motor complexity indexes for hand movements were evaluated. Trials with RTs that were greater than two standard deviations from the mean were discarded from the analyses. The total number of trials did not go over 2% of the entire data set in either of the two samples.

2.3.2. Results and discussion

An overview of the results revealed the same main effects in both countries (the UK and Colombia) in both tasks (i.e., shape-valence and shape-taste matching). It would appear that symmetry/asymmetry and the number of elements seemed to exert the greatest influence as to how the participants matched each shape to a valence word.

In contrast, in the taste task, roundness/ angularity, symmetry/ asymmetry, and the number of elements had varying degrees of influence, on the participants of each country, on how shapes were matched to a taste word. Note that I only present in figures, and in the main text, those effects that displayed significant differences. The results are presented in detail below as a function of task, measurement, and country.

Table 2.1.

The aggregated frequencies per each of the shape properties for the valence and taste tasks in Study 2. A total of 2016 trials were recorded for each task.

Property	Valence		Taste	
	Pleasant	Unpleasant	Sweet	Sour
Round	529	479	634	374
Angular	451	557	183	825
Total	980	1036	817	1199
Symmetry	684	324	467	541
Asymmetry	296	712	350	658
Total	980	1036	817	1199
Less elements	610	398	558	450
More elements	370	638	259	749
Total	980	1036	817	1199

2.3.2.1. Pleasant/Unpleasant task

The UK and Colombian samples displayed a significant main effect of symmetry/asymmetry (UK: Wald χ^2 (1) = 54.51, $p < .001$, Colombia: Wald χ^2 (1) = 33.07, $p < .001$) and the number of elements (UK: Wald χ^2 (1) = 25.00, $p < .001$, Colombia: Wald χ^2 (1) = 37.26, $p < .001$, see also Figure 2.3). Symmetry was more likely to be matched to the word pleasant when compared with asymmetry (Odds ratio – OR – UK: 57.46; OR Colombia: 5.92). Those shapes having fewer elements also presented a higher likelihood of being matched to the word pleasant (OR UK: 8.47; OR Colombia: 2.44).

Symmetry/asymmetry presented the highest influence on the likelihood of matching a shape to a specific valence in both countries. The shapes that were more easily matched to either the word pleasant or unpleasant varied between countries (see Figure 2.3A). These differences and the overall frequencies can be explained by the influence (i.e., effect sizes) of each of the shape properties on the likelihood of matching a specific shape to a valence word (see Figures 2.3B and 2.3C).

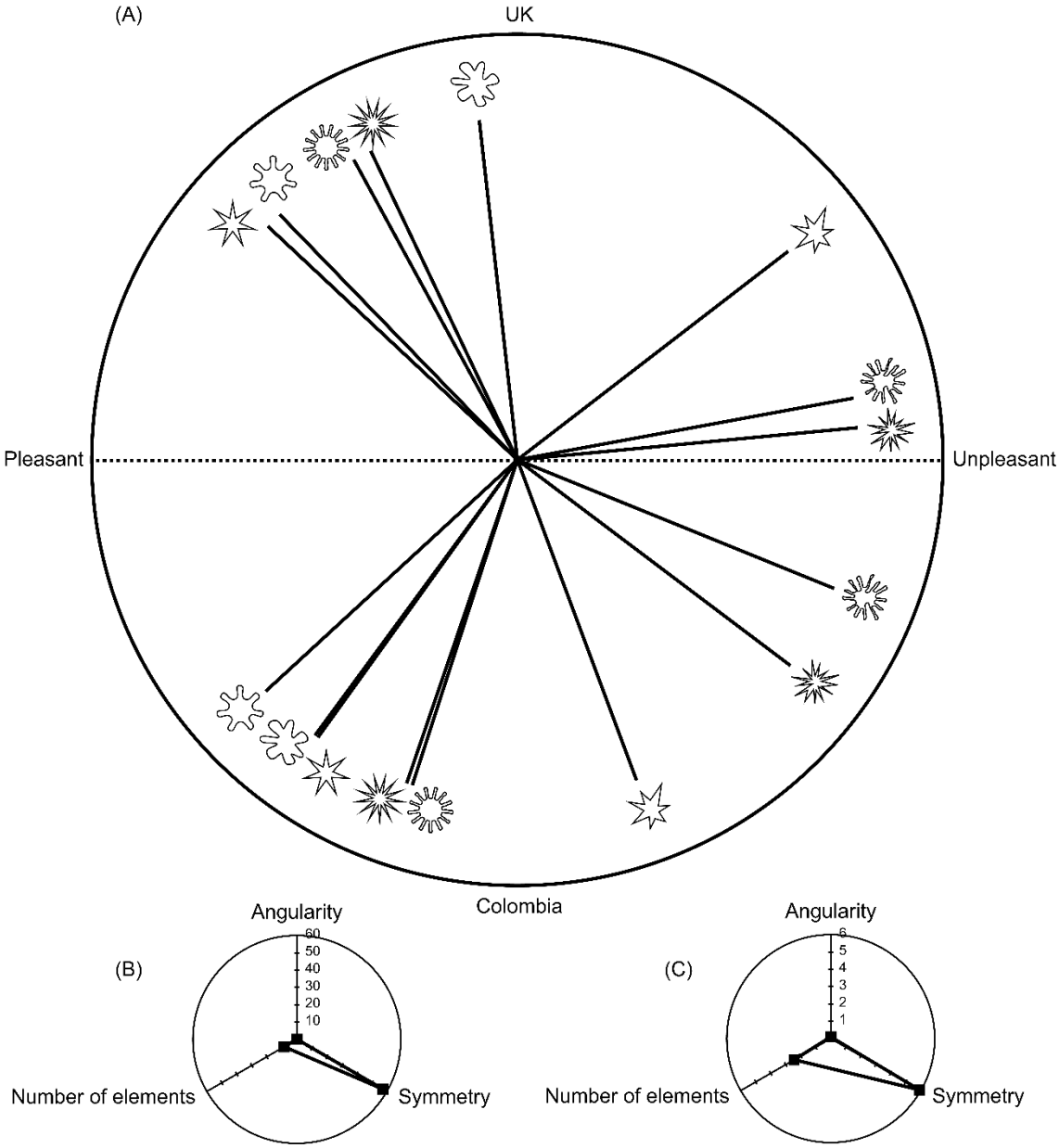


Figure 2.3. Figures showing (A) the mean categorization frequencies for the valence task presented as angles in a 180° range for each of the shape properties in Study 2. The upper part of the circle presents the frequencies for the UK sample, while the bottom part of the circle presents the frequencies for the Colombian sample. Shapes that were more consistently rated as pleasant are presented towards the left, while those shapes that were deemed to be more unpleasant are presented towards the right. (B) The odds ratios for the UK sample representing the influence (i.e., effect size) that each shape property had on the categorizations made by the participants; and (C) the odds ratios for the Colombian sample. (B) and (C) show the overall effect of each shape property on the categorization of each in terms of a valence word. These panels help the reader to understand the order in which the shapes appear in (A), and why there are some variations between countries.

As shown by the interactions (see Table 2.2 and Figure 2.3), roundness/angularity seems to require the presence of other shape properties to communicate valence (i.e., symmetry/asymmetry

in the UK and the number of elements for the Colombian sample). In both countries, arrangements of symmetry and number of elements that communicated the same valence (i.e., more symmetrical shapes and shapes with fewer elements or more asymmetrical and shapes with a greater number of elements) increased the odds of matching a particular shape with a valence word (OR UK: 4.77; OR Colombia: 1.61). For the Colombian sample, congruent roundness/angularity x symmetry/asymmetry x number of elements properties further increased the odds of matching a shape with a specific valence (OR UK: 2.19; OR Colombia: 4.84).

Table 2.2.

The influence of each shape property on shape-valence matches as shown by binary logistic regression GEE in Study 2.

Shape properties	UK	Colombia
Roundness/angularity	No effect	No effect
Symmetry/asymmetry	Symmetrical = pleasant***	Symmetrical = pleasant***
Number of elements	Fewer elements = pleasant***	Fewer elements = pleasant***
Roundness/angularity x symmetry	Rounder x symmetrical = pleasant*	No effect
Roundness/angularity x number of elements	No effect	Rounder x fewer elements = pleasant**
Symmetry/asymmetry x number of elements	Symmetrical x fewer elements = pleasant***	Symmetrical x fewer elements = pleasant***
Roundness/angularity x symmetry/asymmetry x number of elements	No effect	Rounder x symmetrical x fewer elements = pleasant**

* $p < .05$, ** $p < .01$, *** $p < .001$. Note that all effects that are significant include both polar properties (e.g., symmetry and asymmetry, or roundness and angularity).

RTs. A significant main effect of symmetry/asymmetry was found in the UK sample, Wald χ^2 (1) = 8.45, $p < .01$, as well as a main effect of the number of elements Wald χ^2 (1) = 15.88, $p < .001$ (see Figure 2.4A). The participants responded faster (Mean

difference, MD: 166ms, $p < .01$) to shapes that were asymmetrical (Confidence Interval, CI: 2142-2495ms) as compared to those shapes that were symmetrical (CI: 2307-2660ms, see also Figure 2.4A).

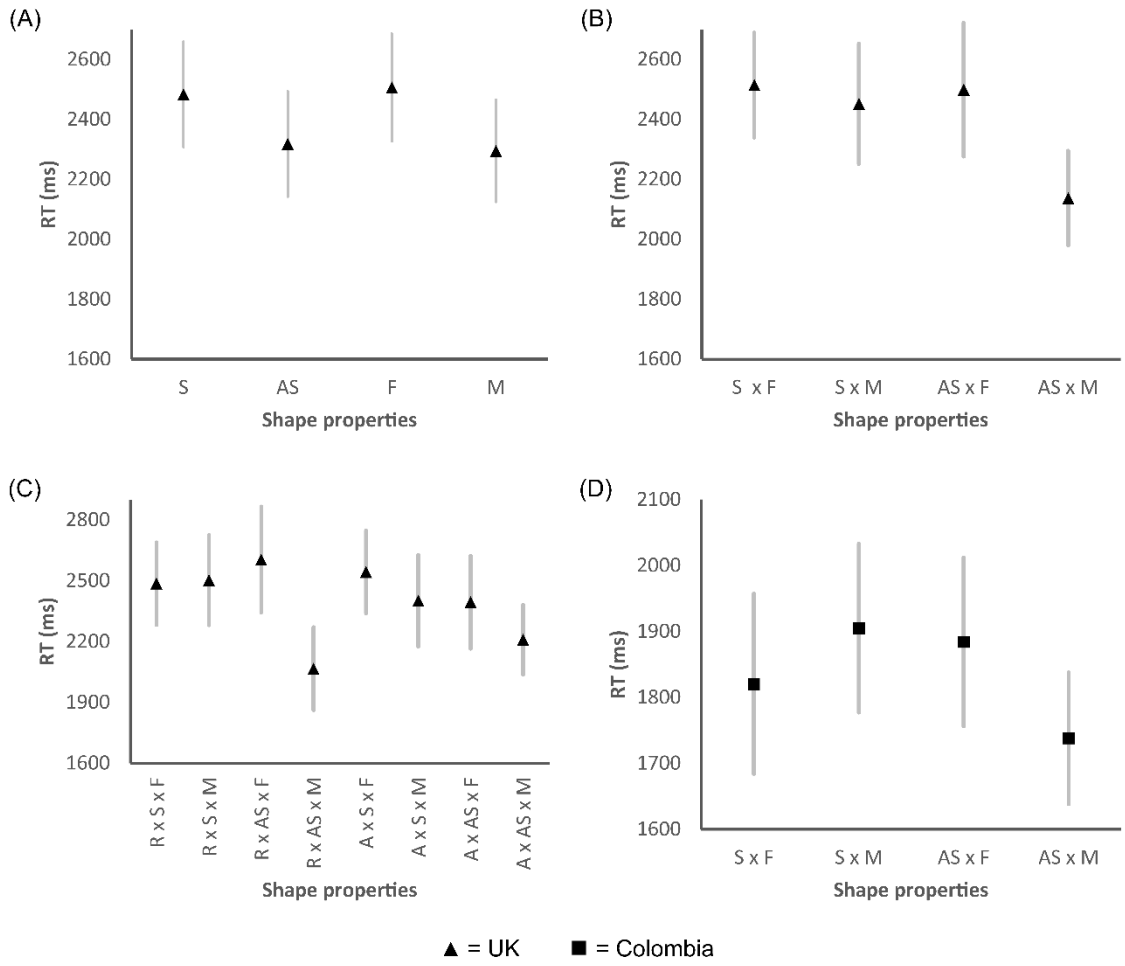


Figure 2.4. Graphs showing the mean RTs for the valence task for those shape properties that displayed significant differences in Study 2. (A) Shape properties that displayed significant differences in the UK sample; (B) Significant two-way interaction between symmetry and the number of elements for the UK sample; (C) Significant three-way interaction between roundness/angularity, symmetry, and the number of elements for the UK sample; (D) Significant two-way interaction between symmetry/asymmetry and the number of elements in the Colombian sample. R = round, A = angular, S = symmetrical, AS = asymmetrical, F = fewer elements, M = more elements. Error bars = standard error.

Shapes that presented a greater number of elements (CI: 2124-2466ms) were also categorized more rapidly (MD: 212ms, $p < .001$) by the participants when compared to shapes with fewer elements (CI: 2327-2687ms, see also Figure 2.4A). A significant

interaction was found between symmetry/asymmetry x the number of elements Wald χ^2 (1) = 8.66, $p < .01$, with the participants responding even more rapidly to those shapes that were asymmetrical and presented a greater number of elements (see Figure 2.4B). The participant responded more rapidly (MD: 314ms, $p < .001$) to asymmetrical shapes that had a greater number of elements (CI: 1980-2295ms) as compared to those shapes that had a greater number of elements, but which were symmetrical (CI: 2251-2653ms, see also Figure 2.4B). A significant three-way interaction was also found, with shapes that were rounder, asymmetrical, and which presented more elements generating faster RTs (see Figure 2.4C). The participants categorized the shapes that appeared to be matched with the word unpleasant (i.e., shapes with a greater number of elements and/or asymmetrical shapes) more quickly than those shapes that were matched to the word pleasant (i.e., those shapes with fewer elements and/or symmetrical shapes).

In the Colombian sample, RTs displayed a significant interaction between symmetry/asymmetry x number of elements Wald χ^2 (1) = 12.45, $p < .001$. The participants responded more rapidly (MD: 167ms, $p < .001$) when presented with shapes that had more elements and were asymmetrical (CI: 1638-1838ms) as compared to those shapes that were made-up of more elements and were symmetrical (CI: 1777-2033ms, see Figure 2.4D). No other effects were found for either of the two samples.

Motor complexity. Motor complexity was calculated by counting the number of hand movements towards and away from the response (y-flips) and from left to right (x-flips) and creating an index to standardize these movements across participants. The motor complexity index is calculated by counting the number of hand reversals on each axis (x and y), before each participant clicked the mouse on each trial (Freeman & Ambady, 2010). A significant main effect was found in the UK participants for the number of elements in the number of x-flips Wald χ^2 (1) = 10.26, $p < .01$ and y-flips Wald χ^2 (1) =

6.03, $p < .01$. A significant interaction was found for the UK sample between symmetry/asymmetry and the number of elements in the x-axis Wald χ^2 (1) = 4.28, $p < .05$ and in the y-axis Wald χ^2 (1) = 8.68, $p < .01$.

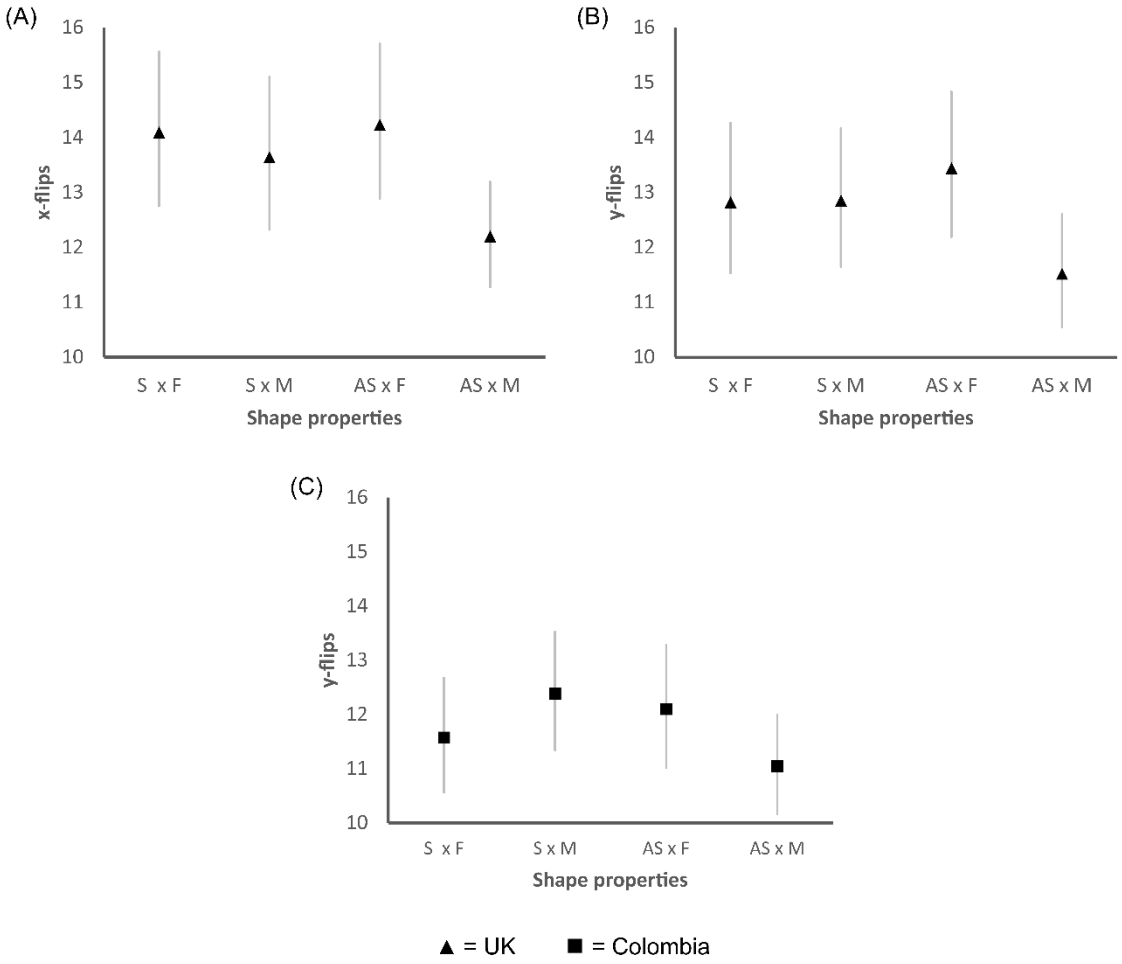


Figure 2.5. Graphs showing the mean hand flips for the valence task for those shape properties that displayed significant interactions in Study 2. Main effects are not shown given that the interactions explain the main effects. (A) Significant two-way interactions between symmetry/asymmetry and the number of elements in the x-axis for the UK sample; (B) two-way interactions between symmetry/asymmetry and the number of elements in the y-axis for the UK sample; (C) two-way interactions between symmetry/asymmetry and the number of elements in the y-axis for the Colombian sample. Significant differences were found when comparing shapes that were both asymmetrical and had fewer elements with the rest of the conditions (AS x M). S = symmetrical, AS = asymmetrical, F = fewer elements, M = more elements. Error bars = standard error.

There were less hand movements prior to making a response when the participants were presented with shapes that were asymmetrical or had more elements. Shapes that were

both asymmetrical and presented more elements further reduced the participants' hand movements prior to clicking a valence word (see Figures 2.5A and 2.5B). No other effects were found for the UK sample. A significant interaction was observed between symmetry/asymmetry and the number of elements Wald χ^2 (1) = 4.91, $p < .05$ in the y-flips of Colombian participants. The participants generated less hand movements when shapes were both asymmetrical and presented more elements (see Figure 2.5C). No other significant effects were found for the Colombian sample. Less flips in both axes suggest that the participants found it easier to associate a specific shape with a valence word. No other effects were found.

Sweet/sour task

Significant main effects for all three shape properties were found in both countries (see Figure 2.6 and Table 2.3). Rounder shapes were more easily matched with the word sweet than were more angular shapes (OR UK: 1.57; OR Colombia: 12.3). More symmetrical shapes (OR UK: 4.24; OR Colombia: 3.42) and shapes that had fewer elements (OR UK: 3.45; OR Colombia: 3.65) were also more likely to be matched to the word sweet when compared with asymmetrical shapes and those shapes having a greater number of elements, respectively. Overall, symmetry/asymmetry was most influential in terms of how shapes were matched to a specific taste word in the UK sample. For the Colombian sample, roundness/angularity was the shape property that had the greatest influence on shape-taste matches.

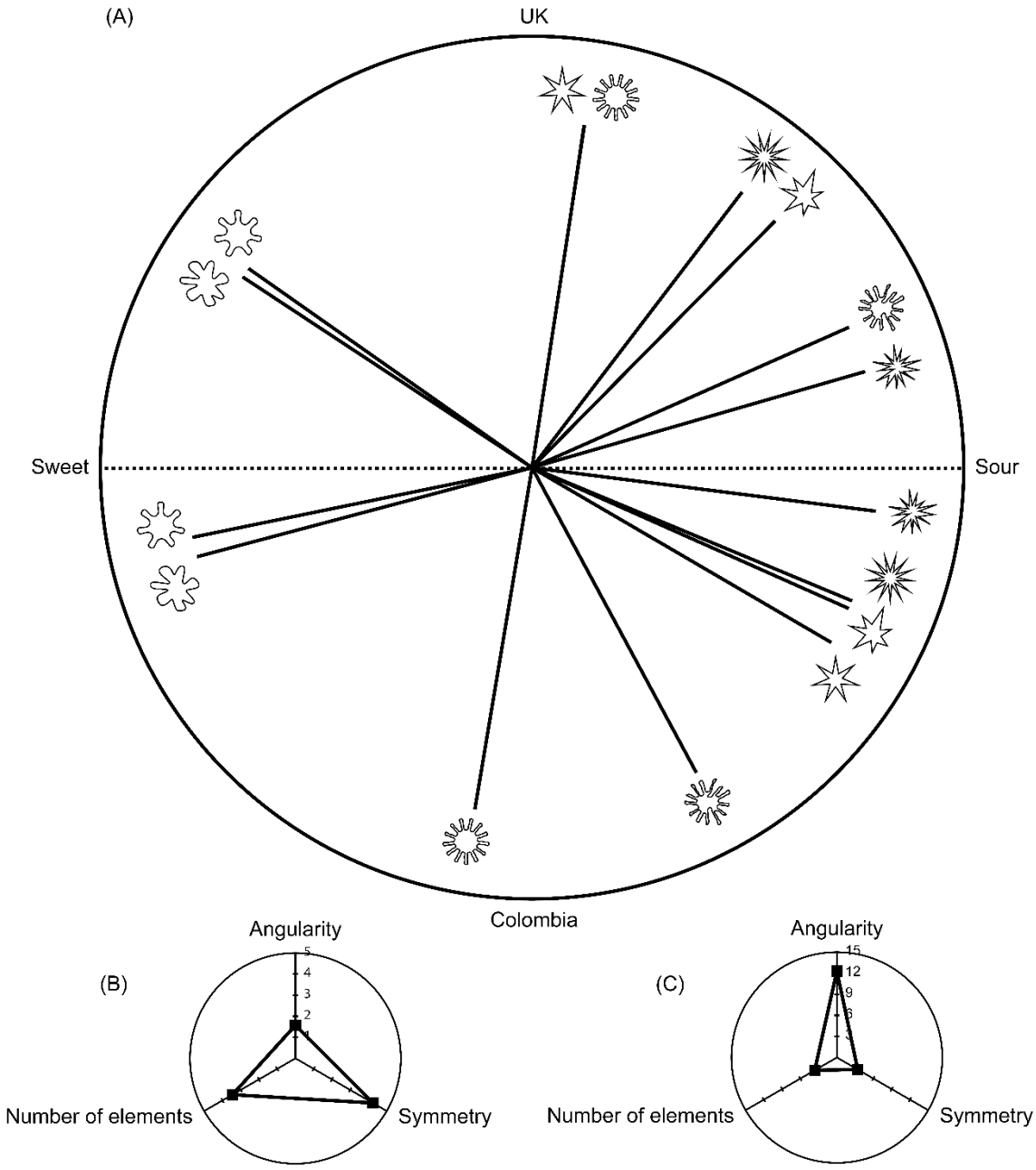


Figure 2.6. (A) The mean categorization frequencies for the taste task in Study 2. The upper part of the circle presents the frequencies for the UK sample, while the bottom part of the circle presents the frequencies for the Colombian sample. Shapes that were more consistently rated as sweet are presented towards the left, while those shapes that were deemed sour are presented towards the right. (B) The odds ratios for the UK; (C) The odds ratios for the Colombian sample. Given that panels (B) and (C) present the effect size for each shape property, they can be used as an explanatory measure to help understand the frequencies observed in the study. The effect sizes can also shed light as to why there are some differences between the two countries, given that the effect sizes were different for each country and for each shape property.

The congruent pairing of roundness/angularity and number of elements appeared to influence the speed of categorization in terms of the words sweet or sour in both countries (OR UK: 8.29; OR

Colombia: 5.88, see also Table 2.3). For the UK sample, congruent symmetry/asymmetry x number of elements (OR: 1.73) and roundness/angularity x symmetry/asymmetry x number of elements combinations (OR: 3.29) increased the odds of matching a shape with a specific taste word (see Table 2.3).

Table 2.3.

The influence of each shape property on shape-taste matches as shown by binary logistic regression GEE in Study 2.

Shape properties	UK	Colombia
Roundness/angularity	Angular = sour*	Angular = sour***
Symmetry/asymmetry	Symmetrical = sweet***	Symmetrical = sweet**
Number of elements	Fewer elements = sweet***	Fewer elements = sweet***
Roundness/angularity x symmetry	No effect	No effect
Roundness/angularity x number of elements	Rounder x fewer elements = sweet**	Rounder x fewer elements = sweet***
Symmetry/asymmetry x number of elements	Symmetrical x fewer elements = sweet**	No effect
Roundness/angularity x symmetry/asymmetry x number of elements	Rounder x symmetrical x fewer elements = sweet*	No effect

Note that all effects that are significant include both polar properties (e.g., symmetry and asymmetry, or roundness and angularity). * $p < .05$, ** $p < .01$, *** $p < .001$.

RTs. In the UK sample, significant main effects of roundness/angularity Wald χ^2 (1) = 5.13, $p < .05$ and symmetry/asymmetry Wald χ^2 (1) = 10.93, $p < .01$ were observed. Angular shapes (CI: 1866-2306ms) were, on average, categorized 119ms faster than rounder shapes (CI: 2000-2411ms). The participants responded 164ms more rapidly to the asymmetrical shapes (CI: 1848-2281ms) than to the symmetrical shapes (CI: 2020-2435ms, see also Figure 2.7A).

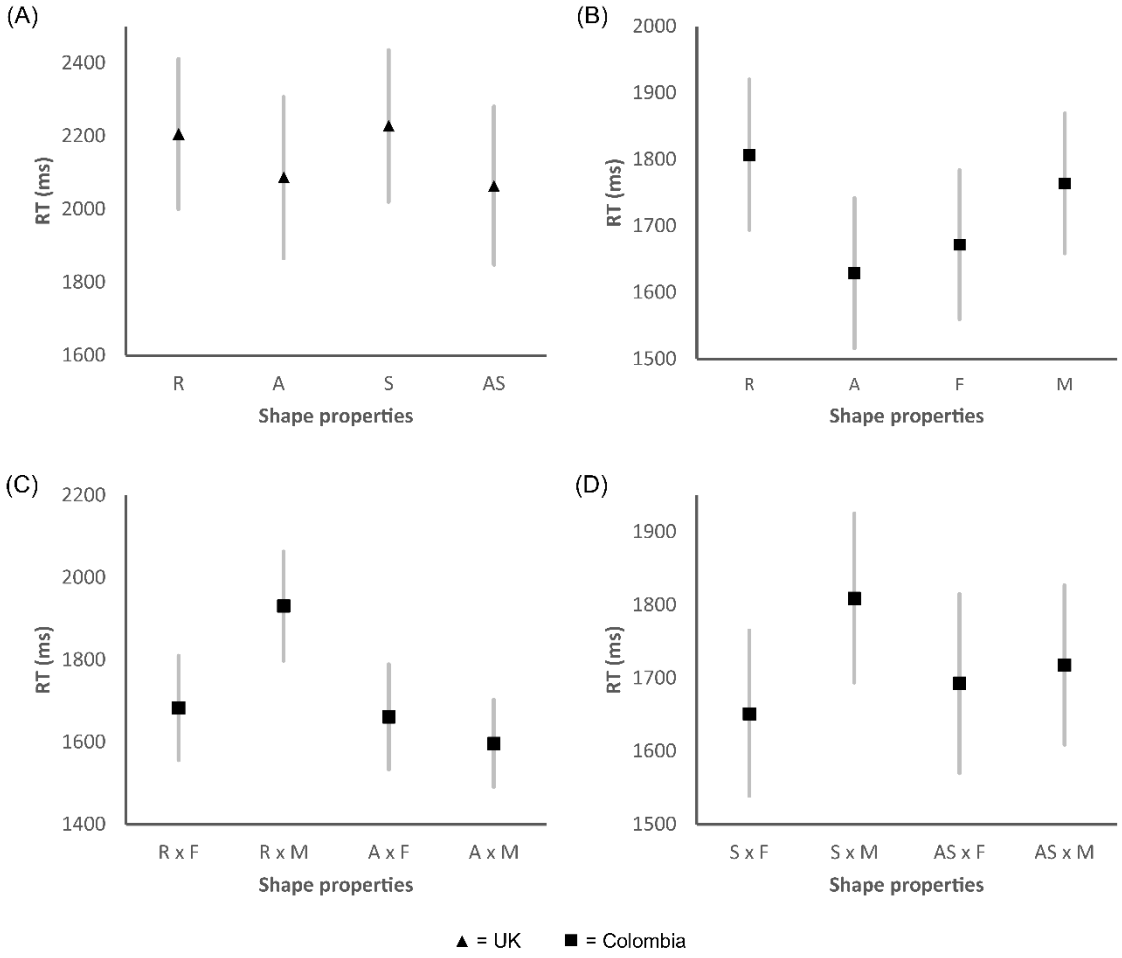


Figure 2.7. Graphs showing the mean RTs for the taste task for those shape properties that displayed significant differences in Study 2. (A) Shape properties that displayed a significant main effect for the UK sample; (B) Shape properties that displayed a significant main effect in the Colombian sample; (C) Significant two-way interaction between roundness/angularity and the number of elements for the Colombian sample; (D) Significant two-way interaction between symmetry and the number of elements for the Colombian sample. R = round, A = angular, S = symmetrical, AS = asymmetrical, F = fewer elements, M = more elements. Error bars = standard error.

The Colombian participants displayed significant RT differences for roundness/angularity Wald χ^2 (1) = 13.77, $p < .001$, as well as for the number of elements, Wald χ^2 (1) = 6.76, $p < .01$ (see Figure 2.7B). Angular shapes (CI: 1538-1794ms) were categorized 210ms ($p < .001$) faster than rounder shapes (CI: 1743-2010ms). Shapes with fewer elements (1602-1857ms) yielded faster responses (83ms, $p < .05$) than those shapes with more elements (CI: 1692-1934). Significant interactions were found between the

number of elements possessed by a shape and both roundness/angularity Wald χ^2 (1) = 17.17, $p < .001$ (see Figure 2.7C) and symmetry/asymmetry Wald χ^2 (1) = 4.35, $p < .05$ (see Figure 2.7D). Those shapes that were both angular and had a greater number of elements (CI: 1567-1843ms) presented the slowest RTs (1705ms), whereas shapes with more elements and that were also round produced the slowest RTs (1999ms). Shapes that were both asymmetrical and presented fewer elements were categorized more rapidly (1727ms) than shapes with other combinations of the same two polar properties (i.e., roundness/angularity and number of elements). Participants produced the slowest RTs when asked to categorize those shapes with a greater number of elements and that were also symmetrical (1865ms), as compared with shapes with varying arrangements of the same two polar properties (i.e., symmetry/asymmetry and number of elements).

Motor complexity. In the taste task, a significant main effect for symmetry/asymmetry was found for the UK sample for hand flips in both the x-axis Wald χ^2 (1) = 10.06, $p < .01$ (see Figure 2.8A) and the y-axis Wald χ^2 (1) = 7.61, $p < .01$ (Figure 2.8B). The number of elements present in a shape also displayed a significant main effect on the number of y-flips that were generated by the participants while categorizing each shape Wald χ^2 (1) = 4.09, $p < .05$ (see Figure 2.8B). In the Colombian sample, roundness/angularity displayed a significant main effect for hand flips in the y-axis Wald χ^2 (1) = 11.21, $p < .001$ (see Figure 2.8C). A significant interaction between symmetry/asymmetry and the number of elements was also found for hand flips in the y-axis Wald χ^2 (1) = 5.30, $p < .05$ (as also shown in Figure 2.8C). Overall, the participants generated more hand flips for those shapes that were more symmetrical and had a greater number of elements. Specifically, for the Colombian sample, rounder shapes also generated more hand flips. No other effects were found.

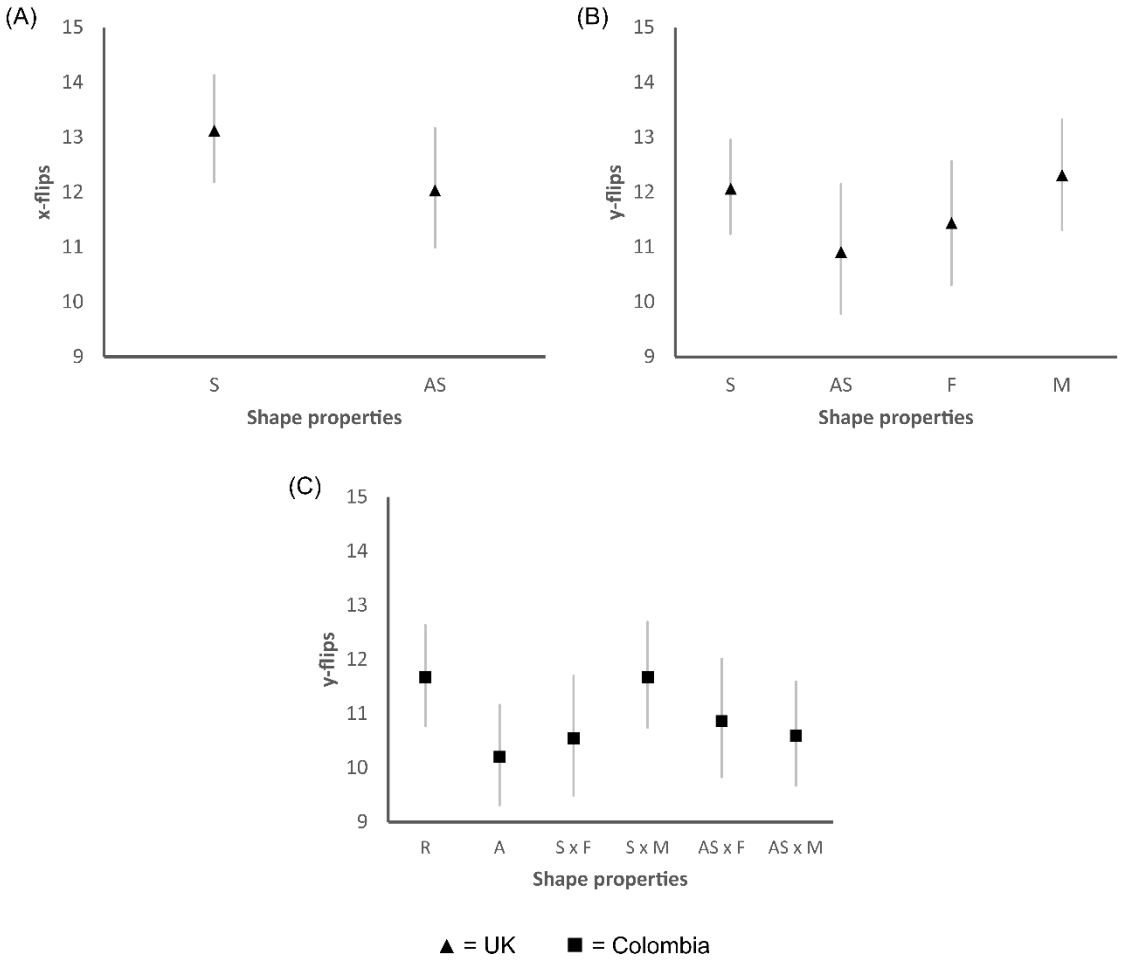


Figure 2.8. Graphs showing the mean hand flips for the taste task for those shape properties that displayed significant differences in Study 2. (A) Significant differences between symmetry and asymmetry for x-flips in the UK sample; (B) Significant differences between symmetry and asymmetry, and between the number of elements for y-flips in the UK sample; (C) Significant differences between roundness and angularity and significant interaction between symmetry/asymmetry and the number of elements for y-flips in the Colombian sample. Significant differences were found in the Colombian sample when comparing shapes that were both asymmetrical and had fewer elements with those shapes that were symmetrical and had more elements (S x F vs. S x M). Significant differences were also found when comparing symmetrical and shapes with more elements with asymmetrical shapes with the same number of elements (S x M vs. AS x M). S = symmetrical, AS = asymmetrical, F = fewer elements, M = more elements. Error bars = standard error.

Task Comparison. In order to compare whether the participants exhibited a tendency to match the same shapes to sweetness and pleasantness and to sourness and unpleasantness, the responses from the UK and Colombian samples were aggregated (8 shapes x 63 participants = 504). Since each participant categorized each shape four times on each task, the categorizations were transformed into ranked values depending on how many

times a shape was consistently classified as sweet/pleasant or sour/unpleasant (i.e., 4 = all were consistently associated with the same word; 3 = ¾ of times a specific shape was associated with the same word; 2 = half of the times a shape was associated with one of the words; 1 = a shape was associated with that particular word only once, also see Table 2.4). This is the reason why in this particular instance there were only 504 data points instead of the original 2016 trials. As a first step, a Pearson correlation was computed to assess the relationship between the responses in the valence and taste task. A moderate significant correlation was found for the matches made by the participants in the two tasks ($r = 0.42$, $n = 504$, $p < .01$); showing that those participants who matched a shape with the word pleasant also associated the same shape with the word sweet. The correlation also revealed that the participants tended to match those shapes with sourness that were also associated with the word unpleasant.

Table 2.4.

Frequencies and standardized residuals used to compare responses between the tasks part of Study 2. Larger standardized residuals suggest a greater tendency to match a shape in both tasks consistently (i.e., pleasant and sweet, or unpleasant and sour).

Taste/Valence		Pleasant 4/4	Pleasant 3/4	50-50 2/4	Unpleasant 3/4	Unpleasant 4/4	Total frequency
Sweet 4/4	Frequency	124	33	15	29	47	248
	SR	3.5	1.5	-1.1	-.4	-3.8	
Sweet 3/4	Frequency	16	8	2	2	9	37
	SR	.7	2.1	-.5	-1.2	-.9	
50-50 2/4	Frequency	16	3	4	4	5	32
	SR	1.3	-.2	.9	.0	-1.7	
Sour 3/4	Frequency	10	0	3	6	13	32
	SR	-.5	-1.8	.3	1.0	.8	
Sour 4/4	Frequency	18	8	16	23	90	155
	SR	-5.1	-2.0	1.1	.7	5.6	
Total frequency		184	52	40	64	164	504

* Fractions on each row and column represent the number of trials that were consistently matched with a specific word. SR = Standardized residuals.

Furthermore, the choices made by the participants were classified in terms of their consistency; that is, whether the participants matched a shape to the same word across the four trials. After this process had been completed for both tasks, standardized residuals were calculated to determine whether the participants categorized shapes as pleasant-sweet and as unpleasant-sour. The standardized residuals (SR, see Table 2.4) show that shapes that were matched to the word sweet were also more likely to be matched to the word pleasant. Moreover, shapes that were categorized as sour were also more likely to be matched to the word unpleasant. Shapes that were matched to the word sour or unpleasant were less likely to be matched to the word sweet or pleasant and vice-versa.

The results also revealed that symmetry/asymmetry influenced how easy it was for participants to match a shape to both the word pleasant and the word sweet (SR = 2.4). On the other hand, shapes that were more asymmetrical were more consistently matched by the participants with the words unpleasant and sour (SR = 2). The number of elements that make-up each shape also had an influence on how likely it was that shapes were categorized as both pleasant and sweet (SR = 2.9) and unpleasant and sour (SR = 1.4).

Study 2 evaluated how roundness/angularity, symmetry/asymmetry, and the number of elements influenced participants' categorization judgments concerning the eight different shapes in the two tasks. In one task, the participants had to categorize the shapes as either pleasant or unpleasant, while in the other task, they categorized them as sweet or sour instead. The results demonstrated that roundness/angularity, symmetry/asymmetry, and the number of elements exerted different degrees of influence over the likelihood that a given shape would be matched to a specific valence and taste word. The results reported here demonstrate that symmetry/asymmetry and the number of elements can influence the perceived valence of a shape; they also reveal that roundness/angularity requires that

symmetry/asymmetry be present in order to convey a specific valence. Regarding shape-taste matches (second task), the results revealed that all three shape attributes (i.e., roundness/angularity, symmetry/asymmetry, and the number of elements) exerted varying degrees of an influence over the way in which shapes are matched to the words sweet and sour. It would seem that symmetry/asymmetry is an important property when it comes to conveying sweetness/sourness. What is more, since, by itself, roundness did not present a significant main effect in terms of valence, if affective matching actually mediates shape-taste correspondences, shape attributes such as symmetry/asymmetry may have a significant contribution when matching shapes to sweet and sour tastes.

Comparing the responses in the two tasks, the correlations and standardized residuals (see Table 2.4) show that there is some consistency in the matches made by the participants across tasks. Hence, our results support the view that emotional valence is involved in shape-taste matching. However, given that the correlation and residuals did not present a large effect, this underscores the existence of other factors that mediate shape-taste correspondences too. More research is therefore needed in order to understand the mechanisms that facilitate the bidirectional matching of shapes and tastes.

2.4. General discussion

The two studies presented in this chapter demonstrate that different visual features can be associated with approach and avoidance motivation (Study 1), with a valence and with specific taste words (Study 2). In Study 1, shapes and objects varying in curvature and symmetry were presented to the participants. The results show that rounded and symmetrical shapes and objects were more likely to be associated with approach motivation whereas those shapes and objects that were angular and asymmetrical were more easily matched to avoidance motivation instead.

Study 2 included a third visual feature (i.e., number of elements) and provided evidence that rounded, symmetrical, shapes with fewer elements were more easily matched to a positive emotional valence and to the word sweet. In contrast, angular, asymmetrical, and shapes with a greater number of elements were deemed unpleasant and matched to the word sour. Subsequent analyses comparing the two tasks, part of Study 2, demonstrated that while the participants can consistently match a shape to a valence, the valence of the stimulus provides a significant but weak prediction of shape-taste matches.

The discrepancies in shape-valence and shape-taste matches had already been reported by Velasco, Woods, Deroy, and Spence (2015). The results of Study 2 validate their findings, showing that the influence of each of the three visual features presented to the participants is different when matching a shape to a valence and to a taste word. The findings from Study 2 may, at the same time, help explain the discrepancies between valence and taste and underscore that valence is not sufficient to explain the crossmodal correspondences between shapes and tastes. The findings of Studies 1 and 2 validate previous experiments providing evidence that is a preference for roundness and symmetry (Palmer, Schloss, & Sammartino, 2013; Shimamura & Palmer, 2014). Studies 1 and 2 include, for the first time, visual features such as symmetry and the number of elements in the study of shape-taste matches. Documenting the influence of different features provides a better understanding of the mechanisms involved in these matches, as well as better guidelines for the design of food, products, and advertisements.

3. CHAPTER 3: Anthropomorphism, valence, and taste

"Our experience of affect guides our philosophical views of good and bad. If the insights gained from taste and olfaction generalize to broader domains, those insights may help us make the world a better place."

Bartoshuk & Snyder (2016, p. 235)

3.1. Introduction

According to evidence presented in the previous chapter, shapes varying in curvature, symmetry, and the number of elements can indeed influence the associations that people make between shapes and tastes. Complementary to the latter evidence, facial expressions can accompany both an emotion and a gustatory experience (see Chapter 1). Is it possible, then, for shapes that resemble facial expressions to be associated with emotions and specific basic tastes? The research reported in this chapter focuses on understanding whether simple visual stimuli (i.e., a line and/or a pair of dots), which resembles facial features, can be associated with a specific valence (and emotion) and with a basic taste. A review of the state of the art regarding anthropomorphic features and emotional valence will be presented first. Afterwards, a case will be made that there is insufficient research addressing how simple lines and dots can be associated with basic tastes. Finally, empirical research will be presented showing that lines and dots that resemble facial features can influence shape-valence and shape-taste associations.

Five different studies will be presented (Studies 3-7). The first study to be reported in this chapter (Study 3) assessed the strength of the associations between simple lines (i.e., convex and concave) with a valence and with specific emotions (i.e., sad or happy). In Study 3, a modified version of the implicit association test (IAT, see Greenwald, McGhee, & Schwartz, 1998) was used in order to determine the strength of association

between a concave line and the word happy and between a convex line and the word sad. Study 4 evaluated whether six different pairs of dots that resembled eyes influenced the perceived valence of an emoticon. Study 5 examined whether the same dots could be matched to specific emotions (i.e., joy, surprise, anger, sadness).

In Study 6, the participants viewed four variants (concave [smile-like] line, convex [frown-like] line, straight line, line absent) of three different products (tea, shampoo, juice) and evaluated the products on visual analogue scales and completed a forced-choice decision task. Study 7 presented the participants with products that displayed the smiling and frowning lines, as well as four dots that resembled eyes. The participants had to rate the products in terms of how sweet, sour, and bitter they considered each one to be.

The importance of understanding how simple visual features can communicate emotions seems even more important when considering the growing tendency to opt for virtual communication which involves anthropomorphised designs to communicate emotions (Derks, Bos, & von Grumbkow, 2007). Moreover, the findings presented in this chapter could also provide some relevant (not to say important) implications for designers, in the sense that they would provide practical information to communicate affective information via simple visual stimuli.

STUDY 3

3.2. The implicit association test and lines that resemble sad and happy mouths[12]

A variety of studies have used the IAT to understand the underlying associations that are present between sensory features (i.e., packaging shapes) and particular products and product categories (Parise & Spence, 2012a, 2012b; Spence, 2012b). Furthermore, Larson, Aronoff, and Steuer (2012) have used the IAT to determine that "Vs" and downward pointing triangles can be associated with a specific valence (i.e., pleasant or unpleasant). However, to date there have been no studies that have extended the current research to other emotions such as joy, surprise, anger, and sadness. The purpose of the fourth study was to establish whether a downward concave and upward convex line can be associated with the words happy and sad, respectively[13].

3.2.1. Methods and materials

Participants: Fifty-four participants (24 from the UK and 30 from Colombia, 29 females, M_{age} = 26.3 years, SD_{age} = 4.3, $range_{age}$ = 19-37 years) volunteered to take part in the experiment. They were invited to participate in the study via the database of the Crossmodal Research Lab and of the Universidad de La Sabana. All of the participants signed a standard consent form; the experiment was reviewed and approved by the Central University Research Ethics Committee at the University of Oxford (MSD-

[12] The information presented in Study 4 was published in Salgado-Montejo, Salgado, Alvarado, and Spence (2016). The figures and text presented in this section were written solely by me. All other authors provided feedback and made comments on the manuscript and figures and reviewed all data analyses.

[13] It is important to note that concavity and convexity is relative to the shape or line (Bertamini & Wagemans, 2013). However, for this case, it is possible to define a concave/convex function by the following statement: Let *m* be the midpoint of a hypothetical function *f*. For function *f*, if all *y* numbers are greater than *m*, then let us define the function as concave. If all *y* numbers, part of function *f*, are less than *m*, let us define the function as convex.

IDREC-C1-2014-034) and by the Research Commission of the International School of Economics and Business Science at Universidad de La Sabana, Chía, Colombia. The experiment took approximately 45 minutes to complete, and individuals received either £5 or academic credit in return for their participation. Sampling procedures, informed consent, and payment was the same in all the experiments reported here.

Apparatus and materials: E-Prime 2.0 software (Psychology Software Tools, Inc.) was used to present the stimuli, and record the participants' responses. The participants sat in front of a 14" 1024x768 pixels LED monitor, with a screen refresh rate of 60 Hz. Adobe Illustrator CS6 was used to create the three distinct lines (concave, convex, and straight) and the same lines together with two dots that resembled a pair of eyes (see Figure 3.1). A modified version of the implicit association test (IAT) was used to evaluate the strength of the association between the convex and concave lines and two different valence words (Sriram & Greenwald, 2009, also see Greenwald et al., 1998; Larson et al., 2012).

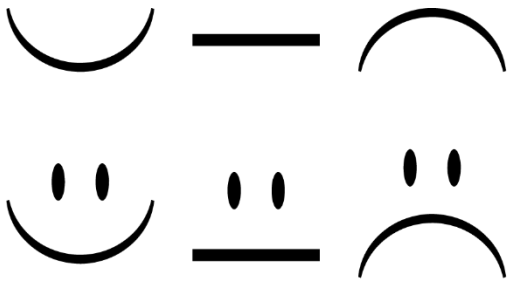


Figure 3.1. The visual stimuli presented to the participants in Study 3, consisting of a downward concave, straight, and upward convex line with and without eyes.

Procedure: Six IATs (three included the "lines without eyes" and the other three included the "lines with eyes") were presented to the participants. The order of stimulus presentation was counterbalanced across participants. Each IAT included two putatively

congruent and incongruent conditions in which the participants had to associate the stimuli with the words happy (left mouse key) or sad (right mouse key). The abbreviated version of the IAT was followed (Table 3.1; see also Sriram & Greenwald, 2009), which reduces the task from seven stages down to four (two congruent and two incongruent). Note that the response keys were not swapped in stages 4 and 6 since our main interest was in determining whether the lines presented to participants could be associated with a particular valence, and if participants performed better when a particular line was paired with a specific word. Within each of the conditions (with or without eyes), each of the IATs (concave-convex, concave-straight, and straight-convex) was presented at random. There were 20 trials per stage. There were two congruent stages and two incongruent stages thus giving rise to a total of 80 trials (see Table 3.1). The two conditions ("without eyes" and "with eyes") were counterbalanced across participants. The stimuli were presented for 2500ms and a screen displaying the words "incorrect", "correct", and "too slow" were presented depending on the response given by participants to provide feedback.

Table 3.1.

Stages of each of the IATs presented to participants during Study 3.

	Congruent stages (1 and 2)		Incongruent stages (3 and 4)	
	Words		Words	
IAT	Happy	Sad	Happy	Sad
Concave-convex	Concave	Convex	Convex	Concave
Concave-straight	Concave	Straight	Straight	Concave
Straight-convex	Straight	Convex	Convex	Straight
Concave-convex with eyes	Concave	Convex	Convex	Concave
Concave-straight with eyes	Concave	Straight	Straight	Concave
Straight-convex with eyes	Straight	Convex	Convex	Straight

The participants were informed that they would be presented with simple lines and with simple lines together with dots that resembled emoticons and that they should pair a line or emoticon with a particular word (either happy or sad).

Data analysis: SPSS 22 (Armonk, NY: IBM Corp.) was used to analyse the data. Data analysis was performed following the procedure suggested by Greenwald, Nosek, and Banaji (2003). The mean RT for each of the four stages was calculated, as well as the inclusive standard deviation for Stages 1 and 3, and 2 and 4 (see Table 3.1). Next, the mean difference between each pair of Stages (1 and 3, and 2 and 4) was computed and divided by its standard deviation. The D measure was then determined by averaging the two resulting ratios. The mean of the correct responses for each stage plus 600ms was added to each RT when the participants chose the wrong association between the word and the line (see Cai, Sriram, & Greenwald, 2004). Individual D measures per participant were also calculated. The aforementioned process was repeated for each of the IATs presented to the participants (see Table 3.1). A repeated measures Analysis of Variance (ANOVA) was performed with the IATs (concave-convex, concave-straight, and straight-convex) and the presence/absence of eyes as factors.

3.2.2 Results

The D measures present medium effect sizes in the concave-convex and concave-straight IATs, with the "without eyes" condition displaying higher scores (see Cohen, 1988, 1992, for literature on how to interpret effect sizes, but see also Rosenthal, Rosnow, & Rubin, 2000). This means that it was easier to associate the word happy with the concave line as compared to the convex line (without eyes $D = 0.53$; with eyes $D = 0.31$) and straight line

(without eyes D = 0.51; with eyes D = 0.46), and to associate the word sad with the convex line. Furthermore, RTs were faster in the "no eyes" condition when compared to the "with eyes" condition. A slower RT suggests that more time is required to process the stimulus when the eyes are present. The analysis of the data revealed that there was a small effect size for the associations in the straight-convex IAT (without eyes D = -0.18; with eyes D = -0.08). Furthermore, in the straight-convex IAT, RTs were faster in the incongruent conditions as compared to the congruent condition (see Figure 3.2).

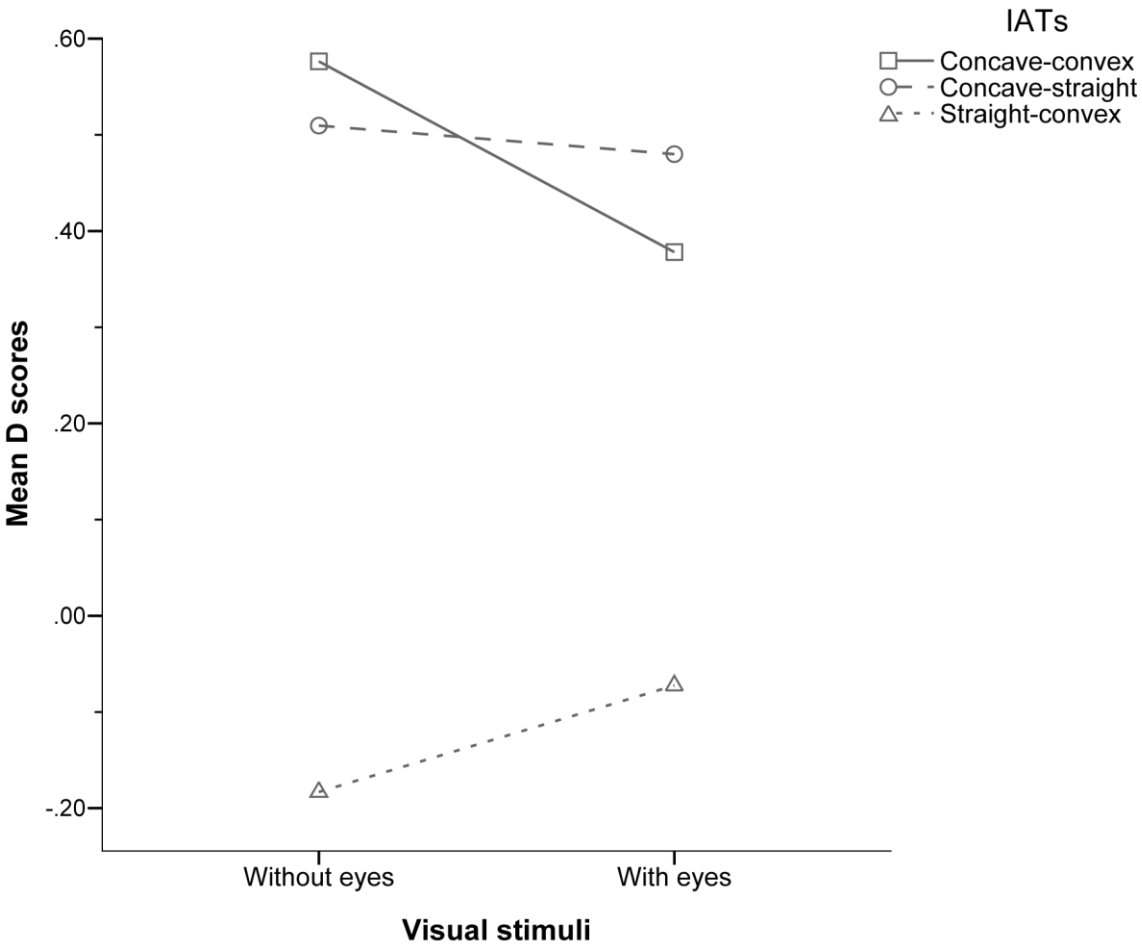


Figure 3.2. Average D measures representing the difference between the congruent and incongruent phases in terms of an effect size in Study 3. Figure shows effect sizes per condition ("without eyes" and "with eyes") and per IAT (concave-convex, concave-straight, and straight-convex). Note that higher D measures indicate that participants' RTs were faster for the congruent stages than for the incongruent stages. They also denote those lines that were more easily associated with a particular word.

Significant differences were found when calculating a D measure per participant and running a repeated measures ANOVA with the line (concave, convex, and straight) and the presence/absence of eyes as factors in order to compare the concave-convex, concave-straight, and straight-convex conditions. The line conditions also displayed significant differences, $F(2, 31) = 44.53$, $p < .001$, $\eta p^2 = 0.59$, thus showing that the participants found it easier to associate certain lines with the words happy or sad. Post hoc tests using Bonferroni correction revealed that the participants responded significantly more rapidly in the congruent phases, as compared to the incongruent phases, and in the concave-convex IAT when compared to the straight-convex IAT ($M = 0.61$, $SD = 0.07$, $p < .05$). Pairwise comparisons also indicated significant differences when comparing the concave-straight and straight-convex IATs ($M = 0.62$, $SD = 0.08$, $p < .05$). The latter result reveals that the concave-straight IAT gave rise to lower RTs in the congruent phase as compared to the incongruent stage. Faster RTs reflect the fact that the participants found it easier to match the concave line with the word happy and the convex line to the word sad when compared with the straight line. A significant interaction was observed between the eyes and the lines, $F(1, 31) = 4.97$, $p < .033$, $\eta p^2 = 0.14$, thus suggesting that particular configurations of the eyes and lines affected the speed of participants' categorization responses.

3.2.3. Discussion

The results of Study 3 support the notion that simple visual elements such as lines can be associated with specific affective categories. Furthermore, the "no eyes" concave-convex IAT yielded the greatest differences in RTs when the congruent and incongruent phases were compared. The latter finding suggests that there is a greater valence contrast between the two lines (i.e., concave and convex) than when compared with the straight

line. Overall, the participants responded more rapidly when they had to associate a concave line with the word happy as compared to when associating the same word with a convex or straight line instead. The findings from Study 3 therefore contribute to the growing body of research showing that basic visual stimuli can be associated with a specific valence. They also expand the research by Larson et al. (2012), by testing stimuli other than a "V" and a downward-pointing triangle and demonstrate that simple visual stimuli can also be associated with a positive valence.

The results of Study 3 further demonstrate that people do not find it especially easy to categorize the word happy with the straight line even when the other option is the convex line, as revealed by the D scores. It is likely that the straight line can be associated with either a positive or negative valence depending on the other visual elements in each display, in this case, the other line (concave or convex) that participants had to categorize in the IATs.

The observed interaction between the lines and the eyes, as well as the D scores presented in Study 3, reveal that the particular arrangements of the eyes and smile- or frown-like lines influence participants' categorization performance. The influence of the eye-like shapes on RTs, however, presented a small effect size thus suggesting that the lines (i.e., concave, convex, and straight) were the main factor determining the valence of the stimuli. Furthermore, it is unclear why the eyes influenced how easy it was to associate a line with a specific valence. It is possible that dots that resemble eyes can also communicate a valence and therefore influence how an emoticon is matched to specific valence.

Gaining a better understanding of how different visual features present in a schematic face can influence the perceived valence could further clarify how emotions are processed and identified in the face. Hence, I conducted Study 4 in order to assess the role of eye-

like shapes in conveying a specific valence. The latter experiment would help determine some of the basic patterns present in a face that underlie a valence judgment.

STUDY 4

3.3. Eye-like dots can convey a specific valence[14]

To determine whether emoticons presenting different dots that resembled eyes could be rated and categorized in terms of different affective dimensions visual analogue (VA) scales and a forced-choice task were used. The VA scales were used to measure participants' explicit ratings of each of the emoticons in terms of their emotional valence, pleasantness, liking, and tension. The forced-choice task provides data concerning how easy it is to match a specific emotion with a particular valence (i.e., pleasant/unpleasant) or emotion (i.e., happy/sad).

The particular shape of the eyes (i.e., symmetrical, vertically or horizontally elongated, oblique, small, or big) might be expected to influence the particular emotion being, in some sense, communicated. Actually, this also happens when perceiving facial expressions of emotion. That is, the different facial muscles can communicate a particular emotion, or else the intensity of emotion, according to the specific combinations of facial movements involved (Cattaneo & Pavesi, 2014; Ekman & Friesen, 1978; Holstege, 2002).

[14] The information presented here was published as Salgado-Montejo, Salgado, Alvarado, and Spence (2016). The figures and text presented in this section were written solely by me and revised by my supervisor Prof. Charles Spence.

3.3.1. Method and materials

Participants: Twenty participants (11 females, *M* = 26 years, *SD* = 3.46, *range* = 19-32 years) were recruited from the participant list of the Crossmodal Research Laboratory. The experiment lasted for approximately 25 minutes.

Apparatus and materials: E-Prime 2.0 software (Psychology Software Tools, Inc.) was used for the VA scales. Mouse tracking software (Freeman & Ambady, 2010) was used to assess performance in the forced-choice task[15]. Adobe Illustrator CS6 was used to develop six different dots that resembled eyes and were paired with the concave and convex lines, respectively (see Figure 3.3 for the stimuli used). The stimulus display conditions were the same as those used in Study 3.

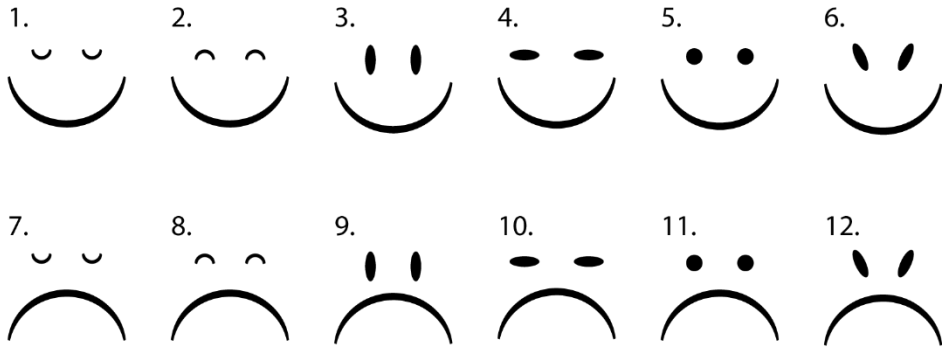


Figure 3.3. The stimuli presented to the participants in Study 4, consisting of a concave and convex line, presenting variations in the shapes that resemble eyes.

The different sets of dots that resembled eyes were designed (Figure 3.3) considering the different facial muscles around the eyes, which are involved in communicating different emotions (see Figure 3.4). The other figures highlight a specific muscle and below the set of dots that more closely resembles the activation of that specific muscle. Dots that

[15] The intention was to use the mouse movements as complementary information to RTs; however, no significant results were found in this case and therefore hand movement measures are not reported.

resemble sad (i.e., concave eyes, see Figure 3.4b), joyful (Figure 3.4c), surprised (Figure 3.4d), and angry eyes (Figure 3.4e) were developed. Two more sets of dots were presented to the participants, which do not match any of the activations of facial muscles proximal to the eyes (i.e., two small circles, see emoticon number four, five, ten and eleven on Figure 3.3). These last sets of dots were used to determine whether it was easier to match specific emotion words to those dots that are associated with specific muscle patterns.

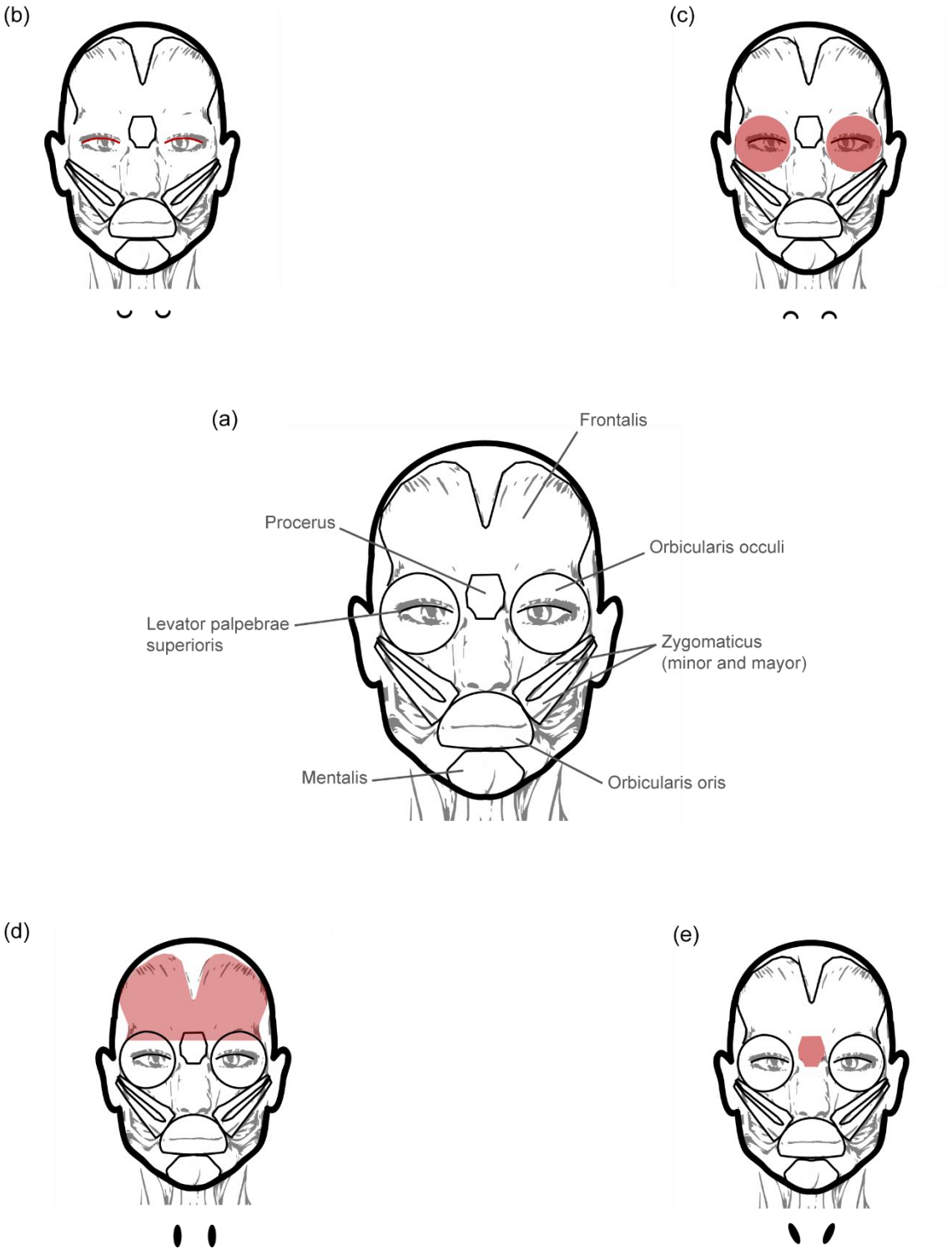


Figure 3.4. (a) The main muscles involved in the facial expressions of emotion; (b) Facial muscles with the palpebralis muscles highlighted and presenting the concave set of eyes that are associated with these muscles; (c) Illustration highlighting the orbicularis occuli muscles and the corresponding eyes at the bottom (convex eyes); (d) frontalis muscles with their corresponding set of eyes at the bottom (vertical dots); (e) Illustration with the procerus muscles highlighted and presenting the oblique eyes at the bottom.

Procedure: VA scales were used to assess the emotional valence (anchored with the labels "sad" and "happy"), pleasantness ("unpleasant" and "pleasant"), liking ("not at all" and "extremely"), and perceived tension ("tense" vs. "relaxed"). The anchors for the pleasantness scales were derived from a study by Larson et al. (2012), in which the same words were used in an IAT. The liking scale was adapted from Finlayson, King, and Blundell (2007, see also Salgado-Montejo et al., 2015) and included the question *"How much would you like to experience the emotion displayed by the emoticon right now?"* The participants rated the twelve emoticons three times on the VA scales thus giving rise to a total of 36 trials. Each VA scale resulted in data that ranged from 0 and 100. The emoticons were presented once in the forced-choice task. The order in which the VA scales and the forced-choice task were completed was counterbalanced across participants.

Data analysis: Participants' responses on each of the VA scales were averaged. Repeated measures ANOVAs were performed in order to examine the participants' responses to the VA scales. Pairwise comparisons with Bonferroni corrections were carried out to determine which of the VA scales presented the significant results. For the forced-choice tasks, a GEE method with a logistic regression model was carried out in order to analyse the participants' choices. RTs were analysed using a GEE with a linear regression model (Hanley, Negassa, Edwardes, & Forrester, 2003; Salgado-Montejo, Alvarado, et al., 2015).

3.3.2. Results

VA scales

Participants' responses on the VA scales were analysed using repeated measures ANOVAs with two factors (lines and eyes). There was a significant main effect with the lines (concave vs. convex) as a factor, when comparing the mean scores of the emotion $F(1, 19) = 476.67$, $p < .001$, $\eta p^2 = 0.96$, liking $F(1, 19) = 371.43$, $p < .001$, $\eta p^2 = 0.95$, pleasure $F(1, 19) = 346.77$, $p < .001$, $\eta p^2 = 0.95$, and tension $F(1, 19) = 114.47$, $p < .001$, $\eta p^2 = 0.86$ VA scales. The aforementioned results confirm the findings of Study 3, showing that a convex line can communicate a negative valence and a concave line a positive valence.

Table 3.2.

Mean scores of the four VA scales by the six eye conditions and the two line conditions (concave and convex) presented in Study 4.

		Condition / Scale							
		Sad				Smile			
Eyes		Emotion	Liking	Pleasure	Tension	Emotion	Liking	Pleasure	Tension
	Mean	13.58	13.40	20.40	34.15	92.60	91.37	93.27	91.25
	Std. Deviation	12.06	12.55	15.22	17.98	8.55	13.63	7.93	11.05
	Mean	16.15	12.35	19.70	44.18	87.88	88.15	89.32	91.27
	Std. Deviation	12.48	10.21	13.30	24.02	8.64	8.64	7.93	8.84
	Mean	12.47	11.12	21.48	32.95	89.33	87.37	86.92	80.97
	Std. Deviation	9.54	8.45	16.23	19.12	7.44	9.57	8.76	9.79
	Mean	14.32	9.23	11.75	21.45	78.10	67.17	74.85	69.33
	Std. Deviation	10.68	8.19	9.33	16.71	12.90	20.01	14.15	19.06
	Mean	13.05	14.82	18.35	34.58	86.52	83.64	86.00	78.18
	Std. Deviation	8.56	11.54	10.92	20.22	10.74	13.37	10.46	12.58
	Mean	18.22	5.78	8.43	9.03	71.33	53.23	60.78	41.60
	Std. Deviation	11.51	7.63	7.30	9.28	15.02	19.05	17.82	17.57

A significant main effect was also found for the six eyes used in the study as factors when comparing the scores of the emotion $F(5, 15) = 5.87$, $p < .01$, $\eta p^2 = 0.66$, liking $F(5, 15) = 15.44$, $p < .001$, $\eta p^2 = 0.84$, pleasure $F(5, 15) = 10.11$, $p < .001$, $\eta p^2 = 0.77$, and tension $F(5, 15) = 26.19$, $p < .001$, $\eta p^2 = 0.90$ VA scales. Overall, those eyes that were paired with the concave line were rated as more positive in all the scales, with the opposite being true for those eyes paired with the convex line (see Table 3.2).

Significant interactions were found between the lines and eyes in terms of the liking $F(5, 15) = 13.74$, $p < .001$, $\eta p^2 = 0.82$, pleasure $F(5, 15) = 4.70$, $p < .01$, $\eta p^2 = 0.61$, and tension $F(5, 15) = 5.80$, $p < .01$, $\eta p^2 = 0.66$ scales. Taken together, these results therefore suggest that line-eye configurations greatly reduce or increase the ratings of how much we enjoy looking at an emotion (liking and pleasure), as well as how much tension we perceive in the face. However, it seems that a line or set of eyes is sufficient to convey a positive or negative valence.

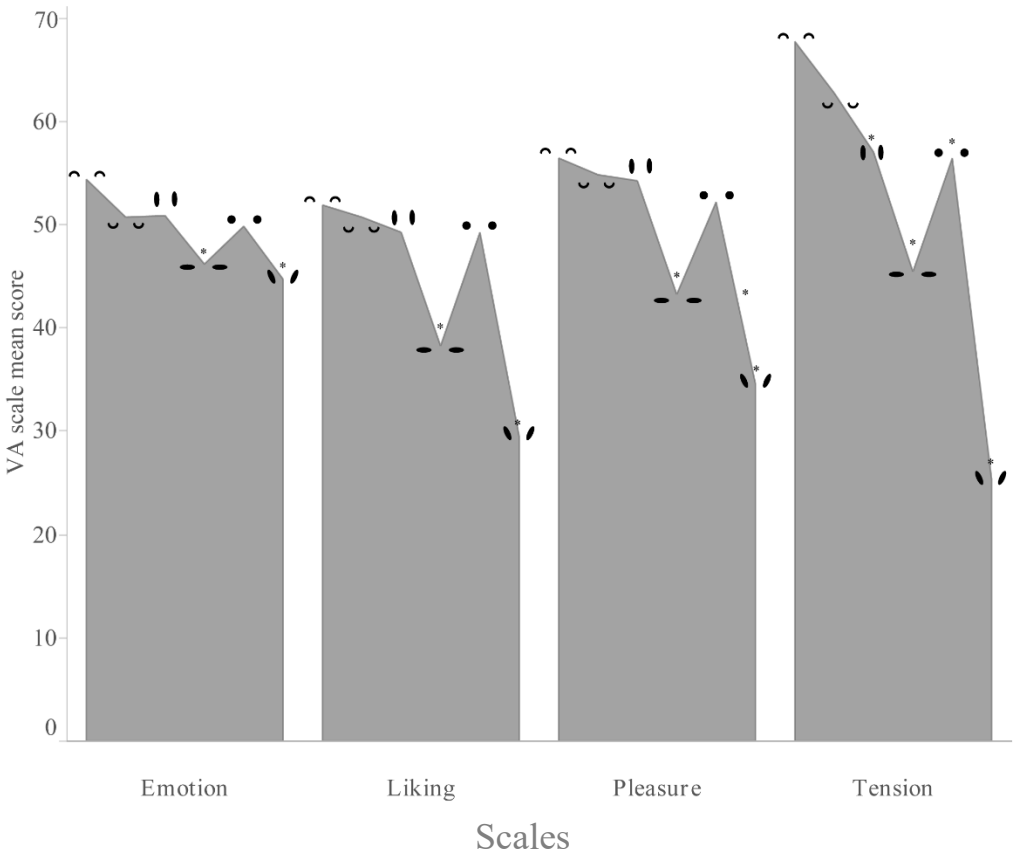


Figure 3.5. Eyes that presented significant differences (Bonferroni corrected) in the post hoc analyses in the VA scales in Study 4. Asterisks indicate significant differences at the .05 level using the convex eyes as a reference. In the emotion, liking, and pleasure scales, the scores of the horizontal oval eyes and the oblique oval eyes were significantly different to the convex eyes. In the tension scale, the score of the convex eyes was significantly greater than for the vertical ovals, horizontal ovals, circle, and oblique oval eyes. A significant difference was found when comparing the scores of the concave eyes with those of the horizontal ovals, circle, and oblique oval eyes. Significant differences were also found between the circle eyes and the horizontal ovals and oblique oval eyes.

Pairwise comparisons revealed that the eyes that were ranked as more positively valenced were those that displayed two convex lines, whereas the eyes giving rise to the least positive valence were the oblique oval-shaped eyes (see Figure 3.5). Post-hoc analyses also showed that the horizontal oval eyes and the oblique oval eyes yielded the greatest number of differences across the scales and mostly when compared with the convex eyes.

Forced-choice task

The participants categorized the convex and concave lines consistently with the words 'sad' and 'happy' and with the words 'unpleasant' and 'pleasant', respectively. For the emotion task, it was not possible to run inferential statistics since the participants classified each set of eyes with the same word every time. The emoticons presenting the concave line were always associated with the word "happy" while the convex line was always matched to the word "sad". For the valence task, a GEE with a logistic regression model found a significant main effect for the line condition Wald χ^2 (1) = 603.34, p < .001. These results suggest, as expected, that the two lines that resemble a mouth can influence the categorization of an emoticon in terms of the words happy/sad and pleasant/unpleasant. There was also a significant effect of the eyes on the categorization of the emoticons in terms of the words "pleasant" and unpleasant" Wald χ^2 (4) = 447.23, p < .001. A significant interaction was found between the line and the eye type for the valence tasks Wald χ^2 (1) = 236.86, p < .001. The latter results suggest that the valence associated with a specific emoticon depends on specific line-eye arrangements.

In the emotion task, as shown by GEEs using a linear model, a significant main effect was found for RTs for the line condition Wald χ^2 (1) = 9.63, p < .01. In the valence task, the eyes had a significant effect on the RTs of the participants Wald χ^2 (5) = 18.91, p < .01. A significant interaction between the eyes and mouth-like line was also found for the

valence task Wald χ^2 (5) = 14.75, $p < .05$. These results demonstrate that the ease with which an emoticon is matched to the words "happy or "sad" is mediated by the line condition. In contrast, sorting the valence of an emoticon requires both the line and eye condition. Furthermore, certain eye-mouth combinations were more difficult to match with a valence word. The pairing of the oblique oval eyes and the smile-like mouth produced the slowest RT, followed by the convex eyes and frown-like mouth (see Figure 3.6).

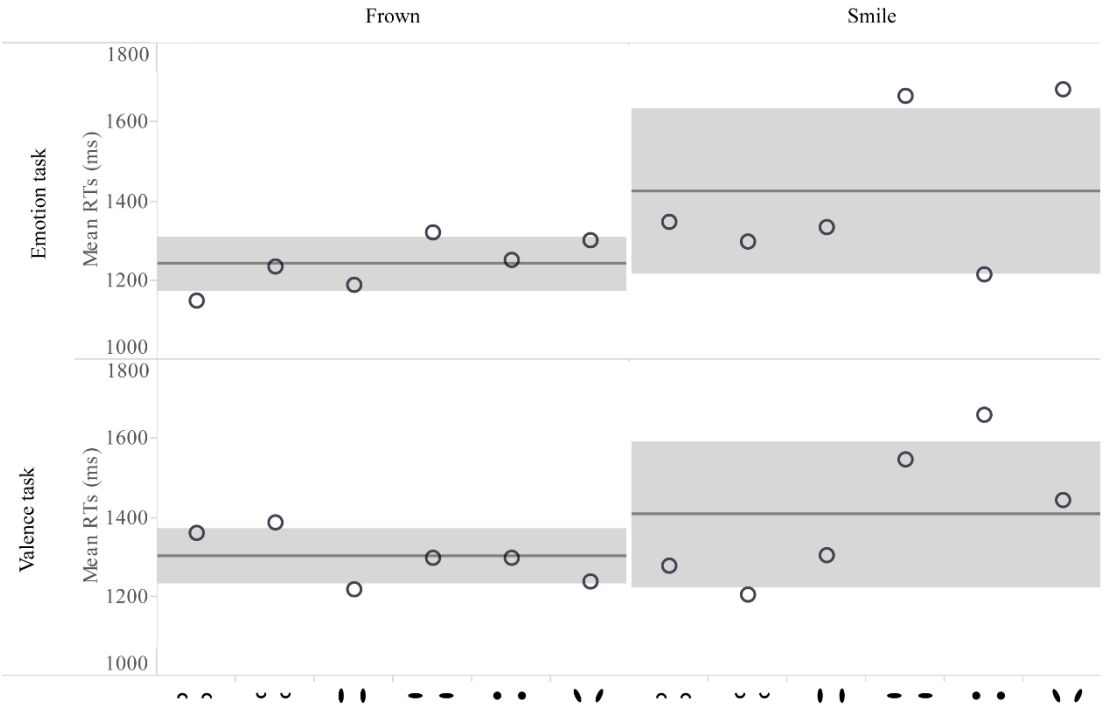


Figure 3.6. The mean RTs for each condition (frown or smile-like mouth) for each of the eye-mouth pairings in the emotion and valence tasks of Study 4. The horizontal line presents the grand average for each condition, and the grey area the 95% confidence interval.

3.3.3. Discussion

The convex eyes presented the highest ratings in the VA scales when presented with the line that resembles a smile, followed by the concave and vertical eyes. Overall, there were

greater discrepancies between the scores of each scale when the eyes were paired with the line that resembled a frown. However, the ratings consistently reflect a negative valence, a tendency towards sadness, and a dislike of experiencing the emotions conveyed by these emoticons.

What is more, those eyes that were matched to a negative valence were also perceived to produce less tension. This could perhaps be explained by either how large the area of the face that is moved or altered by each muscle (e.g., the procerus or the orbicularis oculi) is or by differences in the arousal level elicited by each of the eye-like shapes.

Regarding the forced-choice task, participants' RTs were influenced by how congruent the eye-line arrangements were (see Figure 3.6). For example, it was hard for the participants to match an emotion to the horizontal oval eyes when paired with a frown. The participants also found it more difficult to sort the concave eyes in terms of the valence words when presented together with a frown. The same was true for the horizontal oval, circle, and oblique eyes when paired with a smile. This is consistent with the predictions regarding congruent parings of eyes and lines and association strength. This also suggests that while emoticons may be processed similarly to a face (Churches, Nicholls, Thiessen, Kohler, & Keage, 2014), specific features of each emoticon can convey different information (perhaps just as the face does, see Du, Tao, & Martinez, 2014).

Overall, the results of Study 4 demonstrate that the lines that resemble a mouth (convex and concave) are consistently matched with an emotional word. The results also suggest that the lines can determine the overall valence of the emotion (as shown by both the IATs, VA scale scores, and the participants' choices in the mouse tracking task) and that it is possible that the eyes of the emoticons influence the relative valence (and perhaps also the intensity) of the emotion perceived. The eye-like shapes may be linked to the

communication of emotions or emotional experiences. This is consistent with research on facial expressions showing that the brow and eyes actively contribute to the configuration of particular emotions (Neely, Lisker, & Drapekin, 2014). These particular emotions could be more easily associated with emotional words other than happy or sad which would explain why the pleasant-unpleasant task was more sensitive to differences than the happy-sad task. This means that it is possible that some of the eyes presented in the present study could have been communicating emotions that are not necessarily associated with either happy or sad. Further research is needed to establish whether the eyes that were chosen can communicate emotions different to joy or sadness.

STUDY 5

3.4. Dots that resemble eyes can be associated with distinct emotions[16]

To break down the effect of the eyes on how the participants matched emoticons (and different shapes) to a specific valence, a third study was conducted. The participants had to match different shapes that resembled eyes to four different emotion-related words (i.e., joy, anger, sadness, and surprise). These emotions were chosen because they provide balanced selection of emotions that are related to approach (i.e., joy), avoidance motivation (i.e., sadness), and to both motivational stances (i.e., anger and surprise). These four emotions also display important changes in the muscles surrounding the eyes (i.e., procerus, orbicularis oculi, levator palpebrae, and frontalis).

[16] The findings presented here were published as Salgado-Montejo, Salgado, Alvarado, and Spence (2016). The figures and text presented in this section were written solely by me and revised by my supervisor Prof. Charles Spence.

3.4.1. Methods and materials

Participants: Sixty-two participants (30 from the UK and 32 from Colombia, 32 females, *M* = 23.6 years, *SD* = 3.8, *range* = 18-32 years) took part in this study. The experiment lasted for approximately 15 minutes.

Apparatus and materials: A MTS was used to present the stimuli and register the responses made by the participants. The six different pairs of dots that resembled eyes that had been developed for use Study 4 were once again used in this experiment (see dots number six on Figure 3.7). The stimulus display conditions were the same as in studies 3 and 4.



Figure 3.7. The stimuli presented to the participants in Study 5, consisting of six eye-like dots: concave lines (1), convex lines (2), vertical ovals (3), horizontal ovals (4), circles (5), and oblique ovals (6).

Procedure: The participants were asked to classify each pair of eyes in the mouse tracking task by clicking on one of four words: anger, sad, joy, or surprise. The words were presented on the screen in a cross-like arrangement, all of the words were equidistant (measured from the last letter of each word) from the starting point. The six eyes were presented four times (four blocks) at random for a total of 24 trials. Breaks between each block were suggested to the participants.

Data analysis: The participants' choices were analysed using a Pearson Chi-Squared test (χ^2).

3.4.2. Results

A frequency analysis showed that the convex eyes were consistently associated with the word joy, while the concave eyes were more easily associated with the word sad instead. Participants also categorized the oblique ovals consistently and chose to match this set of eyes with anger. The vertical ovals were more easily associated with surprise, whereas the horizontal were similarly associated to anger and sadness. The participants matched the circle eyes to the surprise and sadness (see Figure 3.8).

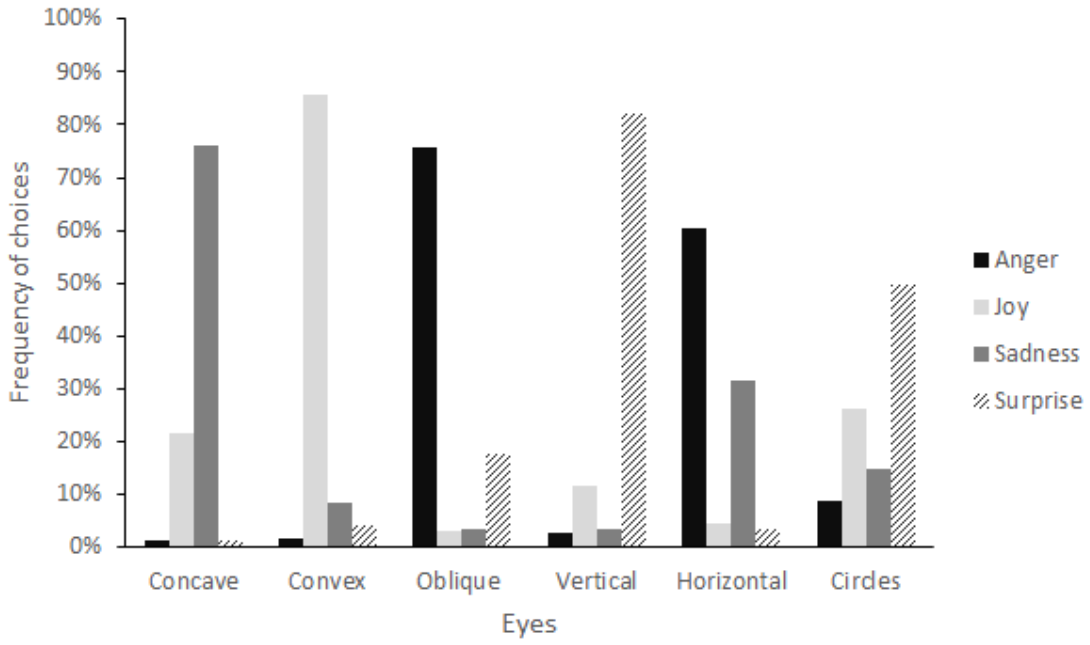


Figure 3.8. Frequency of choices made by participants for each of the set of eyes presented in Study 5.

A Pearson's Chi-squared test ($\chi^2 = 1797.2$, df = 15, $p < .001$) revealed associations between each of the eye conditions and specific emotion-related words. Standardized residuals (SR) were calculated to determine whether the number of cases in a given condition were larger if the null hypothesis were true. The oblique (SR = 15.8) and horizontal ovals (SR = 10.4) were consistently matched with the word anger, with the

latter presenting a weaker association when compared to the oblique ovals. The horizontal ovals were also paired with the word sadness (SR = 2.5), though the association was weaker. The convex eyes were associated with the word joy (SR = 17.8), while the concave eyes were associated with the word sad (SR = 16.9). The vertical ovals were associated with the word surprise (standardized residual = 16.4). Finally, the circle eyes showed a weak association with the word surprise (SR = 6.6). The above results suggest that certain shapes and lines that resemble eyes can more easily convey a particular valence without the presence of other cues (i.e., lines that resemble a mouth).

3.4.3. Discussion

The results of Study 5 demonstrate that simple shapes that resemble gestures around the eyes can communicate specific emotions. These results also show that ovals in a 45° arrangement (Figure 3.7) that seem to form a "V" shape are more easily associated with the emotion word "anger", as compared to the other options (see Figure 3.8). The concave lines that seem to resemble eye closure are more easily matched to the word "sadness". On the other hand, the convex eyes that could result from the activation of the orbicularis oculi are more easily associated with joy. The vertical ovals are also consistently matched with surprise. In contrast, the two eye-like shapes that do not seem to be associated with specific facial expressions of emotion (i.e., horizontal and circle eyes, see Figure 3.8) seem to have less consistent matches.

Moreover, the results presented here are consistent with the predictions made in Study 4, where it was suggested that the concave, convex, oblique, and vertical eyes could communicate particular emotions. These findings provide evidence that lines that resemble a mouth can influence the valence of the eyes (and perhaps other lines or shapes), at least if they are processed as face-like features. To continue the line of research

presented in Studies 4-5, flat, concave, and convex lines were embedded into product packaging to see if these effects are maintained as part of more complex stimuli.

STUDY 6

3.5. Lines that resemble a smile/frown can influence product preferences[17]

The studies presented thus far lead to the question of whether simple geometric shapes or elements that possess a structure that is visually similar to (or could be interpreted in terms of) a smile, could be associated with more positively-valenced emotions. Were such a finding to be observed, it would clearly be important for those working in the area of packaging and logo design (e.g., Airey, 2010; Hsiao & Chen, 2006).

Several studies have demonstrated that the sensory features of a product's packaging can influence the perception and experience of the consumer (e.g., Becker et al., 2011; Klapetek, Ngo, & Spence, 2012; Ngo et al., 2013; Ngo et al., 2012; Spence, 2016; Spence & Gallace, 2011b; Spence, Ngo, Percival, & Smith, 2013; Spence & Piqueras-Fiszman, 2012; Velasco, Woods, Petit, Cheok, & Spence, 2016). There is also growing interest amongst both researchers and practitioners in how lines, shapes, and other visual design elements influence human behaviour (Cheskin, 1981; Spence, 2012b). Included in this general group are those seeking to understand whether certain design elements influence people's behaviour due to their similarity to specific facial features (Toet & Tak, 2013; see DiSalvo & Gemperle, 2003; Lidwell, Holden, & Butler, 2010, for a discussion of how

[17] The information presented in Study 7 was published as Salgado-Montejo, Tapia Leon, Elliot, Salgado, and Spence (2015). Information contained in this section including text and figures was designed and written by me and revised by Prof. Charles Spence.

simple design elements can be interpreted in terms of faces and facial expressions/features).

Furthermore, Winkielman, Berridge, and Wilbarger (2005) have provided evidence suggesting that face stimuli can influence consumer behaviour and the perception of value. These authors explored how implicit information influences consumer behaviour. They presented angry and happy faces using subliminal priming and measured their influence on the pouring and consumption of beverages. They found that faces influenced consumer behaviour (i.e., they influence not only the rating of a product, but also behaviour to engage/purchase/try it). Winkielmann et al.'s study presents evidence that non-conscious affective processing can influence motivation in the context of consumer behaviour (see also Landwehr et al., 2011). Keaveney, Herrmann, Befurt, and Landwehr (2012) have also demonstrated that car headlights (that could be construed as eyes) have a greater influence than a car's grill (i.e., mouth) in consumers' ability to differentiate between products. As yet, however, it is unclear whether simple face-like features (e.g., a smile- or frown-like line) per se can influence consumer perception and behaviour. Thus, there remains a need to address possible links between line curvature (e.g., concave or convex) and consumers' preferences for different products.

The hope here is to understand what, if any, is the effect of the smiling and frowning lines when included in a product packaging. Research in this area will eventually be able to offer concrete and actionable recommendations for enhancing anticipated pleasure and for improving the design of products and their packaging more generally. The aim is to help designers, brand managers, and marketers alike steer the design process in a more evidence-based direction (e.g., Clement, 2007; Landwehr, Wentzel, & Herrmann, 2012; Spence & Piqueras-Fiszman, 2012; Velasco, Salgado-Montejo, Marmolejo-Ramos, & Spence, 2014; Veryzer, 1999; Westerman et al., 2013).



Figure 3.9. Examples, part of Study 6, of logos that have incorporated a smile-like line into their design.

The present research tested whether the inclusion of smile-like lines in product packaging would influence purchase intent and reward processing. If smile-like lines are linked to (or prime) smiles, and, in turn, positive emotion, it is possible that they will have a similar effect on a consumer's decision-making processes. In fact, based on this intuitive idea, numerous brands have already implemented smile-like lines into their logo/packaging designs (see Figure 3.9 for a representative set of examples). Although the use of smile-like symbols has become part of the identity of these products and brands, its impact on consumer behaviour is currently unclear (or at least there is little information available on this issue in the public domain). Since these brands are already well-known internationally, it is difficult to assess the impact of the smile-like line on the consumer's perception of the brand and product/packaging, as distinct from their general liking for

the brand itself. As such, the smile-like line was embedded into a range of mock-up products so that the participants would not be biased in terms of product familiarity, reputation, affiliation, or pre-determined preference.

The primary aim of Study 6 was, therefore, to examine whether changes in the visual elements of packaging design would alter people's perception and purchase intent. It was of particular interest to study whether changing simple design elements, specifically the curvature of a line, would influence consumers' purchase intent and reward processing (particularly wanting and liking). Examples of fruit juice, tea, and shampoo packaging (see Figure 3.10) were presented, with alterations on the curvature of a line (concave, convex, straight, and absent) on the product. It was theorised that a smile-like line would exert the same positive effect that a smile itself has been shown to produce. Importantly, it was also proposed that the mere presence of a smile-like line without other accompanying facial features might be too minimalistic a cue to exert an influence.

VA scales were used in conjunction with a forced-choice task in the present research. VA scales provide explicit ratings of reward estimation and purchase intent toward the products used; the forced-choice task was designed to complement the VA data by assessing whether there would be a change in people's preferences when pairs of products were tested against each other. The use of such methods can provide interesting insights into how different performance measures contribute to an understanding of the perceptions that consumers may have about products and brands. It could potentially also be used to shed light on how decision-making is altered when considering a particular product versus the same product in an explicit comparison.

The primary predictions were that the VA ratings would be higher and that there would be more choices for the smile-like variant of the product, relative to other variants. It was anticipated that lower VA ratings and less choice might be observed for the frown-like

variant of the product, given its similarity to a sad facial expression (which might reduce approach behaviour). The predictions of Study 6 were tested in two countries -- the United Kingdom (UK) and Colombia -- to glean information regarding the generalisability of the findings of the present study across cultures.

3.5.1. Methods and materials

UK sample: Twenty-four participants (16 females, M_{age} = 26.3 years, SD_{age} = 4.3, $range_{age}$ = 19-37 years) completed the experiment. Participants signed a standard consent form; the experiment was reviewed and approved by the Central University Research Ethics Committee at the University of Oxford (MSD-IDREC-C1-2014-034). The experiment took approximately 45 minus to complete, and the participants received £5 for taking part.

Colombian sample: Thirty participants (16 females, M_{age} = 21.36 years, SD_{age} =1.78, $range_{age}$ = 19-28 years) completed the experiment. Participants signed a standard consent form; the experiment was reviewed and approved by the research commission of the International School of Economics and business science at Universidad de la Sabana, Chía, Colombia. The experiment took approximately 45 minutes to complete, and individuals received university credit for their participation.

Apparatus and materials: E-Prime 2.0 software (Psychology Software Tools, Inc.) was used to present the stimuli and record the participant's responses. Participants sat in front of a 14" LED monitor, with a screen resolution of 1024 x 768 pixels, and a screen refresh rate of 60 Hz. Adobe Photoshop CS6 software was used to modify and create the base packaging for the experiment. Adobe Illustrator CS6 was used to include the distinctive elements within the packaging and to arrange them appropriately (see Figure 3.10). The products were chosen to cover a diversity of design features (i.e., shape, colour) and

categories (tea, shampoo, and juice); this minimized the likelihood that any findings would be a mere function of idiosyncratic aspects of the stimuli.



Figure 3.10. The 12 product stimuli used in Study 6, illustrating the three product categories (tea, shampoo, and juice) and four conditions (Concave, straight, absent, and convex lines, respectively).

There were two tasks in Study 6. One task involved a forced-choice decision task in which the participants had to choose between two packaging exemplars from the same category that varied in line design. The other task involved the participant completing a set of VA

scales to rate each of the packaging designs that were presented individually. The packaging exemplars were presented in a random order.

VA scales were used to assess *purchase intent* (anchored with the labels "Would not buy" and "Would buy") and *expected pleasure* ("Would not expect to enjoy it" and "Would expect to enjoy it very much"). VA scales were also used to assess *liking* and *wanting*. These scales were based on measures developed by Finlayson, King, and Blundell (2007), with minor modifications so as to adapt them to the particular products used in the present research. The liking scale was preceded by the question "How pleasant would it be to experience a taste/to use this product now?" and the wanting scale by the question "How much do you want this product now?" The scales were anchored with the labels "Not at all" and "Extremely". Each VA scale resulted in data that ranged from 0 and 100. The order in which the forced-choice task and the VA scales were presented was counterbalanced across participants.

Procedure: Three different product categories were used (tea, shampoo, and juice) and there were four different conditions for the line design (absent, straight, concave, and convex), giving rise to a total of 12 different packaging designs (see Figure 3.10).

The participants were informed that they would be participating in a packaging evaluation experiment. For the VA scales, each of the 12 packaging exemplars was presented in a random order, once per block (three blocks), giving rise to a total of 36 trials. The forced-choice task consisted of a total of 36 trials repeated four times, producing a total of 144 trials. Each trial lasted for 2,500ms and consisted of the presentation of two packaging exemplars, one placed on each side of the screen; the location of the stimuli (left or right) was counterbalanced across trials. Participants were instructed to choose the packaging exemplar that they would be most likely to purchase by pressing the left or right arrow

key on the computer keyboard. Before each part of the experiment, the participants performed two practice trials, during which they could ask questions for clarification.

Data analysis: SPSS 22 (Armonk, NY: IBM Corp.) was used to analyse the data. Participants' responses to the VA scales were averaged. For the forced-choice task, the frequencies were summed for each participant. A Friedman's test was used to analyse the participants' responses for each VA scale, as well as for the forced-choice task. Wilcoxon signed-ranked tests were performed to determine whether there were differences in participants' choices between each of the conditions.

3.5.2. Results

VA scales

Comparison of the scores for each of the line conditions (concave, straight, absent, and convex) was performed using Friedman's test separately for each product category (tea, shampoo, and juice) for each of the VA scales. Pairwise comparisons were additionally performed using a Wilcoxon signed-rank test.

In the UK sample, the Freidman's test revealed significant differences in the tea category in terms of purchase intent ($\chi^2(3) = 19.98$, $p < .001$), expected pleasure ($\chi^2(3) = 10.47$, $p = .015$), liking ($\chi^2(3) = 10.37$, $p = .016$), and wanting ($\chi^2(3) = 10.39$, $p = .015$). The Friedman's test revealed significant differences in the shampoo category in terms of expected pleasure ($\chi^2(3) = 11.00$, $p = .012$) and wanting ($\chi^2(3) = 8.16$, $p = .043$). The Friedman's test also yielded significant differences in the juice category in terms of purchase intent ($\chi^2(3)= 12.37$, $p = .006$) and wanting ($\chi^2(3)= 9.77$, $p = .021$). The means showed that the concave (smile-like) condition elicited the highest ratings in the juice and shampoo categories across the VA scales (excepting the expected pleasure scale for shampoo, where it was second highest), while the straight condition produced the highest

score in the tea category. The convex (frown-like) condition elicited the lowest ratings in almost all instances (the exceptions being the purchase intent and expected pleasure scales in the juice category, where it was second lowest; see Table 3.3).

Table 3.3.

Mean scores of the four VA scales by the three product categories for the UK and Colombian samples in Study 6.

	Tea		Shampoo		Juice	
Purchase intent	UK***	Colombia**	UK	Colombia***	UK**	Colombia**
Concave	59.67	67.64	50.74	65.97	59.29	63.09
Straight	62.53	61.91	49.06	58.07	56.85	56.16
Absent	60.46	59.68	45.97	53.09	50.01	51.91
Convex	48.57	51.67	43.21	50.46	53.13	53.06
Expected pleasure	UK*	Colombia**	UK*	Colombia***	UK	Colombia***
Concave	61.22	64.98	52.29	65.04	59.99	65.98
Straight	63.72	59.83	51.39	57.40	57.10	57.66
Absent	58.07	58.07	52.78	52.78	52.69	52.69
Convex	53.37	51.21	44.42	46.30	52.96	51.98
Liking	UK	Colombia***	UK	Colombia**	UK	Colombia*
Concave	59.24	62.07	46.10	58.84	60.54	63.84
Straight	60.19	57.68	45.86	52.40	57.29	53.49
Absent	59.29	55.10	41.83	48.98	54.47	50.20
Convex	51.08	43.82	39.24	44.00	53.03	50.52
Wanting	UK*	Colombia**	UK*	Colombia***	UK*	Colombia**
Concave	55.22	59.74	44.90	54.52	55.43	55.97
Straight	55.50	51.33	42.39	47.52	53.05	49.68
Absent	55.11	49.47	40.13	42.14	49.03	44.88
Convex	44.50	42.09	35.51	38.78	47.75	43.95

Note. Asterisks indicate significant differences among means for each scale *$p < .05$, **$p < .01$, ***$p < .001$. VA = visual analogue.

Pairwise comparisons indicated that the ratings in the concave condition were higher than those in the convex and absent conditions in the majority of contrasts, and were higher than those in the straight condition in about half of the contrasts. Pairwise comparisons also indicated that ratings in the convex condition were lower than those in the straight and absent conditions for some (albeit a minority) of the contrasts (see Table 3.4).

Table 3.4.

Conditions and product categories that showed significant differences in the Wilcoxon signed-rank test for the four VA scales in the UK sample in Study 6.

Line condition	Purchase intent	Expected pleasure	Liking	Wanting
Concave-convex	Tea***, Juice*	Tea**, Shampoo***	Tea***	Tea**, Shampoo***, Juice**
Concave-straight	Tea*, Juice***	Shampoo*		Tea**, Juice**
Concave-absent	Tea*, Juice***	Tea*, Shampoo***		Tea**, Shampoo***, Juice***
Straight-convex	Tea**	Shampoo*	Tea***	Shampoo**
Straight-absent				Shampoo*
Convex-absent	Tea*		Tea**	

Note. *$p < .05$, **$p < .01$, ***$p < .001$. VA = visual analogue.

In the Colombian sample, the Friedman's test revealed significant differences in the tea category in terms of purchase intent ($\chi^2(3) = 12.56$, $p < .01$), expected pleasure ($\chi^2(3) = 9.37$, $p < .05$), liking ($\chi^2(3) = 18.31$, $p < .001$), and wanting ($\chi^2(3) = 13.01$, $p < .01$). The Friedman's test also yielded significant differences in the shampoo category in terms of purchase intent ($\chi^2(3) = 18.07$, $p < .001$), expected pleasure ($\chi^2(3) = 19.63$, $p < .001$), liking ($\chi^2(3) = 14.39$, $p < .01$), and wanting ($\chi^2(3) = 24.12$, $p < .001$). Finally, the Friedman's test revealed significant differences in the juice category in terms of purchase intent ($\chi^2(3) = 12.93$, $p < .01$), expected pleasure ($\chi^2(3) = 16.82$, $p < .001$), liking ($\chi^2(3) = 11.05$, $p < .05$), and wanting ($\chi^2(3) = 13.14$, $p < .01$). The means showed that the concave condition elicited the highest ratings in all product categories, and the convex condition elicited the lowest ratings in most instances (the exceptions being purchase intent and liking in the juice category, where it was second lowest; see Table 3.5).

Table 3.5

Conditions and product categories that showed significant differences in the Wilcoxon signed-rank test for the VA scales in the Colombian sample in Study 6.

Line condition	Purchase intent	Expected pleasure	Liking	Wanting
Concave-convex	Tea***, Shampoo***, Juice*	Tea**, Shampoo***, Juice**	Tea***, Shampoo***, Juice**	Tea**, Shampoo***, Juice**
Concave-straight	Tea*, Shampoo**, Juice***	Shampoo*	Juice**	Tea**, Juice**
Concave-absent	Tea*, Shampoo***, Juice***	Tea*, Shampoo***, Juice***	Shampoo**, Juice**	Tea**, Shampoo***, Juice***
Straight-convex	Tea**, Shampoo*	Shampoo*, Juice**	Tea***	Shampoo**
Straight-absent	Shampoo**			Shampoo*
Convex-absent	Tea*		Tea**	

Note. $*p < .05$, $**p < .01$, $***p < .001$. VA = visual analogue.

Pairwise comparisons indicated that the ratings in the concave condition were higher than those in the convex and absent conditions in all but one instance (liking in the tea condition), and were higher than those in the straight condition in a majority of the contrasts. Pairwise comparisons also indicated that ratings in the convex condition were lower than those in the straight and absent conditions for some (albeit a minority) of the contrasts (see Table 3.5). Overall, the concave line presented the highest score across scales and the convex line the lowest (see Table 3.6).

Table 3.6

Mean scores across scales by the three product categories for the UK and Colombian samples in Study 6.

Product category	Country	Concave	Straight	Absent	Convex

Tea	UK	58.84	60.49	58.23	49.38
	Colombia	63.61	57.69	55.58	47.20
Shampoo	UK	48.51	47.17	45.18	40.59
	Colombia	61.09	53.85	49.25	44.89
Juice	UK	58.81	56.07	51.55	51.72
	Colombia	62.22	54.25	49.92	49.88
Average		**58.85**	**54.92**	**51.62**	**47.27**

Forced-choice task

Comparison of the frequencies for each of the line conditions was performed using Friedman's test separately for each product category (tea, shampoo, and juice). Pairwise comparisons were additionally performed using a Wilcoxon signed-rank test.

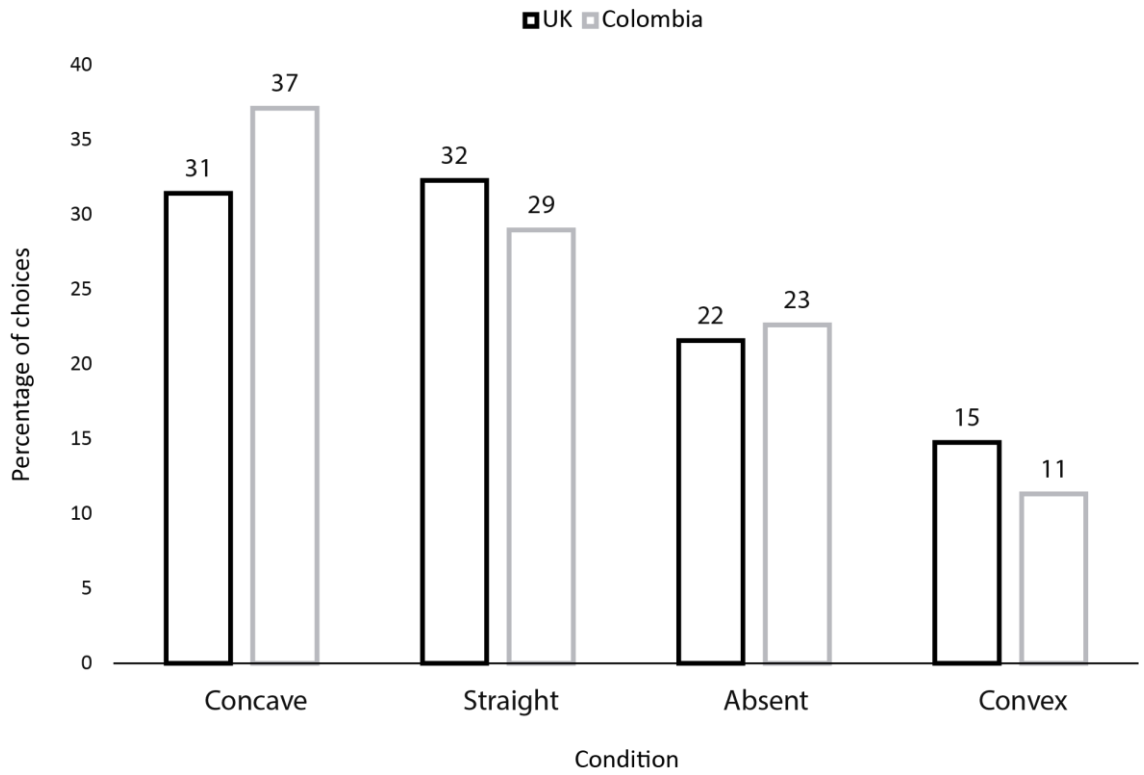


Figure 3.11. Percentage of choices per condition in each country in the forced-choice task in Study 6. Note that the probability of choosing each of the conditions at random was 25%.

In the UK sample, the Friedman's test revealed significant differences in the tea ($\chi^2(3) = 14.90$, $p = .002$), shampoo ($\chi^2(3) = 15.93$, $p = .001$), and juice categories ($\chi^2(3) = 14.74$, $p = .002$). In the Colombian sample, the Friedman's test likewise revealed significant

differences in the tea ($\chi^2(3) = 14.90$, $p = .002$), shampoo ($\chi^2(3) = 15.93$, $p = .001$), and juice categories ($\chi^2(3) = 14.74$, $p = .002$).

The means showed that the concave line was selected most in both countries in all product categories, with the exception being that in the UK, the straight line was chosen most in the tea category. The convex line was chosen least frequently in both countries in all product categories (see Table 3.7 and Figure 3.11).

Table 3.7

Frequency of choices in the forced-choice task for each of the product categories in Study 6.

Product category	Country	Concave	Straight	Absent	Convex
Tea	UK**	28%	34%	24%	14%
	Colombia***	36%	30%	24%	10%
Shampoo	UK**	34%	31%	21%	14%
	Colombia***	37%	29%	21%	12%
Juice	UK**	33%	32%	20%	15%
	Colombia***	37%	28%	20%	15%
Total mean frequency		**34%**	**31%**	**22%**	**14%**

* $p < .05$, ** $p < .01$, *** $p < .001$

Pairwise comparisons indicated that the participants in both countries chose the concave and straight lines more frequently relative to the convex line in all product categories. In Colombia, the participants also chose the concave line more frequently relative to the absent line in all product categories, and relative to the straight line in all but the tea category (see Table 3.7).

3.5.3. Discussion

The participants in Study 6 rated the products more positively and choose them more frequently when they displayed a concave (smile-like) line relative to a convex (frown-

like) line. Although there were some differential results across scales, products, and countries, the most striking aspect of the findings presented here was the consistent advantage granted by a concave relative to convex line on the packaging. Accordingly, these findings suggest that simple lines resembling facial features can influence people's product evaluations and choice behaviour.

To date, this is the first study to test whether subtle visual cues in the form of face-relevant line segments, can exert an influence on people's preference for products. The results reported herein in Study 6 suggest that design elements in packaging can subtly communicate positive and negative valence and can influence consumers' evaluations and motivation to choose one product over another. Overall, the present results suggest that line segments that may be construed as a smile can exert a significant positive impact on consumers' attitudes toward and intentions to purchase a product. Line segments that resemble a frown may also exert a significant, but negative, impact on attitudes and purchase intentions. It is likely that these smile- and frown-relevant line segments can also trigger overt behaviours associated with approach and avoidance motivation, respectively, although this remains an open question in need of subsequent research.

Another item on the future research agenda is to explore the psychological mechanisms responsible for the observed effects. Research indicating that smiles and frowns carry important social messages (Lundqvist, Esteves, & Ohman, 1999; Schug, Matsumoto, Horita, Yamagishi, & Bonnet, 2010), suggest that self-reported affective feeling, either in general or related to social connection (e.g., warmth, security), might be a good meditational candidate. It is also possible that face-relevant stimuli may represent implicit cues that exert their influence subtly by making perception and attention more expansive or more restrictive, rigid, and aversive (for frowns; see Derryberry & Reed, 1998; Fredrickson & Branigan, 2005; Isen, 2000). Now that a direct effect has been established,

further research is needed in order to tackle such "second generation" (mechanism-based) questions (Zanna & Fazio, 1982).

Comparing the concave and convex conditions to the straight and absent line conditions in the experiments conducted herein both grounds the concave-convex findings to a baseline and at the same time helps determine the relative strength of the concave and convex effects. Overall (across the two samples), the results for the VA scales are stronger for the concave condition than for the convex condition. When comparing the straight condition against the convex and the concave conditions: concave showed higher ratings in 12 of 24 comparisons, whereas convex showed lower ratings in 10 of 24 comparisons. The latter is also true when comparing the concave and convex conditions with the absent condition (concave showed higher ratings in 18 of 24 comparisons, whereas convex showed lower ratings in just 4 of 24 comparisons). The forced-choice results are of about equal strength for the concave and convex conditions, although the relative strength did differ as a function of the specific comparison condition (straight: concave showed higher ratings in 2 of 6 comparisons, whereas convex showed lower ratings in all 6 comparisons; absent: concave showed higher ratings in 5 of 6 comparisons, whereas convex showed lower ratings in 2 of 6 comparisons). In short, not only is there extremely strong evidence that concave lines yield higher evaluations and more product choice than do convex lines, but there is also promising evidence for concave and convex effects per se (i.e., relative to neutral baselines), with somewhat stronger evidence for concave effects. Thus, although the research was primarily interested in the potentially positive implications of concave lines for product design, these experiments also present intriguing results regarding the inimical implications of convex lines.

The results both within and across the tasks presented to the participants in Study 6 were not completely uniform, in that there was some variation in the significance and

magnitude of the effects across the different scales, products, and countries. For example, the results were somewhat stronger for the forced-choice than for the VA scales, were somewhat weaker for the juice than for the tea and shampoo products, and were somewhat stronger for the Colombian than for the UK sample. Nevertheless, the same basic findings were observed with what could be characterized as noteworthy consistency across these various categories. In subsequent research, an even broader range of scales, products, and countries can be used/sampled to test the robustness and generalisability of these effects even further.

Although the considerable consistency that was observed across the various categories is the main (empirical) take home message from Study 6, it would still be beneficial to probe more deeply into the inconsistencies that did emerge. More specifically, it would be interesting to consider the issue of location and overall balance of product elements when considering the slightly weaker results for the juice, relative to the tea and shampoo, products.

In packaging design, the particular arrangement of design elements can influence the consumers' perception of a given product (Deng & Kahn, 2009; Piqueras-Fiszman, Velasco, Salgado-Montejo, & Spence, 2013). For example, Deng and Kahn reported that products with images located on the bottom, right, and bottom-right of the packaging are perceived as "heavier", while products with images on the top, left, and top-left are perceived as "lighter" (but see Berlyne, 1960, p. 244). Furthermore, the way in which a particular feature fits within the broader Gestalt of the entire product design may be critical for aesthetic value and reward estimation (Veryzer & Borja de Mozota, 2005; Veryzer & Hutchinson, 1998; M. Yamamoto & Lambert, 1994). In Study 6, the manipulated line stimulus was placed at the bottom centre of the design for the tea and shampoo products, but was placed in the middle of the design for the juice product. This

spacing allowed several additional features to be included above the line stimulus for the tea and shampoo products, whereas only one additional feature was included above the line stimulus for the juice product (see Figure 3.10). It is possible that the location and context in which the line stimulus was placed on the tea and juice products allowed it to be more readily construed as a face-like feature (i.e., the line stimulus was toward the bottom of the "face" of the product with "nose-like" and "eye-like" stimuli residing above), resulting in (slightly) stronger positive and negative results for the concave and convex lines respectively. These considerations highlight the complexity of product design from a psychological perspective, and emphasize the need to approach product design questions from multiple theoretical perspectives (Crilly, Moultrie, & Clarkson, 2004; Lauer, 1979; Veryzer, 1993, for discussions on how visual arrangement and balance can influence aesthetic judgment).

Looking at the results of Study 6, it is possible to conclude that studying distinct visual elements within ecologically valid stimulus contexts (i.e., product packages) has the potential to contribute to both theoretical knowledge and practical application. In terms of theory, it can shed light on how sensory information influences reward estimation (Apitz & Bunzeck, 2012; Chelazzi, Perlato, Santandrea, & Della Libera, 2013; Komura et al., 2001) and it can advance the current understanding of the subtle influence of adaptation-relevant stimuli (such as face-relevant cues) on evaluation and decision making (see Calvo, Fernández-Martín, & Nummenmaa, 2012; Reed, Zeglen, & Schmidt, 2012; Scharlemann, Eckel, Kacelnik, & Wilson, 2001). In terms of application, it can provide concrete guidelines for product designers regarding what features and combinations of features to select and avoid, and the use of ecologically valid methods maximizes the likelihood of positive transfer from the lab to the real world. The hope is that Study 6 may encourage other researchers to engage in this fascinating area of inquiry

on face-relevant stimuli and product design, and will also encourage the more general use of methodologies that integrate conceptual and pragmatic considerations.

STUDY 7

3.6. Shapes associated with emotion can influence product taste expectations

The experiments reported thus far in this chapter, demonstrate that facial gestures can be simplified into lines and dots and still convey a valence and emotion. However, there is no research that addresses whether these same lines and shapes can also be associated with specific tastes (i.e., sweet, sour, and bitter). As previously stated, gustatory experiences are sometimes accompanied by a facial expression (Chapter 2). These facial expressions of taste share similarities with those expressions produced when experiencing an emotion. For instance, a very sour or bitter substance tends to activate facial muscles that are also involved in the expression of anger and disgust, while sweet substances seem to match those gestures associated with joy. It would seem plausible, then, that if tastes and emotions share certain facial gestures, a shape that conveys a specific emotion may also influence taste expectations. To explore the aforementioned effect, some of the dots that resemble eyes presented in a previous section of this chapter as well as the line that resembled a frown and a smile (see Figure 3.1) were embedded into the design of four products (see Figure 3.12). Only the dots that displayed a consistent match to an emotion in Section 3.4 (see Figure 3.8) were included in the study. The expectation was that the participants would expect the taste of the product to be more bitter or sour when presented with the set of dots that are matched to anger. It was also expected that the participants would expect the product to be sweeter when confronted with the dots that were associated with joy. Furthermore, I expected that products that

presented the smile-like line would be rated as sweeter than those displaying the frown-like line.

3.6.1. Methods and materials

Participants: 100 participants (60% males, M_{age} = 30.01 years, SD_{age} = 8.16, $range_{age}$ = 18-53 years) completed the experiment. The participants viewed an online version of the consent form; the experiment was reviewed and approved by the Central University Research Ethics Committee at the University of Oxford (MS-IDREC-C1-2015-218). The experiment took approximately 15 minutes to complete, and the participants received £1.50 for taking part.

Apparatus and materials: Survey Gizmo was used to set-up the study and record the responses made by the participants and Prolific Academic was used to recruit the participants. Adobe Photoshop CC 2017 software was used to edit and create the packaging for the experiment. Adobe Illustrator CC 2017 was used to embed the four dots (i.e., concave, convex, vertical ovals, and oblique ovals) and two lines (i.e., a smile and a frown) within the packaging (see Figure 3.12). A control condition was also added, which presented a blank space. Different product categories were selected as a way of testing whether any effects found transversal to different categories and designs. The latter also reduces the chance that any effect found is explained by specific characteristics of a given exemplar of packaging rather than by the dots or lines.

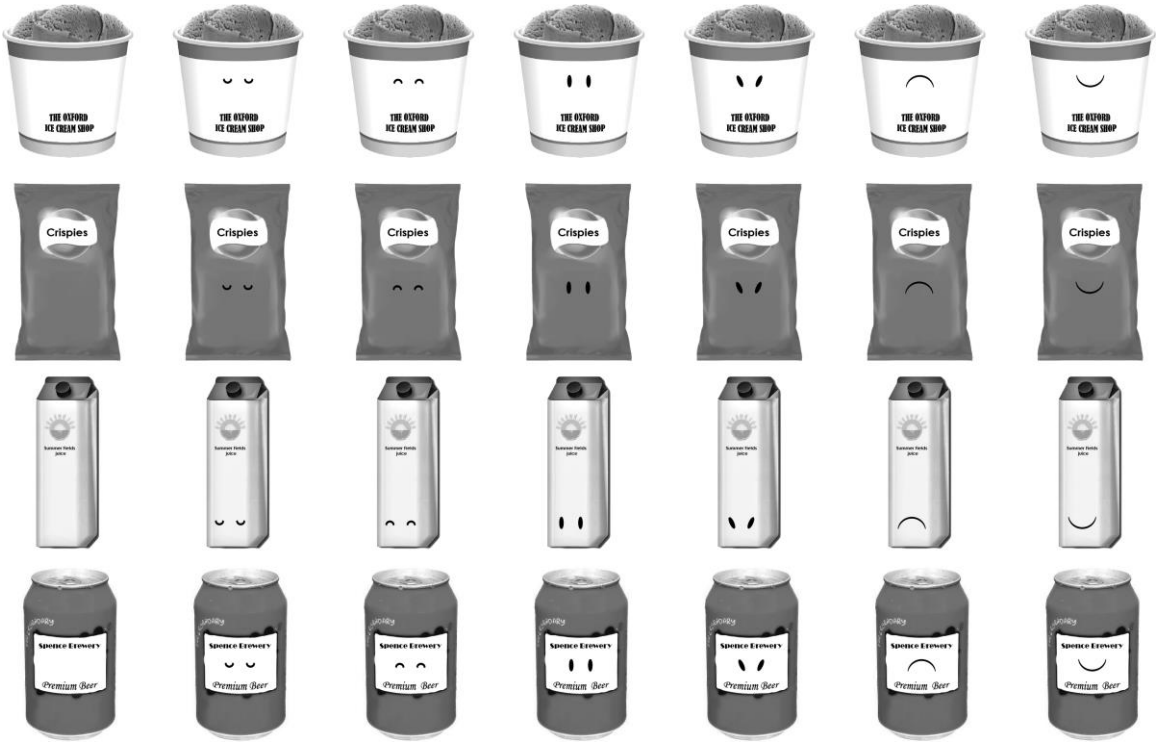


Figure 3.12. The 28 products (ice cream, crisps, juice, and beer) presented to the participants in Study 7 illustrating the seven conditions (absent, concave, convex, vertical, oblique, frown, and smile).

VA scales were presented to the participants to measure the perceived sweetness, sourness, and bitterness of each of the products (anchored with the labels "not at all" and "extremely"). The VA scales produced data that ranged from 0 to 100 and were presented in a random order to each participant.

Procedure: Four product categories were used (ice cream, crisps, juice, and beer). Each of the products had seven different conditions: Absent, concave eyes, convex eyes, vertical eyes, oblique eyes, concave line and convex line, giving rise to a total of 28 different product designs (see Figure 3.12).

The participants were presented with an online version of informed consent before starting the study. Each stimulus was presented once and the participants could see the product while they rated it on each of the three VA scales.

Data analysis: SPSS 23 (Armonk, NY: IBM Corp.) was used to analyse the data. The scores from the VA scales were analysed using an ANOVA for each of the product categories.

3.6.2. Results

Individual repeated-measures ANOVAs were used to analyse the influence of the different design elements (i.e., dots and lines) on the ratings made by the participants (how sweet, sour, or bitter) regarding the expected taste of each product, on each of the four categories (i.e., ice cream, crisps, juice, and beer). The design elements yielded a significant effect in the four product categories. Furthermore, a significant interaction was found between the design elements and the scales. A detailed account of the results is presented hereafter.

There was a significant main effect of design element in the ice-cream category $F(5.05, 505.08) = 8.28$, $p < .001$, and a small effect-size (partial $\eta^2 = .076$). A significant effect for scale was also found $F(1.27, 126.97) = 152.85$, $p < .001$ (partial $\eta^2 = .61$). A significant interaction was found between design element and the scale, $F(6.53, 652.66) = 14.16$, $p < .001$ (partial $\eta^2 = .12$). The results show that the ratings made by the participants of each of the products in terms of how sweet, sour, or bitter varied depending on which of the lines or dots was present in the packaging. Furthermore, the interaction suggests that together the design element and the scale had an influence on the ratings made by the participants. Overall, the participants rated the expected taste of the ice cream as sweet regardless of the element that was being presented and similar ratings for sour and bitter (see Figure 3.13).

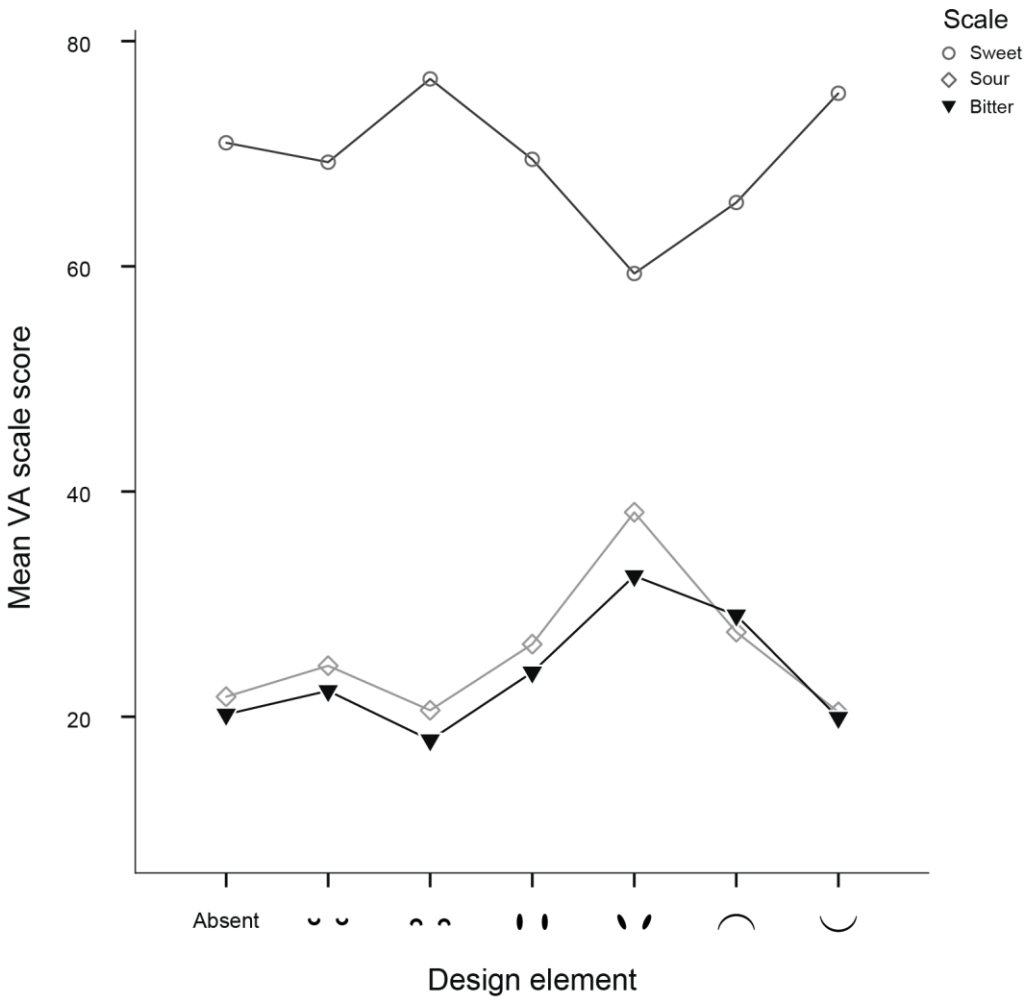


Figure 3.13. Graph displaying the mean scores for the ice cream packaging, in Study 7, for each of the VA scales (sweet, sour, and bitter) and for each of the seven design elements that were embedded into the design of the product. Higher scores in the "y" axis indicate higher taste intensity.

Post-hoc tests ($p < .05$) revealed that the convex eyes were rated the sweetest (M = 76.65, CI_{95}: 72.28 - 81.01), followed by the smiling line (M = 75.37, CI_{95}: 71.35 - 79.39). The oblique eyes yielded the highest ratings in the sour (M = 38.15, CI_{95}: 32.32 - 43.98) and bitter scales (M = 32.50, CI_{95}: 26.76 - 38.24).

A significant effect was found for Design Element $F(4.10, 410.18) = 8.94$, $p < .001$ (partial $\eta^2 = .082$) and scale $F(1.74, 173.96) = 4.30$, $p < .05$ (partial $\eta^2 = .041$) in the crisps category. A significant interaction between Design element and scale was found $F(6.32, 632.23) = 16.54$, $p < .001$ (partial $\eta^2 = .14$). In general, the crisps packages were rated higher in the sour scale (see Figure 3.14).

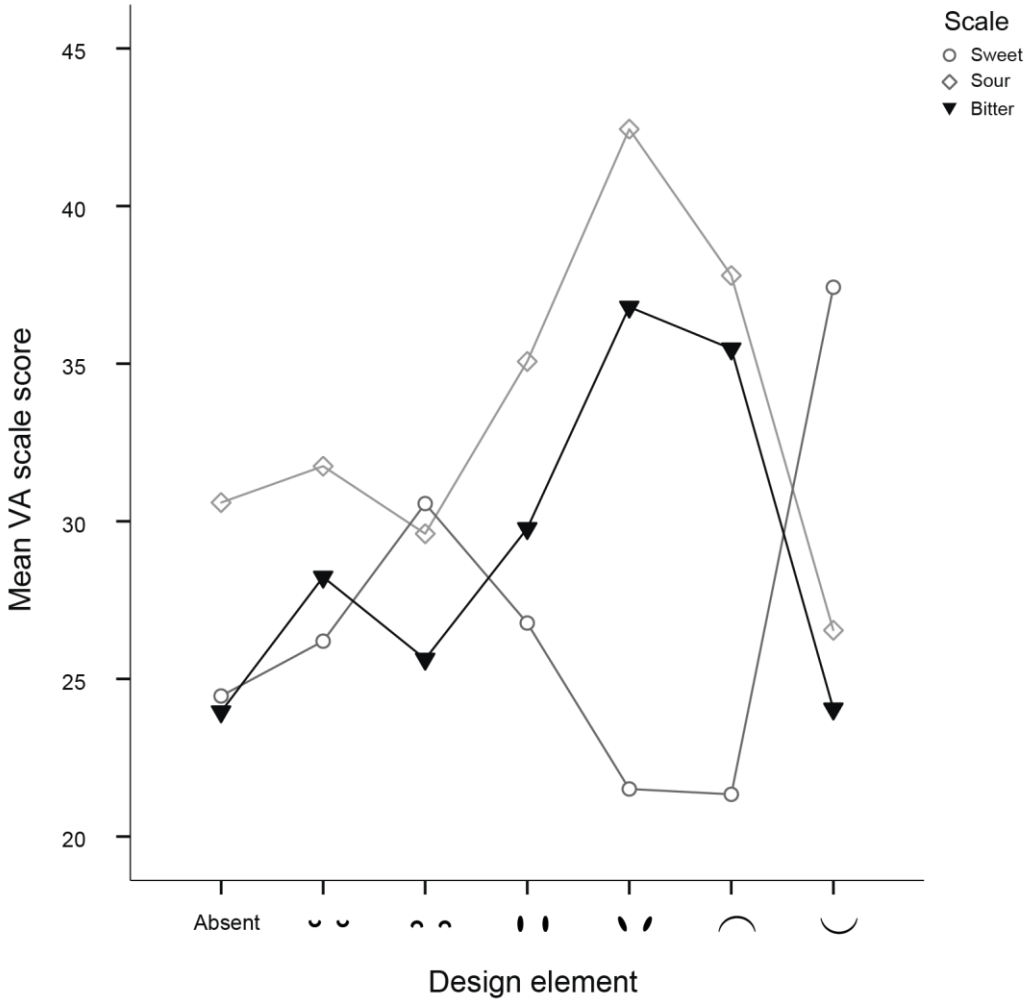


Figure 3.14. Mean scores for the crisps packaging, in Study 7, for each of the VA scales (sweet, sour, and bitter) and for each of the seven design elements that were embedded into the design of the product.

Subsequent analyses show that the smiling line was rated the sweetest (M = 37.43, CI_{95}: 31.58 - 43.31), followed by the convex eyes (M = 30.56, CI_{95}: 25.28 – 35.84). The oblique eyes received the highest ratings in terms of sour (M = 42.44, CI_{95}: 37.05 - 47.84) and bitter (M = 36.80, CI_{95}: 30.82 - 42.78).

Analysis of the juice packaging category revealed a significant main effect for Design Element, $F(4.29, 428.82) = 4.78$, $p < .001$ (partial $\eta^2 = .046$), and Scale, $F(1.82, 182.25) = 92.194$, $p < .001$ (partial $\eta^2 = .48$). A significant interaction was found between Design Element and Scale, $F(5.40, 539.58) = 152.85$, $p < .001$ (partial $\eta^2 = .61$). The participants generated higher responses in the sweet scale for the juice packaging (see Figure 3.15).

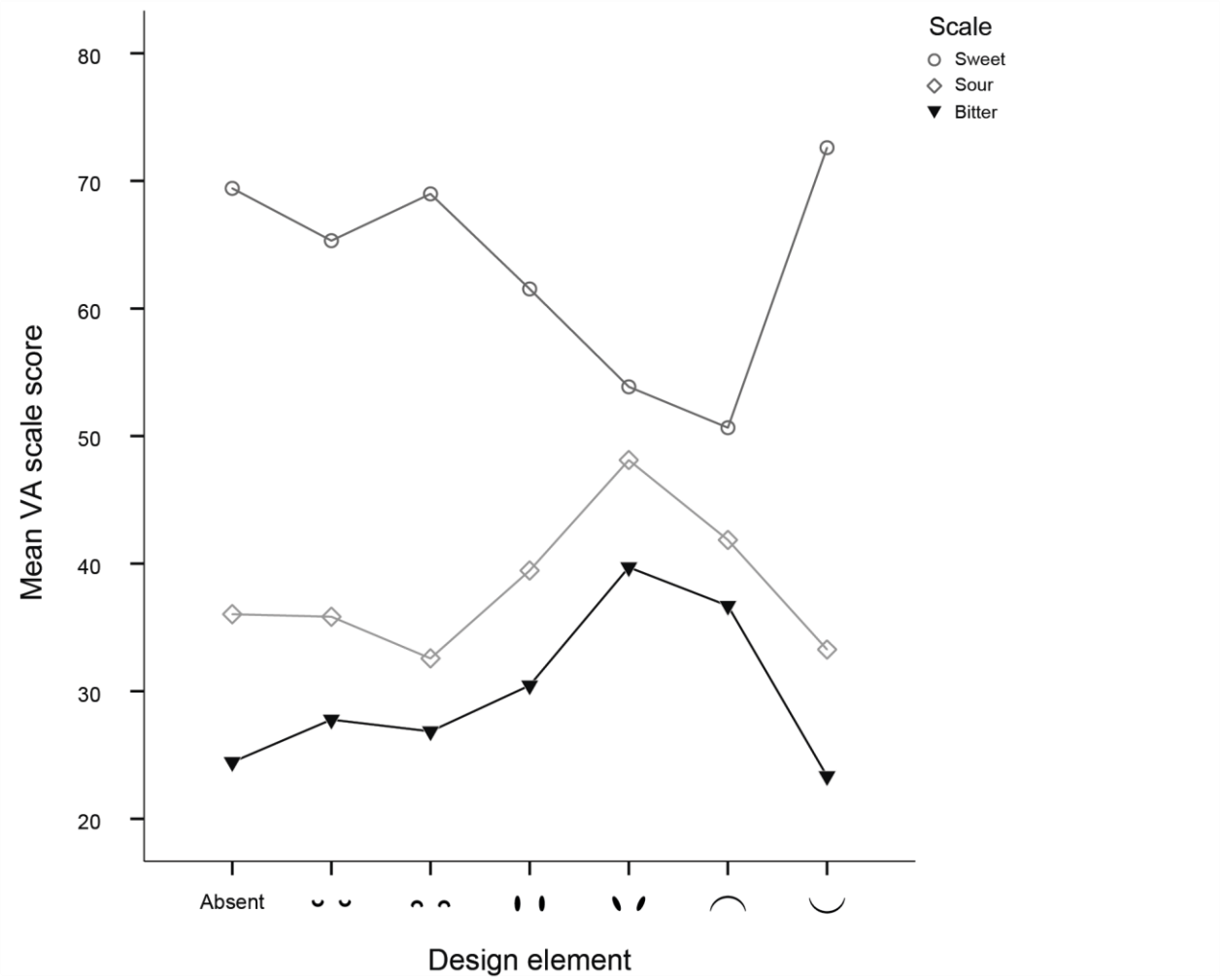


Figure 3.15. Mean scores for the juice packaging, in Study 7, for each of the VA scales (sweet, sour, and bitter) and for each of the seven design elements that were embedded into the design of the product.

Post-hoc tests in this category are consistent with findings reported above, showing that the juice packaging is rated as the sweetest when the smiling line is present (M = 72.61, CI_{95}: 69.02 - 76.19). The presence of the oblique eyes on the product packaging produces the highest ratings on the sour scale regarding the expected taste of the product (M = 48.12, CI_{95}: 42.71 - 53.53) and most bitter (M = 39.71, CI_{95}: 33.88 - 45.54). The frowning line was also rated as sour (M = 41.86, CI_{95}: 36.33 - 47.39) and bitter (M = 36.70, CI_{95}: 31.14 - 42.25), but with lower ratings than those of the oblique eyes.

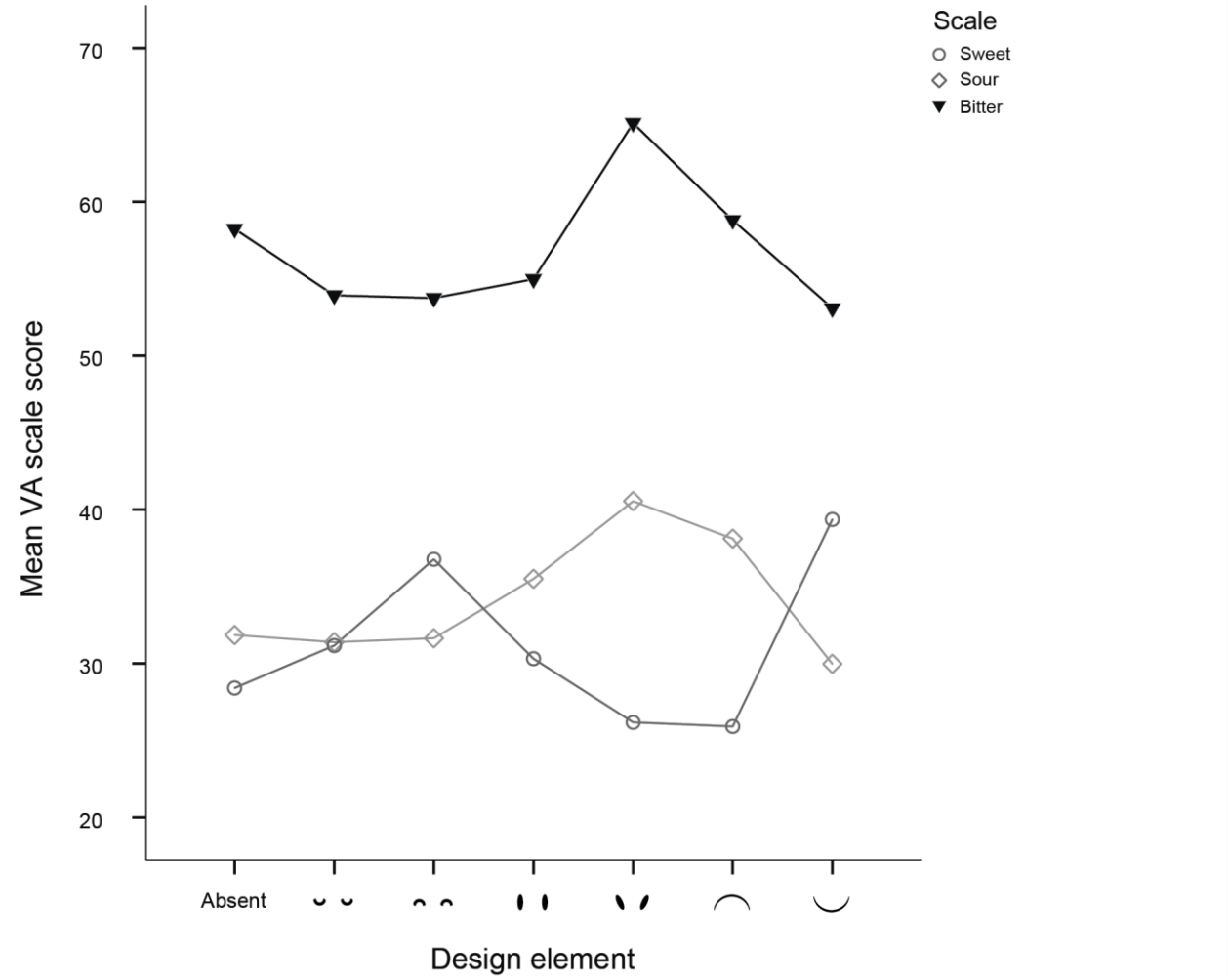


Figure 3.16. Mean scores for the beer packaging, in Study 7, for each of the VA scales (sweet, sour, and bitter) and for each of the seven design elements that were embedded into the design of the product.

Design Element, $F(5.56, 556.40) = 4.40$, $p < .001$ (partial $\eta^2 = .051$), and Scale, $F(2, 200) = 51.02$, $p < .001$ (partial $\eta^2 = .34$), yielded significant effects in the beer category. A significant interaction was found between Design Element and Scale $F(6.75, 675.30) = 11.22$, $p < .001$ (partial $\eta^2 = .10$). The highest ratings produced by the participants in the beer category were when presented with the bitter scale (Figure 3.16)

Consistent with the results reported in this section, the smiling line had the greatest influence when rating expected taste of the products as sweet (M = 48.12, CI_{95}: 42.71 - 53.53). The oblique eyes (Bitter: M = 65.12, CI_{95}: 60.76 - 69.49; Sour: M = 40.55, CI_{95}:

34.59 - 46.51) and the frowning line (Bitter: M = 58.82, CI_{95}: 54.20 - 63.44; Sour: M = 40.55, CI_{95}: 34.59 - 46.51) were rated as bitter and sour.

3.6.3. Discussion

The present study demonstrates that shapes that resemble facial gestures and that can be associated with a specific emotion can also influence taste expectations in the context of product packaging. The easier it is to match a valence to a specific shape (i.e., positive or negative), the easier and more consistently it is matched to a specific taste (i.e., sweet, sour and/or bitter) across product categories.

Overall, the eyes that were associated with sourness were also matched to bitterness. As reported in Chapter 1 (Section 1.1), evolutionarily speaking, sourness and bitterness signal potentially dangerous or toxic substances. Hence, it is not surprising that the oblique eyes, which are matched to anger (see Figure 3.8 and Section 3.4), and the frowning mouth which is associated with sadness (see Section 3.2), are also associated to these two basic tastes. Moreover, the association of bitter and sour with the oblique eyes is consistent with evidence showing that sour and bitter substances may activate muscles proximal to the eyes (e.g., the procerus, see Figure 3.4) and produce an expression that may also signal disgust and/or anger. To sum up, shapes that are associated with a negative valence and especially those that may be associated with a facial expression of taste (e.g., activating the procerus or levator labii, see Chapter 2 for a more through discussion on this topic) may be easier to match to sour and bitter tastes.

In contrast, the smiling line and the convex eyes which were matched to joy (see Sections 3.2 and 3.4, respectively), are more easily associated with sweetness. Again, it is possible to observe that shapes that convey specific emotions and that are also involved in facial expressions of taste can more easily influence taste expectations. A bird’s-eye view of

the results, reveal that the strength of association between the oblique eyes and the frowning line with bitterns and sourness is not only dependent on their valence but on the product category. For example, if we take the beer category, where the taste is expected to be bitter rather than sour, the ratings for these two elements in terms of the bitter scale are higher when compared to the sour ratings. In contrast, in the juice category, the same elements are rated as sourer. The design elements presented to the participants as part of the product packaging (see Figure 3.12), modulate this expectation but cannot fully overpower it.

Study 7 demonstrates that shapes that resemble facial gestures and that convey a specific emotion can also influence taste expectations. The results presented here further corroborate that the emotional valence of a shape may be involved in shape-taste matching. A novel finding that further extends the link between emotion, shapes, and tastes is that the face seems to be a common denominator when it comes to shapes that both convey emotion and taste. Further research should consider the face and the sensation derived from the movement of the face as a potential mechanism to explain shape-taste matching.

3.7. General Discussion

Consistent with previous research (see Watson et al., 2011), the results of the studies reported in the present chapter demonstrate that facial features and gestures can be reduced to simple lines and geometric shapes and still retain their meaning. To date, most research has focused on avoidance motivation when it comes to understanding the relation between shape and emotion (Fox et al., 2000). However, there could also be evolutionary advantages associated with the ability to rapidly spot positive emotions (e.g., smiles and smile-like features) in the environment (Becker et al., 2012; Becker,

Anderson, Mortensen, Neufeld, & Neel, 2011; Calvo, Gutiérrez-García, Avero, & Lundqvist, 2013; Calvo, Nummenmaa, & Avero, 2008; Calvo & Nummenmaa, 2008; Fox, Russo, & Dutton, 2002). The evidence presented here extends the current knowledge and shows that shapes can also be associated with approach motivation and with distinct emotions such as anger, joy, sadness, and surprise. Interestingly, these simple visual elements can be included as part of the design of a product and influence the ratings and reaction times made by participants when evaluating which product to try or buy.

Of the five studies presented in this chapter, four focused on extending current research and showing that simple visual elements can be associated with approach and avoidance motivation. Furthermore, these four studies (Sections 3.2.4-3.5) demonstrate that a smiling line can be associated with joy. Consistent with the latter, there is evidence to suggest that expressive facial features such as the mouth are more salient than others, and are actually coded prior to conscious affective evaluation (Calvo et al., 2012). The saliency of a smile or smile-like line like could explain the pervasive effect of this element across the first four studies presented here. Smiles have been linked in a number of studies to cooperative behaviour and positive emotion. The results presented here could help explain some of the findings that have been documented recently in applied contexts such as product packaging (e.g., Kumar, 2016; Landwehr, 2016).

Sections 3.3 and 3.4 demonstrate that it could be possible to "tailor" an emotional message by arranging particular lines and shapes together. So far, there is evidence that different areas of the face are involved in the communication of distinct emotions. For instance, the amount of feedback provided by upper or lower areas of the face to discern between emotions is actually dependent on the particular emotion being displayed (Bassili, 1979). Bassili's feedback hypothesis has been supported by work by Holstege (2002) showing that there are specific subgroups of motor neurons innervating the upper

and lower facial muscles. The latter may suggest that emotional expression in the face is a complex construction and that muscles in upper and lower area may signal a specific valence and together signal a composite emotion (Du et al., 2014).

Interestingly, the results from Sections 3.3 demonstrate that these compound expressions are not only discriminated when participants are presented with a face but also when judging simple visual arrangements that resemble eyes and mouths. Section 3.3 then demonstrates that the specific features of an emoticon can influence the emotion that is perceived. The aforementioned evidence is relevant to understand the number of visual features and time that is required to identify an emotion in the face. The results presented here showing that such low-level visual features (lines and dots) seem to signal a specific emotion, points to the idea that emotions are processed before conscious awareness. What is more, it is possible that the identification of emotion may be part of a more primitive pattern detection system focused on identifying dangerous and appetitive signals (LoBue, 2014; LoBue & Larson, 2010).

Section 3.4 further validates the claims of Section 3.3 and contributes to the growing evidence that low level visual features can be associated with a motivational stance (i.e., avoidance) and with an emotional valence (e.g., Larson, Aronoff, Sarinopoulos, & Zhu, 2009b; Larson et al., 2007, 2012; Watson et al., 2012). Until now, however, most studies had demonstrated this effect for elements associated with threat and anger. The results presented here extend this research and show that simple visual elements can be associated with approach motivation and with emotions such as joy, sadness and surprise.

Section 3.5 extends the research on low-level visual features to an applied context (i.e., product design) and shows that simple lines that resemble a mouth can influence consumer expectations and intentions about products. Even more interesting, are the findings of Study 7, which, for the first time, link research on low-level visual features

that convey a valence and an emotion with the field of crossmodal correspondences. The study of the crossmodal correspondences seeks to determine how information in one sensory modality is matched to information derived from the other senses. For example, how a shape can be matched to a specific taste (i.e., bitter, sweet, or sour). Different authors have suggested that the matching of shapes to tastes is mediated by emotional valence (see Spence & Deroy, 2013; Velasco, Woods, Deroy, & Spence, 2015). However, the mechanisms that explain how emotional information facilitates these seemingly unrelated associations between shapes and tastes remains incomplete. As Velasco et al. (2015) underscore, emotional valence (or hedonic mediation, as they refer to it) does not seem to fully account for the participants' responses when matching shapes to tastes. The latter is consistent with findings presented in Chapter 3, where it was shown that emotional valence has a weak influence on shape-taste matching. Consequently, it is likely that the role of valence in shape-taste matching is not entirely understood and there may be other mechanisms at play that have not yet been clearly documented.

An interesting approach to further explore how shapes are matched to tastes comes from the prevailing evidence showing that embodied cognition is involved in how we judge actions and associate information (Niedenthal et al., 2010; Zajonc & Markus, 1984). This would explain why it is that the brain interprets basic lines and shapes as communicating particular emotions. It also hints at the possibility that the face and the body are being used as a reference when evaluating visual arrangements including design, art, products, and other visual information that is filled with lines and shapes. While emotion research, especially nonverbal behaviour research, has been focused on decoding complex visual features to understand emotion, the results in the different studies that are part of this chapter show that the brain is capable of matching simple visual stimuli (i.e., lines and dots) to specific emotions. In this sense, the lines that seem to be associated with emotions

are, perhaps, not the result of a top-down process that recognizes the resemblance of these lines to facial expressions of emotion. Rather, it is possible that the brain is performing a bottom-up process, identifying certain lines and shapes as potentially containing emotional information that, in later stages of visual processing, could become a facial expression of emotion.

In short, it is not that a shape or a line conveys a valence or even a specific emotion devoid of context. Evidence from electrophysiology shows that the right configuration of sensory information (e.g., a dot that simulates the flying path of an insect) and can provide sufficient context in-and-of-itself (i.e., produce a behavioural response such as a frog launching its tongue to catch an insect, e.g., Ewert, 1987). Hence, a line or shape is not automatically devoid of any context. It would be interesting to conduct electroencephalographic studies (combined with other physiological measures) focused on measuring how quickly simple visual features and facial expressions are processed and induce a motivational stance.

These studies could be of great importance to assess whether emotions (and intentions) derived from nonverbal behaviour are identified using low-level visual patterns rather than more complex arrangements. The latter would explain why stimuli that are not associated with a facial gesture can convey a valence or even an emotion. For example, LoBue (2014) reports that a line that resembles a snake can be associated with threat; but is the line really associated with a snake or is it that both the line and the snake convey the same more basic pattern of danger? Clearly, then, more research is needed to disentangle the relationship between embodied cognition and the association of shapes with a valence and with a specific taste.

4.CHAPTER 4: The role of facial expressions in shape-taste correspondences

"Psychology has always been too mental, relatively uninterested in the body, treating it sometimes as just a means of transporting the mind from one place to another. The opposite is true… Being embodied is how we experience, what we experience, and whom we experience."

Eccleston (2016, p. 260)

4.1. Introduction

A problem that remains unsolved when studying the crossmodal correspondences between shapes and tastes is to identify the mechanism(s) that explain / underpin this phenomenon / these phenomena. The internalization of the statistical regularities of the environment can explain many (if not all) of the correspondences (see Parise & Ernst, 2015; Parise, 2015; Spence, 2011). However, in the case of shapes and tastes, a taste is not consistently presented with the same shape across time. Take, for example, how sour fruits can be both round and angular (e.g., lime, passion fruit, kiwi) or how coffee grains that look the same can have a stronger or milder taste. Yet, if participants are presented with the juice of a fruit, they will consistently associate it with a specific shape (e.g., Ngo et al., 2013).

Another possibility that has been put forward is that features from different senses may share a semantic category (e.g., good/bad, soft/strong, light/heavy) that facilitates the matching of shapes to tastes (Martino & Marks, 2001; Velasco, Woods, Deroy, et al., 2015). Affective matching, as mentioned in Chapter 3, has also been considered a candidate mechanism to explain how shapes are matched to tastes (see Spence & Deroy, 2013). Recent evidence suggests, however, that while the valence of a stimulus influences the matching of shapes to tastes, it does so only to a certain degree (see Velasco et al.,

2015). The latter evidence is consistent with the findings presented in Chapter 3, demonstrating that the correlation coefficients and residuals did not present a large effect, thus suggesting that the valence of shapes and taste words cannot fully account for shape-taste matching (see Section 3.7.2, Table 3.4).

It is very likely that, even before a valence is assigned to a stimulus, an organism can form mental representations of sensory stimuli and associate information from different senses.

> *"…while the sight of a lion or the smell of a rose may eventually – but not necessarily – evoke fear or bliss, these exteroceptive isomorphic images evoke the feelings only after additional processing by different brain systems that provide the affective and inner-body aspects."* (Feinberg & Mallatt, 2016, p. 130).

However, because some senses, such as gustation, are hardwired to detect threats and potential sources of nutrition (see Chapter 2), a gustatory experience may already imply an emotional valence. This would explain why it is that a taste can be consistently matched to an emotional valence (see Section 3.7 and Velasco et al., 2015) and why, until now the valence of the stimulus has been linked to shape-taste associations. Nevertheless, preference (and valence for that matter) in visual experience, is mediated by aesthetics (more general and consistent across humans) and personal experience. As the philosopher David Hume suggested more than two centuries ago: *"Beauty is not a quality in things themselves: it exists merely in the mind which contemplates them; and each mind perceives a different beauty."* (Hume, 1757/1894, p. 136) It is, then, likely that the consistent associations found between shapes and an emotional valence are mediated by aesthetic features (e.g., symmetry, curvature, and the number of elements, see Chapter 3). However, there is no guarantee that shape-valence and taste-valence matches will be congruent across contexts and time, which explains why, in previous studies, the valence of the stimulus was not a strong predictor of shape-taste matches.

The question now is what does gustation and visual experience have in common that can facilitate the crossmodal correspondences between shapes and taste? I would like to posit that facial expressions provide a common element in both gustation and emotion, and that these gestures inherently display a shape. Every time a facial expression is produced, be it due to an emotional experience or when experiencing a taste in the mouth, the muscles of the face become more angular or rounder.

Evidence from neuroscience (Holstege, 2002; Holstege & Huynh, 2013; Morecraft, Stilwell-Morecraft, & Rossing, 2004) demonstrates that innervations of the facial musculature are bidirectional and can receive motor commands as well as transmit sensations. The sensations carried by the nerves in the face reach the somatosensory cortex, which, in turn, aids in the representation of the facial expression in terms of a valence but also in terms of a sensory experience (i.e., feeling the shape of the face). Consequently, because tastes, shapes, and feelings share a common motor structure (i.e., facial expression), it is possible for the brain to form associations between them.

In this final experimental chapter, I provide initial evidence of the importance of studying facial expressions to understand the crossmodal correspondences that have been documented to exist between shapes and tastes. The research presented in this chapter will hopefully lay the foundations to demonstrate that facial expressions constitute the "hard presentations" of basic tastes, shapes, and of the feelings associated with these sensory stimuli. The objective of the study reported in this final experimental chapter, is to explore whether facial expressions can influence the perceived intensity of a basic taste. The participants tasted sweet, sour, and bitter solutions while their faces were being recorded using a high-speed video camera. After the participants tried each solution, they were asked to produce either a joy, angry, or neutral facial expression and rate each taste using a VA scale.

STUDY 8

4.2. Facial expressions influence the perceived intensity of basic tastes

The purpose of this study was to determine whether producing a congruent/incongruent facial expression to that of the taste being experienced would change the associations made by the participants of each of the taste solutions in terms of angularity and pleasantness, as well as its perceived intensity. If a facial expression can systematically influence the perceived intensity of a taste, this would provide initial evidence that embodied cognition may be the missing link between shapes, tastes, and a specific valence.

4.2.1. Methods and materials

Participants: Twenty-seven participants (15 males, M_{age} = 24.6 years, SD_{age} = 6.3, $range_{age}$ = 19-49 years) volunteered to take part in the experiment. They were invited to participate in the study via the database of the Crossmodal Research Lab. All the participants signed a standard consent form; the experiment was reviewed and approved by the Central University Research Ethics Committee at the University of Oxford (MS-IDREC-C1-2015-218). The experiment took approximately 45 minutes to complete, and individuals received either £7 or academic credit in return for their participation.

Apparatus and materials. Three water-based solutions of each basic taste (i.e., sweet, sour, and bitter) varying in concentration (i.e., weak, mild, strong) were crossed, giving rise to a total of nine different solutions (see Table 4.1).

Table 4.1.

The concentrations in milligrams per litter of water of the basic tastes used in Study 8.

Compound/Concentration	Low	Mild	High
Sucrose	12	24	48
Caffeine	0.27	0.54	1.08
Citric acid	0.6	1.2	2.4

Random numbers were generated in Excel and were assigned to each of the water based-solutions (see Table 4.2). Afterwards, the Excel matrix with the random numbers was printed in a white piece of paper using Arial 16 pt. The numbers were cut-out and were evenly placed in a 30 x 20 cm cardboard strip, which was then laminated using a self-adhesive film. Each of the numbers corresponded to a specific taste and concentration. The random numbers were used to reduce the chances that the participants could predict the concentration of each by any other means than by tasting it.

Table 4.2.

Random numbers presented to the participants during Study 8.

Taste/Concentration	Low	Mild	High	Low	Mild	High	Low	Mild	High
Sweet	619	406	114	328	105	485	695	725	411
Bitter	839	943	576	970	538	231	362	225	189
Sour	294	587	709	158	543	239	351	749	817

A syringe was used to transfer five millilitres of each of the solutions into plastic shot glasses. Each shot glass was placed above its corresponding number on the cardboard strip. E-Prime 2.0 software (Psychology Software Tools, Inc.) was used to signal to the participants which facial expression, present the random taste numbers, and rate each taste using VA scales. The participants sat in front of a 14" 1024x768 pixels LED monitor,

with a screen refresh rate of 60 Hz. A Garmin Virb Pro was used to record the faces of the participants at 60 frames/s using a high-definition resolution (720p).

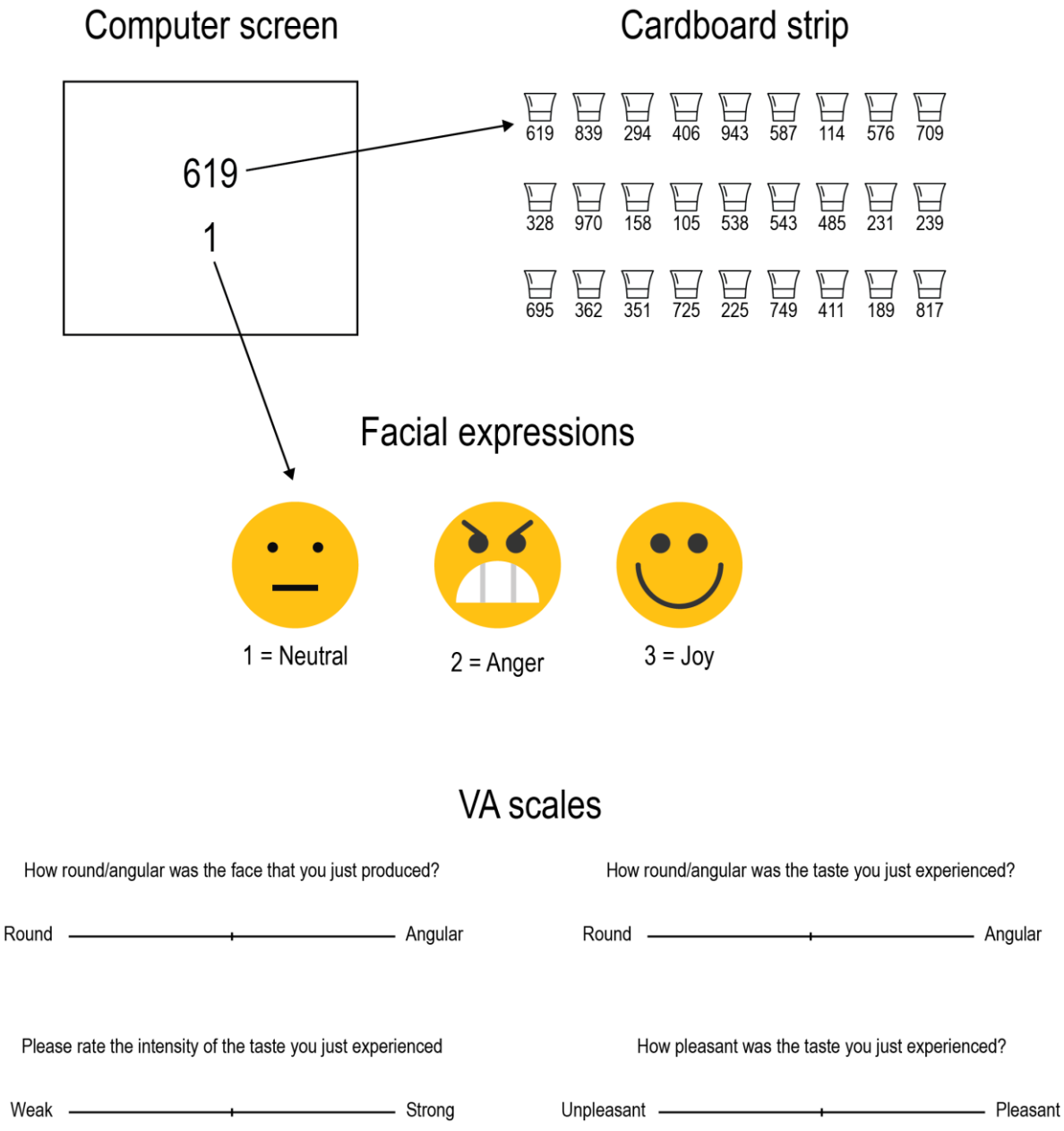


Figure 4.1. The procedure used in Study 8, showing the two numbers that were presented to the participants on each trial, the numbers on the cardboard strip, the facial expressions that the participants produced, and the four VA scales used to rate each taste.

Procedure. A 3 x 3 x 3 experimental designed was used, with facial expression (neutral, joy, anger), taste (sweet, sour, bitter), and concentration (weak, mild, strong) as factors.

The participants were trained to produce a facial expression that activated the orbicularis oculi and zygomaticus muscles, the procerus and levator labii, and to keep a neutral face (no muscle activation). The facial expressions that were chosen for the experiment were derived from the existing literature on facial expressions of emotion (see Chapter 4) and of taste (Chapter 2).

The participants were then asked to produce a facial expression (i.e., neutral, joy, anger) after drinking from a shot glass on each trial. Subsequently, they had to rate each of the tastes in terms of four VA scales: the perceived angularity of the facial expression (anchored with the labels "round" and "angular"), the angularity of the taste, the intensity of the taste ("weak" and "strong"), and how pleasant each taste was ("unpleasant" and "pleasant"). The data from the VA scales ranged from 0 to 100. On each trial, two numbers appeared on the screen, one for the facial expression and another which corresponded to a number on the cardboard strip. The participants had to find the shot glass that was labelled with the same number as the one presented on the screen, drink from it, produce the specific facial expression for that trial, and then rate the taste on each of the four VA scales (see Figure 4.1). The number for each facial expression, the scales, and taste numbers were presented in a random order to each participant.

Analyses. SPSS 22 (Armonk, NY: IBM Corp.) was used to analyse the data. A GEE (see Chapter 3, Section 3.6.1., for an explanation on the advantages of using this statistical method) with a repeated measures linear model and an interchangeable matrix was used to analyse the scores produced by the participants on each VA scale. Pairwise comparisons with Bonferroni corrections were carried out to determine how each facial expression influenced the perceived intensity and pleasantness of each taste solution.

4.2.2. Results

Separate GEEs were used to analyse each of the four VA scales presented to the participants. The facial expression produced after trying each solution had an influence on the perceived intensity of the tastes. There was a correlation between the taste and face roundness/angularity scores, suggesting that more angular faces were associated with more angular tastes. Note that lower scores in the VA scales for taste/face roundness/angularity indicate that the participants rated the face or taste as more angular.

Roundness/angularity of the facial expression

A significant effect was found for face Wald χ^2 (2) = 36.10, $p < .001$, taste Wald χ^2 (2) = 43.98, $p < .001$, and intensity Wald χ^2 (2) = 23.57, $p < .001$. A significant interaction was found between face and taste Wald χ^2 (4) = 16.98, $p < .01$. Post-hoc comparisons confirmed that the expression of anger (Mean = 29.32, CI: 25.33-33.31) was felt by the participants as more angular than the neutral (M = 51.80, CI: 39.92-45.06, $p < .001$) or joyous faces (M = 51.80, CI: 47.16-56-44, $p < .001$), note that lower scores indicate greater angularity. The interaction between face and taste demonstrates that the taste had an influence on the perceived angularity of the face.

Roundness/angularity of the taste

Face Wald χ^2 (2) = 10.30, $p < .01$, taste Wald χ^2 (2) = 91.54, $p < .001$, and intensity Wald χ^2 (2) = 35.94, $p < .001$, presented significant effects. Pairwise comparisons confirm that the bitter taste (M = 27.92, CI: 24.08-31.75) was rated the most angular when compared to the sour (M = 38.48, CI: 24.08-31.75, $p < .001$) and sweet tastes (M = 57.97, CI: 54.11-61.84, $p < .001$). There were also significant differences between the sweet and sour tastes

($p < .001$). The latter evidence indicates that the participants ranked the bitter taste as being more angular, followed by the sour taste, and the sweet taste as not angular.

A significant interaction was found between taste and intensity, Wald χ^2 (4) = 67.13, $p < .01$, suggesting that both the taste and the intensity of the taste influenced the angularity ratings. The participants rated bitter and sour solutions with the highest concentration as more angular than the mild and low concentrated solutions. The sweet taste with the highest concentration was rated as rounder when compared to the mild and weakly concentrated solution and more than any of the sour or bitter solutions.

An interaction between face and taste was found, Wald χ^2 (4) = 18.34, $p < .01$, indicating that the face generated by the participants influenced the ratings of how angular or round was each taste. Post-hoc analyses revealed that the sweet taste was deemed rounder when the participants produced a joyous expression (M = 63.06, CI: 59.04-67.09, note that lower values indicate greater angularity) when compared to a neutral expression (M = 54.20, CI: 49.92-58.48) at the level of $p < .05$. There were no differences in the angularity ratings of the sweet and bitter tastes when the participants produced an expression of anger or joy. The bitter ratings were significantly more angular when the participants produced an expression of anger (M = 23.54, CI: 18.85-28.24) compared to a neutral expression (M = 30.62, CI: 26.25-34.98) at the level of $p < .05$. No differences were found for the sour taste.

Pleasantness

Face Wald χ^2 (2) = 6.87, $p < .05$, taste Wald χ^2 (2) = 76.28, $p < .001$, and intensity Wald χ^2 (2) = 27.39, $p < .001$, presented significant effects. Significant interactions between face and taste, Wald χ^2 (4) = 12.23, $p < .05$, were observed. The interaction indicates that the facial expression produced by the participants influenced the pleasant/unpleasant

ratings for each taste. The participants rated all tastes as more unpleasant when producing the angry face, followed by the neutral, and as more pleasant when producing a facial expression of joy (see Table 4.3).

Table 4.3.

The mean scores, standard error and confidence interval for the pleasant/unpleasant VA scale in Study 8.

				95% confidence interval	
Face	Taste	Mean	Standard error	Inferior	Superior
Anger	Bitter	18.37	2.383	13.70	23.04
	Sour	37.70	2.189	33.41	41.99
	Sweet	46.70	3.409	40.02	53.39
Joy	Bitter	20.57	1.925	16.79	24.34
	Sour	37.31	2.358	32.69	41.93
	Sweet	51.47	3.004	45.58	57.36
Neutral	Bitter	24.62	2.662	19.40	29.83
	Sour	37.63	1.942	33.82	41.44
	Sweet	51.15	2.765	45.73	56.57

Taste x intensity yielded a significant interaction and taste and intensity, Wald χ^2 (4) = 107.93, $p < .001$. The interaction suggests that the higher the concentration of the solution the greater the difference between the scores for each taste. For the sweet taste, higher concentrations were rated as more pleasant; lower concentrations of the sour and bitter solutions were deemed more pleasant and higher more unpleasant.

Intensity of the taste

Face Wald χ^2 (2) = 20.06, $p < .001$. taste Wald χ^2 (2) = 35.51, $p < .001$, and intensity Wald χ^2 (2) = 221.87, $p < .001$ presented significant effects. Overall, the angry (M = 60.73, CI: 55.29-66.18) and joyous (M = 56.64, CI: 51.42-61.87) face conditions yielded higher scores in the VA scale than the neutral condition (51.47, CI: 45.33-57.61), suggesting that the participants deemed the tastes as more intense. Pairwise comparisons

demonstrate that there was a significant difference between the angry and joyous conditions with the neutral condition ($p < .05$) but not between the angry and joy conditions.

The interaction between face and intensity was significant Wald χ^2 (4) = 12.77, $p < .05$ and suggests that the face modulates the perceived intensity of the taste. Pairwise comparisons demonstrate that when the participants were presented with mild concentrations, the face did not influence the VA scale ratings.

Table 4.4.

The mean scores, standard error, and confidence interval for the taste intensity scale in Study 8.

Face	Concentration	Mean	Standard error	95% confidence interval	
				Lower	Upper
Anger	Weak	47.43	3.570	40.43	54.43
	Mild	55.99	3.207	49.70	62.27
	Strong	78.78	2.484	73.91	83.65
Joy	Weak	41.81	3.256	35.43	48.20
	Mild	50.44	3.083	44.40	56.49
	Strong	77.67	2.866	72.05	83.28
Neutral	Weak	34.75	3.548	27.80	41.71
	Mild	49.05	3.613	41.97	56.13
	Strong	70.60	3.295	64.15	77.06

However, when presented with a weak concentration both the angry and joy faces increase the perceived intensity of the taste when compared to the neutral face ($p < .05$). The angry face produced an effect on the strong concentrations condition when compared to the neutral face ($p < .05$), while the joyous face did not (see Table 4.4).

The interaction between the face and the concentration of the taste demonstrate that specific facial expressions can alter the perceive intensity of a basic taste.

4.2.3. Discussion

The findings of Study 8 demonstrate that a facial expression can be consistently rated in terms of its angularity/roundness. The angry face was considered more angular than a joyous or neutral face. The latter two were also rated as rounder when compared to the angry facial expression. The study confirms that sweet, sour, and bitter solutions can be consistently rated as round/angular and that the concentration of the taste influences this rating. More concentrated solutions of bitter and sour tastes were deemed angular, whereas higher concentrations of the sweet solution were considered rounder. The concentration of each taste also influenced pleasantness ratings, and shows that overall, sour and bitter tastes are less pleasant than the sweet taste and that this difference increases when the concentration is higher. These results demonstrate that facial expressions are associated with the angularity/roundness, valence, and perceived intensity of basic tastes.

The face and taste angularity ratings suggest that the relationship between facial expressions and tastes is bidirectional. Tastes can influence the perceived angularity of a face and vice versa. Therefore, it is possible that genetic traits (e.g., sensitivity to bitter substances), and acquired preferences for different tastes and taste concentrations, may influence how angular/round we perceive a shape and our own facial expression. The latter would, then, explain both why there seems to be some consistency in shape-taste matching (e.g., Ngo et al., 2013; Velasco, Woods, Petit, Cheok, & Spence, 2016) as well as individual and cultural differences (Bremner et al., 2013; Wan et al., 2014). The connections between the motor and somatosensory cortices with the gustatory cortex may facilitate the bidirectional relationship between shapes and facial expressions. The latter is confirmed by research showing that the facial musculature sends feedback to the somatosensory cortex and to the emotional motor system (Holstege, Bandler, & Saper,

1996; Holstege, 2002; Holstege & Huynh, 2013; Morecraft, Stilwell-Morecraft, & Rossing, 2004).

Evidence form neuroscience confirms that the orbitofrontal cortex is one of the places were the integration of gustatory, olfactory and visual information occurs (Rolls & Baylis, 1994; Rolls, 2004; Rolls & Grabenhorst, 2008; Wallis, 2007), further demonstrating that visual and gustatory experiences may share a common representation the brain. Öngür and Price (2000) have demonstrated that the ventral lateral prefrontal cortex is involved in forming representations of perceptual stimuli and again suggests that motor and sensory systems are tightly linked. What is more, the aforementioned area of the brain plays an important role in the integration of visceral, autonomic, and emotional information (Mitchell, 2011) and thus may serve as a key structure in forming associations between facial expressions, tastes, and a specific emotional valence. Future studies seeking to explore the relationship between facial expressions, tastes, and shapes should assess the role of the ventral lateral prefrontal cortex in facilitating many of the correspondences between shapes and tastes.

Interactions between face and taste in the taste angularity VA scale suggest that facial expressions can interfere with shape-taste associations. The interference of the face on taste shape-associations underscores the importance of studying the face to further understand the correspondences. Moreover, the influence of the taste on the angularity of the face and of the face on the angularity of the taste further demonstrate the bidirectional relationship between shapes and tastes. Surprisingly, when looking at the angularity of the taste ratings, none of the facial expressions of the study seemed to influence the ratings of the sour taste. The latter would indicate that either another facial expression could mediate this correspondence or that other mechanisms may be at play.

The post-hoc analyses from the Taste x Intensity interaction suggest that higher concentrations of a taste do not change whether a taste is angular or round, but rather it influences how round or angular they are rated. It would be interesting to replicate this study with different concentrations of a sweet taste and see whether scores of angularity/roundness changes as a how pleasant/unpleasant the participants find the taste. The scores of the participants on the taste angularity VA scale are consistent with the evidence presented in Chapter 3 showing that sour tastes are rated as more angular than sweet tastes. What is more, the ranking of the three tastes in terms of angularity is congruent with research on the importance of gustatory perception in the identification of potential food sources and threats. The results confirm that taste perception is organized in terms of approach/avoidance stances. What is more, the results demonstrate that higher concentrations of sour and bitter tastes increase ratings of unpleasantness. As was reported in Chapter 2, the more bitter the substance, the less appetitive and more dangerous it is considered. Furthermore, the interaction between the face and the taste shows that the facial expression is involved in encoding the valence of a gustatory experience. Hence, it may very well be that affective matching is more likely a concurrent association to shapes and tastes rather than a mechanism. Affective matching is a by-product of the relationship between tastes and facial expressions given that facial expressions (which convey a specific shape) tend to be associated with an emotional valence.

5. CHAPTER 5: Concluding remarks: Bringing vision and taste together

> *"For people who naively look around, their own eyes appear to be a kind of window. As soon as the curtains, the eyelids, are opened there 'is' a visible world of things and of other beings out there. Nothing could arouse the suspicion that any of its recognizable properties might originate in the observer or could be codetermined by the observer's nature – except perhaps for the effects of greater or lesser transparency of the 'window panes'."*
>
> (Metzger, 2009, p. xv)

Vision serves as an early detection system that facilitates predictions about the nature of things (e.g., good / bad, sweet / sour / bitter, smooth / rugged, safe / dangerous, cold / hot etc.). Hence, we have evolved the capacity to detect patterns in the visual channel that signal a wide range of attributes in the other senses. The case of vision and taste is but one example and yet understanding the relation that these two senses share has enormous potential to develop product packaging (e.g., packaging that accurately conveys product attributes), food (e.g., healthier food that is also deemed tastier), and advertisements (e.g., that more readily creates a specific gustatory expectation).

Throughout the present thesis, I have repeatedly stressed three fundamental points. First, that we evolved to taste because it is an effective mechanism to sort noxious substances from those that are nutritious. This automatic categorization of tastes, in turn, enables the encoding of gustatory experiences in terms of approach and avoidance (see Chapter 2). The second point is that specific visual features can influence how tastes are matched to visual information (e.g., as conveyed by shapes, lines, dots, and product packaging). Specifically, I have demonstrated that features such as symmetry, curvature, and the number of elements can influence how participants match shapes and taste words. The results reported in Chapter 3 provide consistent evidence that symmetry, roundness,

and/or fewer elements tend to be matched with the word sweet, while asymmetry, angularity, and a greater number of elements to the word sour.

Furthermore, evidence was presented showing that anthropomorphic features that resemble eyes and mouths (i.e., dots and lines) also influence how shapes are matched to tastes. Dots and lines that presented a positive valence, swayed responses towards expectations of sweetness, whereas negatively-valenced dots and lines were more easily matched to bitterness and sourness (Chapter 4). All in all, it is clear from previous evidence that shapes can be matched to tastes. The main contribution of this thesis, then, in that respect, is that it demonstrates that specific visual features mediate these matches. The third and final point addresses the mechanism that facilitates the matching of specific visual features with basic tastes. The last study reported in this thesis (see Study 8 reported in Chapter 5), provides initial evidence that facial expressions can influence the perceived intensity of a basic taste. Overall, incongruent facial expressions to those that generally accompany a gustatory experience reduced the perceived intensity of each taste (e.g., smiling when tasting a bitter solution or frowning when tasting a sweet solution). The aforementioned evidence connects research on the crossmodal correspondences between shapes and tastes with that on embodied cognition.

5.1. A closer look at how specific visual features are matched to tastes

The evidence presented in this thesis demonstrates that aesthetic and anthropomorphic features are associated with specific basic tastes (i.e., sweet, sour, and bitter). Previous evidence (e.g., Enquist & Johnstone, 1997; Enquist & Arak, 1994; Parise & Spence, 2013), suggests that there are two overarching mechanisms that may explain how aesthetic and anthropomorphic features are matched to gustatory tastes. The first is an innate ability to detect and form expectations about some of these features. For example,

there is consistent evidence that symmetry can be detected by many species and is associated with biological fitness, quality, and resources (e.g., Barlow & Reeves, 1979; de Kuijer, Deregowski, & McGeorge, 2004; Henderson, Holzleitner, Talamas, & Perrett, 2016; Little, Apicella, & Marlowe, 2007; Martín & López, 2000; Rodríguez, Gumbert, De Ibarra, Kunze, & Giurfa, 2004; Sasaki, Vanduffel, Knutsen, Tyler, & Tootell, 2005). What is more, there are a few studies that have identified specific brain areas dedicated to the detection of symmetry, which further underscores the importance of this feature for many species. Whether other aesthetic features are also "hard-wired" is up for debate, but what is clear is that they seem to reliably signal different qualities about objects and are associated with specific basic tastes. In summary, evolutionary (hard-wired) mechanisms may facilitate the detection of patterns in the environment, which in turn may facilitate the associations of information derived from different senses.

The second mechanism is associative learning derived from statistical regularities in the environment. That is, matching two features (e.g., symmetry and sweetness) because they are consistently presented together. Differences in how distinct cultures match specific features to basic tastes underscores the influence of associative learning in shape-taste correspondences (Chen, Huang, Woods, & Spence, 2016). For example, in Chapter 3, I reported that while Colombian and British participants made similar associations between shapes and tastes, the aesthetic features that biased towards specific responses were different (i.e., curvature was more relevant for the Colombians, whereas symmetry and the number of elements presented a greater effect size in the British sample). Designers should look for those visual features that seem to communicate the same taste across diverse cultures if they want to increase the effectivity of packaging and ads to communicate product attributes universally (Salgado-Montejo, Velasco, Ariza, Salgado, & Moreno, 2017).

5.2. Embodied cognition and shape-taste correspondences

In the previous section (see Section 5.1.), the importance of an innate ability to detect patterns and associative learning in matching shapes to tastes was explored. However, while these two mechanisms seem to be involved in shape-taste matches, what remains missing is the "how" of this process. That is, how is it that the brain is capable of "translating" the pattern it has detected in the visual channel into a gustatory expectation? Embodied cognition is a viable candidate to explain how specific visual features are matched to tastes and how it is possible to associate a specific emotional valence to shapes and tastes.

The research presented in Chapter 5 provides initial evidence that facial expressions constitute "hard presentations" of basic tastes, shapes, and of the feelings that are associated with these sensory stimuli. Consequently, because tastes, shapes, and feelings share a common bodily response (e.g., facial expression), it is possible for the brain to form associations between them. Both a sour or bitter taste, are generally accompanied by a facial expression that activates those muscles that are involved in disgust and anger. A sweet taste, in contrast, goes together with a facial expression that resembles that of joy (see Chapters 2 and 4).

I would like to posit that the inherent shape of a facial expression, produced because of experiencing an emotion or a gustatory taste, enables the brain to form a correspondence between gustatory and visual information. Research by Velasco, Woods, and Deroy, et al. (2015, see also Chapter 2, Section 2.3) has demonstrated that the variance explained by affective matching is rather small, making it unlikely that it is the sole mechanism that explains shape-tastes matches. It is possible that affective matching it is simply another layer of association facilitated by embodied cognition.

Given the close connection between olfaction and facial expressions, it is very likely that embodied cognition plays a role in the matching of visual and olfactory information. With more time, I would have liked to test whether facial expressions can influence olfactory perception. Indeed, if embodied cognition is involved in the crossmodal correspondences between shapes and tastes it is possible that expectations can shape perceptions. It is not inconceivable to think that in the future, research on the crossmodal correspondences can help influence sensory perception rather than only form expectations. If expectations can shape perception, then perhaps the space around us (e.g., how round or angular it looks), visual stimuli (e.g., dots, lines, and shapes), or our facial expressions (e.g., activating the zygomaticus or the levator labii muscles) may be enough to modify our gustatory perception.

The motor system and specifically facial expression may facilitate the associations between shapes and tastes. However, as it stands now, the role of embodied cognition in the crossmodal correspondences between shapes and tastes is an intractable problem. Most research has focused on the "mental" experience of participants, leaving aside the body as a possible source for answers. Much research is needed to understand how facial expressions facilitate the encoding of shapes in terms of tastes and vice versa, especially because there is no bridge between embodied cognition and crossmodal correspondences. It is my hope that this thesis has provided an initial connection between these two fields of research. Future research should address the importance of embodied cognition in the matching of information from different senses. As mentioned earlier, crossmodal smell-vision associations seem to be a good candidate to continue exploring the role of facial expressions in the crossmodal correspondences.

It would be interesting to include psychophysiological measures, such as electromyography, to determine if the intensity of a facial expression predicts the change

in magnitude of the perceived intensity of a taste or smell. Furthermore, including electroencephalographic and fMRI measures could aid in determining whether the valence of the stimulus is assigned before or after the correspondences are formed. Considering previous evidence (Mitchell, 2011; Öngür & Price, 2000), it would be interesting to study the involvement of the ventral lateral prefrontal cortex in the crossmodal correspondences. The aforementioned area of the brain has been known to integrate emotional, motor, and sensory information.

An approach that could help determine just how "hard-wired" or basic are shape-taste correspondences, would be to taste these matches in babies and children. Preferences for different aesthetic or anthropomorphic features could be assessed by 3-D printing different objects varying in curvature, symmetry, and number of elements and assessing the frequency and latency of grasps of these objects. It would also be possible to create a game where children guess whether different shapes are either sweet, sour, or bitter and measure reactions times and consistency of choices. If indeed the correspondences are mediated by statistical regularities and associative learning, then it is likely there will be a specific stage of development where the matches between shapes and tastes are not consistent. If, however, we discover that these matches are either preverbal or at the very least present even when the child has not been exposed to many associations, then it would be necessary to explore other more basic mechanisms.

Expanding the research on shapes and tastes to infants would provide interesting conclusions as to the potential mechanism that sustain many of the correspondences. What is more, research with this specific population provides arguments for the debate as to how universal and consistent are the crossmodal correspondences. There is already some evidence showing a preference for rounded shapes and objects in infants between one and two years (Jadva et al., 2010). There is research showing that 3-4-month-old

infants can match visual and auditory information and that 2-year-olds seem to be able to match sounds to objects (Maurer et al., 2006; Walker et al., 2010). However, no such studies exist for shape-taste correspondences, stressing the importance of conducting research that enquires as to the nature of these associations in infants.

A pressing issue for the study of the crossmodal correspondences is to become more relevant in terms of real world applications as this would increase funding. For example, it is possible that crossmodal correspondences may help rowers synchronise their movements or facilitate recovery after a stroke (Tinga et al., 2016, see also Salgado-Montejo, Marmolejo-Ramos, et al., 2016). For teaching, crossmodal correspondences could inform editors on how to design more intuitive textbooks and teachers on how to create more successful learning experiences (e.g., sound symbolic words may be easier to learn). Understanding the correspondences has provided guidelines for marketers (e.g., Spence, 2012b; Spence, Puccinelli, Grewal, & Roggeveen, 2014), but it could also reduce human error in finance and medicine by aiding in the design of interfaces that are more intuitive.

If the correspondences are embodied, that would mean that all organisms with a body are able to develop some sort of crossmodal correspondences. An interesting way to demonstrate the influence of embodied cognition in the correspondences would be to determine if different species have them and if their distinct bodily characteristics create unique correspondences (e.g., bat sonar). In other words, it would be interesting to determine whether the body of the organism, in some way, frames the sensory associations that it can develop/learn.

A novel approach would be to forego vertebrates altogether and study the crossmodal correspondences in invertebrates. Aside from being able to taste hundreds of subjects and

several generations, an invertebrate model could prove very useful to determine if there are any genetic markers that facilitate these sensory associations or if they, in some way, modify behaviour across different generations. An initial step could be, for example, to present jumping spiders with two hunting grounds (one symmetrical and one asymmetrical) and see if there is an innate preference. After determining that symmetry can be detected by an invertebrate (i.e., the jumping spider), it would be interesting to see if via statistical regularities in the environment it is possible to associate a symmetrical hunting ground with a stimulus in another sensory modality. The idea would be to measure prey identification speed and successful hunts. The question is not whether the correspondences are real or not, but what are they good for, what are their limitations and possibilities. To answer these questions is to define how much we can enhance or push the boundaries of human perception.

REFERENCES

Aggarwal, P., & McGill, A. L. (2007). Is that car smiling at me? Schema congruity as a basis for evaluating anthropomorphized products. *Journal of Consumer Research*, *34*, 468–479.

Airey, D. (2010). *Logo design love: A guide to creating iconic brand identities*. Berkeley, CA: New Riders.

Apitz, T., & Bunzeck, N. (2012). Reward modulates the neural dynamics of early visual category processing. *NeuroImage*, *63*, 1614–1622.

Apthorp, D., & Bell, J. (2015). Symmetry is less than meets the eye. *Current Biology*, *25*, R267–R268.

Aronoff, J. (2006). How we recognize angry and happy emotion in people, places, and things. *Cross-Cultural Research*, *40*, 83–105.

Aronoff, J., Barclay, A. M., & Stevenson, L. A. (1988). The recognition of threatening facial stimuli. *Journal of Personality and Social Psychology*, *54*, 647–655.

Aronoff, J., Woike, B. A., & Hyman, L. M. (1992). Which are the stimuli in facial displays of anger and happiness? Configurational bases of emotion recognition. *Journal of Personality and Social Psychology*, *62*, 1050–1066.

Ballard, O., & Morrow, A. L. (2013). Human milk composition: Nutrients and bioactive factors. *Pediatric Clinics of North America*, *60*, 49–74.

Bar, M., & Neta, M. (2006). Humans prefer curved visual objects. *Psychological Science*, *17*, 645–648.

Barlow, H., & Reeves, B. (1979). The versitility and absolute efficience of detectig mirror symmetry in random dot displays. *Vision Research*, *19*, 783–793.

Bartoshuk, L. M., & Snyder, D. J. (2016). The affect of taste and olfaction. In L. Feldman, M. Lewis, & J. M. Haviland-Jones (Eds.), *Handbook of Emotions* (pp. 235–252). New York, NY: The Guildford Press.

Bassili, J. N. (1978). Facial motion in the perception of faces and of emotional expression. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 373–379.

Bassili, J. N. (1979). Emotion recognition: The role of facial movement and the relative importance of upper and lower areas of the face. *Journal of Personality and Social Psychology*, *37*, 2049–2058.

Becker, D. V., Anderson, U. S., Mortensen, C. R., Neufeld, S. L., & Neel, R. (2011). The face in the crowd effect unconfounded: Happy faces, not angry faces, are more efficiently detected in single- and multiple-target visual search tasks. *Journal of Experimental Psychology: General*, *140*, 637–659.

Becker, D. V., Neel, R., Srinivasan, N., Neufeld, S., Kumar, D., & Fouse, S. (2012).

The Vividness of Happiness in Dynamic Facial Displays of Emotion. *PLoS ONE, 7*, e26551.

Becker, L., van Rompay, T. J. L., Schifferstein, H. N. J., & Galetzka, M. (2011). Tough package, strong taste: The influence of packaging design on taste impressions and product evaluations. *Food Quality and Preference*, *22*, 17–23.

Behrens, M., & Meyerhof, W. (2011). Gustatory and extragustatory functions of mammalian taste receptors. *Physiology and Behavior*, *105*, 4–13.

Behrens, M., & Meyerhof, W. (2013). Bitter taste receptor research comes of age: From characterization to modulation of TAS2Rs. *Seminars in Cell and Developmental Biology*, *24*, 215–221.

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity*. New York: McGraw-Hill.

Berridge, K. (2000). Measuring hedonic impact in animals and infants: Microstructure of affective taste reactivity patterns. *Neuroscience & Biobehavioral Reviews*, *24*, 173–198.

Bertamini, M., Friedenberg, J., & Argyle, L. (2002). No within-object advantage for detection of rotation. *Acta Psychologica*, *111*, 59–81.

Bertamini, M., Palumbo, L., Gheorghes, T. N., & Galatsidas, M. (2015). Do observers like curvature or do they dislike angularity? *British Journal of Psychology*, *107*, 154–178.

Bertamini, M., & Wagemans, J. (2013). Processing convexity and concavity along a 2-D contour: Figure-ground, structural shape, and attention. *Psychonomic Bulletin and Review*, *20*, 191–207.

Bigiani, A., Ghiaroni, V., & Fieni, F. (2003). Channels as taste receptors in vertebrates. *Progress in Biophysics and Molecular Biology*, *83*, 193–225.

Birch, L. L. (1999). Development of food preferences. *Annual Review of Nutrition*, *19*,

41–62.

Brain, R. M. (2015). *The pulse of modernism: Physiologcal aesthetics in fin-de-siècle Europe*. Seattle: University of Washington Press.

Bredie, W. L. P., Tan, H. S. G., & Wendin, K. (2014). A comparative study on facially expressed emotions in response to basic tastes. *Chemosensory Perception*, *7*, 1–9.

Bremner, A. J., Caparos, S., Davidoff, J., de Fockert, J., Linnell, K. J., & Spence, C. (2013). "Bouba" and "Kiki" in Namibia? A remote culture make similar shape-sound matches, but different shape-taste matches to Westerners. *Cognition*, *126*, 165–172.

Breslin, P. A. S. (2013). An evolutionary perspective on food and human taste. *Current Biology*, *23*, R409–R418.

Brown, S., Gao, X., Tisdelle, L., Eickhoff, S. B., & Liotti, M. (2011). Naturalizing aesthetics: Brain areas for aesthetic appraisal across sensory modalities. *NeuroImage*, *58*, 250–258.

Bruce, V. G., & Morgan, M. J. (1975). Violations of symmetry and repetition in visual patterns. *Perception*, *4*, 239–249.

Cai, H., Sriram, N., & Greenwald, A. G. (2004). The IAT's D measure can minimize a cognitive skill confound: Comment on McFarland and Crouch (2002). *Social Cognition*, *22*, 673–684.

Calvo, M. G., Fernández-Martín, A., & Nummenmaa, L. (2012). Perceptual, categorical, and affective processing of ambiguous smiling facial expressions. *Cognition*, *125*, 373–393.

Calvo, M. G., Gutiérrez-García, A., Avero, P., & Lundqvist, D. (2013). Attentional mechanisms in judging genuine and fake smiles: Eye-movement patterns. *Emotion*, *13*, 792–802.

Calvo, M. G., & Nummenmaa, L. (2008). Detection of emotional faces: Salient physical features guide effective visual search. *Journal of Experimental Psychology: General*, *137*, 471–494.

Calvo, M. G., Nummenmaa, L., & Avero, P. (2008). Visual search of emotional faces eye-movement assessment of component processes. *Experimental Psychology*, *55*, 359–370.

Cela-Conde, C. J., Agnati, L., Huston, J. P., Mora, F., & Nadal, M. (2011). The neural foundations of aesthetic appreciation. *Progress in Neurobiology*, *94*, 39–48.

Chandrashekar, J., Hoon, M. A., Ryba, N. J. P., & Zuker, C. S. (2006). The receptors and cells for mammalian taste. *Nature*, *444*, 288–294.

Chandrashekar, J., Kuhn, C., Oka, Y., Yarmolinsky, D. A., Hummler, E., Ryba, N. J. P., & Zuker, C. S. (2010). The cells and peripheral representation of sodium taste in mice. *Nature*, *464*, 297–301.

Chandrashekar, J., Yarmolinsky, D., von Buchholtz, L., Oka, Y., Sly, W., Ryba, N. J. P., & Zuker, C. S. (2009). The taste of carbonation. *Science*, *326*, 443–445.

Chapman, H. A., Kim, D. A., Susskind, J. M., & Anderson, A. K. (2009). In bad taste: Evidence for the oral origins of moral disgust. *Science*, *323*, 1222–1226.

Chatterjee, A. (2011). Neuroaesthetics: A coming of age story. *Journal of Cognitive Neuroscience*, *23*, 53–62.

Chatterjee, A. (2014). *The aesthetic brain: How we evolved to desire beauty and enjoy art*. New York: Oxford University Press.

Chelazzi, L., Perlato, A., Santandrea, E., & Della Libera, C. (2013). Rewards teach visual selective attention. *Vision Research*, *85*, 58–62.

Chen, Y.-C., Huang, P.-C., Woods, A., & Spence, C. (2016). When “Bouba” equals “Kiki”: Cultural commonalities and cultural differences in sound-shape

correspondences. *Scientific Reports*, *6*, 26681.

Cheskin, L. (1981). Research design and analysis in the testing of symbols. In W. Stern (Ed.), *Handbook of package design research* (pp. 211–220). New York: Wiley Interscience.

Churches, O., Nicholls, M., Thiessen, M., Kohler, M., & Keage, H. (2014). Emoticons in mind: An event-related potential study. *Social Neuroscience*, *9*, 196–202.

Cinzia, D. D., & Vittorio, G. (2009). Neuroaesthetics: a review. *Current Opinion in Neurobiology*, *19*, 682–687.

Clement, J. (2007). Visual influence on in-store buying decisions: an eye-track experiment on the visual influence of packaging design. *Journal of Marketing Management*, *23*, 917–928.

Clyne, P. T., Warr, C. G., & Carlson, J. R. (2000). Candidate taste receptors in drosophila. *Science*, *287*, 1830–1834.

Cohen, J. (1988). *Statistical power for the behavioral sciences*. Hillsdale, NJ: Erlbaum.

Cohen, J. (1992). Statistical power analysis. *Current Directions in Psychological Science*, *1*, 98–101.

Collier, G. L. (1996). Affective synesthesia: Extracting emotion space from simple perceptual stimuli. *Motivation and Emotion*, *20*, 1–32.

Collingwood, R. G. (1958). *The principles of art (vol. 62)*. USA: Oxford University Press.

Crilly, N., Moultrie, J., & Clarkson, P. J. (2004). Seeing things: Consumer response to the visual domain in product design. *Design Studies*, *25*, 547–577.

Cytowic, R. E., & Wood, F. B. (1982). Synesthesia: II. Psychophysical relations in the synesthesia of geometrically shaped taste and colored hearing. *Brain and Cognition*, *1*, 36–49.

Dazkir, S. S., & Read, M. A. (2011). Furniture forms and their influence on our emotional responses toward interior environments. *Environment and Behavior*, *44*, 722–732.

de Kuijer, J., Deregowski, J. B., & McGeorge, P. (2004). The influence of visual symmetry on the encoding of objects. *Acta Psychologica*, *116*, 75–91.

Deng, X., & Kahn, B. E. (2009). Is your product on the right side? The "location effect" on perceived product heaviness and package evaluation. *Journal of Marketing Research*, *46*, 725–738.

Derks, D., Bos, A. E. R., & von Grumbkow, J. (2007). Emoticons and online message interpretation. *Social Science Computer Review*, *26*, 379–388.

Deroy, O., Crisinel, A.-S., & Spence, C. (2013). Crossmodal correspondences between odors and contingent features: Odors, musical notes, and geometrical shapes. *Psychonomic Bulletin & Review*, *20*, 878–896.

Derryberry, D., & Reed, M. A. (1998). Anxiety and attentional focusing: Trait, state and hemispheric influences. *Personality and Individual Differences*, *25*, 745–761.

DeSimone, J. A., & Lyall, V. (2006). Taste receptors in the gastrointestinal tract III. Salty and sour taste: Sensing of sodium and protons by the tongue. *American Journal of Physiology. Gastrointestinal and Liver Physiology*, *291*, G1005-1010.

DiSalvo, C., & Gemperle, F. (2003). From seduction to fulfillment: The use of anthropomorphic form in design. *DPPI '03 Proceedings of the 2003 International Conference on Designing Pleasurable Products and Interfaces*, 67–72.

Du, S., Tao, Y., & Martinez, A. M. (2014). Compound facial expressions of emotion. *Proceedings of the National Academy of Sciences of the United States of America*, *111*, E1454-62.

Eccleston, C. (2016). *Embodied: The psychology of physical sensation*. Oxford, UK:

Oxford University Press.

Enquist, M., & Arak, A. (1994). Symmetry, beauty and evolution. *Nature*, *372*, 169–172.

Enquist, M., & Johnstone, R. A. (1997). Generalization and the evolution of symmetry preferences. *Proceedings of the Royal Society B: Biological Sciences*, *264*, 1345–1348.

Epley, N., Akalis, S., Waytz, A., & Cacioppo, J. T. (2008). Creating social connection through inferential reproduction. *Psychological Science, 19*, 114–120.

Epley, N., Waytz, A., Akalis, S., & Cacioppo, J. T. (2008). When we need a human: Motivational determinants of anthropomorphism. *Social Cognition*, *26*, 143–155.

Epley, N., Waytz, A., & Cacioppo, J. T. (2007). On seeing human: A three-factor theory of anthropomorphism. *Psychological Review*, *114*, 864–886.

Ewert, J.-P. (1987). Neuroethology of releasing mechanisms: Prey-catching in toads. *Behavioral and Brain Sciences*, *10*, 337–405.

Feinberg, T. E., & Mallatt, J. M. (2016). *The ancient origins of consciousness: How the brain created experience*. Cambridge, MA: MIT Press.

Feldman, L. (2006). Valence is a basic building block of emotional life. *Journal of Research in Personality, 40*, 35–55.

Feng, T., Zhang, Z., Zhuang, H., Zhou, J., & Xu, Z. (2016). Effect of peptides on new taste sensation: Kokumi-review. *Mini-Reviews in Organic Chemistry*, *13*, 255–261.

Fetterman, A. K., Ode, S., & Robinson, M. D. (2013). For which side the bell tolls: The laterality of approach-avoidance associative networks. *Motivation and Emotion, 37*, 33–38.

Fink, B., Neave, N., Manning, J. T., & Grammer, K. (2005). Facial symmetry and the

"big-five" personality factors. *Personality and Individual Differences, 39,* 523–529.

Fink, B., Neave, N., Manning, J. T., & Grammer, K. (2006). Facial symmetry and judgements of attractiveness, health and personality. *Personality and Individual Differences, 41,* 491–499.

Fox, E., Lester, V., Russo, R., Bowles, R. J., Pichler, A., & Dutton, K. (2000). Facial expressions of emotion: Are angry faces detected more efficiently? *Cognition & Emotion, 14,* 61–92.

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition & Emotion, 16,* 355–379.

Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. *Cognition & Emotion, 19,* 313–332.

Freeman, J. B., & Ambady, N. (2010). MouseTracker: Software for studying real-time mental processing using a computer mouse-tracking method. *Behavior Research Methods, 42,* 226–241.

Gallace, A., Boschin, E., & Spence, C. (2011). On the taste of "Bouba" and "Kiki": An exploration of word-food associations in neurologically normal participants. *Cognitive Neuroscience, 2,* 34–46.

Ganchrow, J. R., Steiner, J. E., & Daher, M. (1983). Neonatal facial expressions in response to different qualities and intensities of gustatory stimuli. *Infant Behavior and Development, 6,* 473–484.

Gangestad, S. W., Thornhill, R., & Yeo, R. A. (1994). Facial attractiveness, developmental stability, and fluctuating asymmetry. *Ethology and Sociobiology, 15,* 73–85.

Gordon, K. (1909). *Esthetics*. New York, NY: Henry Holt.

Greenwald, A. G., McGhee, D. E., & Schwartz, J. L. K. (1998). Measuring individual differences in implicit cognition: The Implicit Association Test. *Journal of Personality and Social Psychology, 74*, 1464–1480.

Greenwald, A. G., Nosek, B. A., & Banaji, M. R. (2003). Understanding and using the implicit association test: I. An improved scoring algorithm. *Journal of Personality and Social Psychology, 85*, 197–216.

Guevara, E. E., Veilleux, C. C., Saltonstall, K., Caccone, A., Mundy, N. I., & Bradley, B. J. (2016). Potential arms race in the coevolution of primates and angiosperms: Brazzein sweet proteins and gorilla taste receptors. *American Journal of Physical Anthropology, 161*, 181–185.

Hair, H. I. (1995). Mood categories of lines, colors, words, and music. *Bulletin of the Council for Research in Music Education, 127*, 99–105.

Hanley, J. A., Negassa, A., Edwardes, M. D. deB., & Forrester, J. E. (2003). Statistical analysis of correlated data using generalized estimating equations: An orientation. *American Journal of Epidemiology, 157*, 364–375.

Hardin, J. A., & Hilbe, J. M. (2012). *Generalized estimating equations*. Boca Raton, FL: Chapman and Hall.

Hayes, J. E., & Duffy, V. B. (2008). Oral sensory phenotype identifies level of sugar and fat required for maximal liking. *Physiology and Behavior, 95*, 77–87.

Henderson, A. J., Holzleitner, I. J., Talamas, S. N., & Perrett, D. I. (2016). Perception of health from facial cues. *Philosophical Transactions of the Royal Society B: Biological Sciences, 371*, 20150380.

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and Brain Sciences, 33*, 61–135.

Hevner, K. (1935). Experimental studies of the affective value of colors and lines.

Journal of Applied Psychology, *19*, 385–398.

Hobbs, J., & Salome, R. (1991). *The visual experience*. Worcester, MA: Davis Publications.

Höfel, L., & Jacobsen, T. (2007). Electrophysiological indices of processing aesthetics: Spontaneous or intentional processes? *International Journal of Psychophysiology*, *65*, 20–31.

Holstege, G. (2002). Emotional innervation of facial musculature. *Movement Disorders*, *17*, S12–S16.

Holstege, G., Bandler, R., & Saper, C. B. (1996). The emotional motor system. *Progress in Brain Research*, *107*, 3–6.

Holstege, G., & Huynh, H. K. (2013). Emotions studied by imaging of the human brain: The somatic and emotional motor systems. In D. W. Pfaff (Ed.), *Neuroscience in the 21st century: From basic to clinical* (pp. 2045–2068). New York: Springer.

Hsiao, K. A., & Chen, L. L. (2006). Fundamental dimensions of affective responses to product shapes. *International Journal of Industrial Ergonomics*, *36*, 553–564.

Hume, D. (1757). *On the standards of taste: Essays Moral and Political*. London, UK: George Routledge and Sons.

Ingle, D. J. (1983). Brain mechanisms of visual localization by frogs and toads. In J.-P. Ewert, R. R. Capranica, & D. J. Ingle (Eds.), *Advances in Vertebrate Neuroethology* (pp. 177–226). Boston, MA: Springer US.

Isen, A. M. (2000). Positive affect and decision making. In M. Lewis & J. M. Haviland-Jones (Eds.), *Handbook of emotions* (pp. 417–435). New York: Guildford Press.

Ishimaru, Y. (2015). Molecular mechanisms underlying the reception and transmission of sour taste information. *Bioscience, Biotechnology, and Biochemistry*, *79*, 171–176.

Iwasaki, K., Kasahara, T., & Sato, M. (1985). Gustatory effectiveness of amino acids in mice: Behavioral and neurophysiological studies. *Physiology and Behavior, 34*, 531–542.

Jacobsen, T. (2010). Beauty and the brain: Culture, history and individual differences in aesthetic appreciation. *Journal of Anatomy*, *216*, 184–191.

Jacobsen, T., & Höfel, L. (2003). Descriptive and evaluative judgment processes: Behavioral and electrophysiological indices of processing symmetry and aesthetics. *Cognitive, Affective & Behavioral Neuroscience, 3*, 289–299.

Jacobsen, T., Schubotz, R. I., Höfel, L., & Cramon, D. Y. V. (2006). Brain correlates of aesthetic judgment of beauty. *NeuroImage, 29*, 276–285.

Jadva, V., Hines, M., & Golombok, S. (2010). Infants' preferences for toys, colors, and shapes: Sex differences and similarities. *Archives of Sexual Behavior, 39*, 1261–1273.

Jansson, L., Forkman, B., & Enquist, M. (2002). Experimental evidence of receiver bias for symmetry. *Animal Behaviour, 63*, 617–621.

Johnstone, R. A. (1994). Female preference for symmetrical males as a by-product of selection for mate recognition. *Nature, 372*, 172–175.

Jones, B. C., Little, A. C., Feinberg, D. R., Penton-Voak, I. S., Tiddeman, B. P., & Perrett, D. I. (2004). The relationship between shape symmetry and perceived skin condition in male facial attractiveness. *Evolution and Human Behavior, 25*, 24–30.

Jones, B. C., Little, A. C., Penton-Voak, I. S., Tiddeman, B. P., Burt, D. M., & Perrett, D. I. (2001). Facial symmetry and judgements of apparent health: Support for a "good genes" explanation of the attractiveness-symmetry relationship. *Evolution and Human Behavior, 22*, 417–429.

Joung, I. S., & Cheatham, T. E. (2008). Determination of alkali and halide monovalent

ion parameters for use in explicitly solvated biomolecular simulations. *Journal of Physical Chemistry B*, *112*, 9020–9041.

Jubb, J., & Bensing, J. M. (2013). The sweetest pill to swallow: How patient neurobiology can be harnessed to maximise placebo effects. *Neuroscience and Biobehavioral Reviews*, *37*, 2709–2720.

Kawase, H., Okata, Y., & Ito, K. (2013). Role of huge geometric circular structures in the reproduction of a marine pufferfish. *Scientific Reports*, *3*, 4–8.

Keast, R. S., & Costanzo, A. (2015). Is fat the sixth taste primary? Evidence and implications. *Flavour*, *4*, 5.

Keaveney, S. M., Herrmann, A., Befurt, R., & Landwehr, J. R. (2012). The eyes have it: How a car's face influences consumer categorization and evaluation of product line extensions. *Psychology & Marketing*, *29*, 36–51.

Kelley, A. E., & Berridge, K. C. (2002). The neuroscience of natural rewards: Relevance to addictive drugs. *The Journal of Neuroscience*, *22*, 3306–3311.

Kenneth, J. H. (1923). Mental reactions to smell stimuli. *Psychological Review*, *30*, 77–79.

Kim, S., & McGill, A. L. (2011). Gaming with Mr. Slot or gaming the slot machine? Power, anthropomorphism, and risk perception. *Journal of Consumer Research*, *38*, 94–107.

Kirk, U., Skov, M., Christensen, M. S., & Nygaard, N. (2009). Brain correlates of aesthetic expertise: A parametric fMRI study. *Brain and Cognition*, *69*, 306–315.

Klapetek, A., Ngo, M. K., & Spence, C. (2012). Does crossmodal correspondence modulate the facilitatory effect of auditory cues on visual search? *Attention, Perception & Psychophysics*, *74*, 1154–1167.

Koffka, K. (1953). *Principles of Gestalt psychology*. London, UK: Kegan Paul, Trench,

Trübner & Co.

Köhler, W. (1929). *Gestalt psychology*. New York: Liveright.

Komura, Y., Tamura, R., Uwano, T., Nishijo, H., Kaga, K., & Ono, T. (2001). Retrospective and prospective coding for predicted reward in the sensory thalamus. *Nature, 412*, 546–549.

Kumar, M. (2016). Aesthetic principles of product form and cognitive appraisals: Predicting emotional responses to beauty. In R. Batra, C. Seifert, & D. Brei (Eds.), *The psychology of design: Creating consumer appeal* (pp. 234–251). New York, NY: Routledge.

Kuroda, M., & Miyamura, N. (2015). Mechanism of the perception of "kokumi" substances and the sensory characteristics of the "kokumi" peptide, γ-Glu-Val-Gly. *Flavour*, *4*, 11.

Landwehr, J. R. (2016). Processing fluency of product design: Cognitive and affective routes to aesthetic preferences. In R. Batra, C. Seifert, & D. Brei (Eds.), *The psychology of design: Creating consumer appeal* (pp. 218–233). New York, NY: Routledge.

Landwehr, J. R., McGill, A. L., & Herrmann, A. (2011). It's got the look: The effect of friendly and aggressive "facial" expressions on product liking and sales. *Journal of Marketing*, *75*, 132–146.

Landwehr, J. R., Wentzel, D., & Herrmann, A. (2012). The tipping point of design: How product design and brands interact to affect consumers' preferences. *Psychology & Marketing, 29*, 422–433.

Lane, R. D., Chua, P. M. L., & Dolan, R. J. (1999). Common effects of emotional valence, arousal and attention on neural activation during visual processing of pictures. *Neuropsychologia, 37*, 989–997.

Larson, C. L., Aronoff, J., Sarinopoulos, I. C., & Zhu, D. C. (2009). Recognizing threat: A simple geometric shape activates neural circuitry for threat detection. *Journal of Cognitive Neuroscience, 21*, 1523–1535.

Larson, C. L., Aronoff, J., & Stearns, J. J. (2007). The shape of threat: Simple geometric forms evoke rapid and sustained capture of attention. *Emotion, 7*, 526–534.

Larson, C. L., Aronoff, J., & Steuer, E. L. (2012). Simple geometric shapes are implicitly associated with affective value. *Motivation and Emotion, 36*, 404–413.

Lauer, D. A. (1979). *Design basics*. New York: Holt, Rinehart, and Winston.

Leder, H., & Carbon, C. C. (2005). Dimensions in appreciation of car interior design. *Applied Cognitive Psychology, 19*, 603–618.

Leder, H., Tinio, P. P. L., & Bar, M. (2011). Emotional valence modulates the preference for curved objects. *Perception, 40*, 649–655.

Leeuwenberg, E. L. J. (1971). A perceptual coding language for visual and auditory patterns. *The American Journal of Psychology*, *84*, 307–349.

Li, X., Bachmanov, A. A., Maehashi, K., Li, W., Lim, R., Brand, J. G., … Floriano, W. B. (2011). Sweet taste receptor gene variation and aspartame taste in primates and other species. *Chemical Senses*, *36*, 453–475.

Liang, K.-Y., & Zeger, S. L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika, 73*, 13–22.

Lidwell, W., Holden, K., & Butler, J. (2010). *Universal principles of design: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design*. Beverly, MT: Rockport Publishers.

Lim, J., & Lawless, H. T. (2006). Detection thresholds and taste qualities of iron salts. *Food Quality and Preference, 17*, 513–521.

Lindemann, B. (2001). Receptors and transduction in taste. *Nature*, *413*, 219–225.

Little, A. C., Apicella, C. L., & Marlowe, F. W. (2007). Preferences for symmetry in human faces in two cultures: data from the UK and the Hadza, an isolated group of hunter-gatherers. *Proceedings of the Royal Society B: Biological Sciences*, *274*, 3113–3117.

Little, A. C., Jones, B. C., & DeBruine, L. M. (2011). Facial attractiveness: Evolutionary based research. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*, 1638–1659.

Liu, B., Ha, M., Meng, X. Y., Khaleduzzaman, M., Zhang, Z., Li, X., & Cui, M. (2012). Functional characterization of the heterodimeric sweet taste receptor T1R2 and T1R3 from a New World monkey species (squirrel monkey) and its response to sweet-tasting proteins. *Biochemical and Biophysical Research Communications*, *427*, 431–437.

LoBue, V. (2014). Deconstructing the snake: The relative roles of perception, cognition, and emotion on threat detection. *Emotion*, *14*, 701–711.

LoBue, V., & Larson, C. L. (2010). What makes an angry face look so … angry? Examining visual attention to the shape of threat in children and adults, *18*, 1165–1178.

Looy, H., & Weingarten, H. P. (1991). Effects of metabolic state on sweet taste reactivity in humans depend on underlying hedonic response profile. *Chemical Senses*, *16*, 123–130.

Lundholm, H. (1921). The affective tone of lines: Experimental researches. *Psychological Review*, *28*, 43–60.

Lundqvist, D., Esteves, F., & Ohman, A. (1999). The face of wrath: Critical features for conveying facial threat. *Cognition and Emotion*, *13*, 691–711.

Lyman, B. (1979). Representation of complex emotional and abstract meanings by simple forms. *Perceptual and Motor Skills*, *49*, 839–842.

Mach, E. (1959). *The analysis of sensations and the relation of the physical to the psychical*. New York, NY: Dover (Original work published 1886).

Machery, E. (2010). Explaining why experimental behavior varies across cultures: A missing step in "The weirdest people in the world?" *Behavioral and Brain Sciences*, *33*, 101–102.

Maestripieri, D., & Call, J. (1996). Mother-infant communication in primates. *Advances in the Study of Behavior*, *25*, 613–642.

Makin, A. D. J., Pecchinenda, A., & Bertamini, M. (2012). Implicit affective evaluation of visual symmetry. *Emotion*, *12*, 1021–1030.

Marsh, A. A., Adams, R. B., & Kleck, R. E. (2005). Why do fear and anger look the way they do? Form and social function in facial expressions. *Personality and Social Psychology Bulletin*, *31*, 73–86.

Marsh, A. A., Ambady, N., & Kleck, R. E. (2005). The effects of fear and anger facial expressions on approach- and avoidance-related behaviors. *Emotion*, *5*, 119–124.

Martín, J., & López, P. (2000). Chemoreception, symmetry and mate choice in lizards. *Proceedings of the Royal Society B: Biological Sciences*, *267*, 1265–9.

Martino, G., & Marks, L. E. (2001). Synesthesia: Strong and weak. *Current Directions in Psychological Science*, *10*, 61–65.

Masuda, T., Gonzalez, R., Kwan, L., & Nisbett, R. E. (2008). Culture and aesthetic preference: Comparing the attention to context of East Asians and Americans. *Personality and Social Psychology Bulletin*, *34*, 1260–1275.

Mattes, R. D. (2011). Accumulating evidence supports a taste component for free fatty acids in humans. *Physiology and Behavior*, *104*, 624–631.

Maurer, D., Pathman, T., & Mondloch, C. J. (2006). The shape of boubas: Sound-shape correspondences in toddlers and adults. *Developmental Science, 9,* 316–322.

McCabe, C., & Rolls, E. T. (2007). Umami: A delicious flavor formed by convergence of taste and olfactory pathways in the human brain. *European Journal of Neuroscience, 25,* 1855–1864.

Mennella, J. A. (2014). Ontogeny of taste preferences: Basic biology and implications for health. *American Journal of Clinical Nutrition, 99,* 704–711.

Mennella, J. A., Forestell, C. A., Morgan, L. K., & Beauchamp, G. K. (2009). Early milk feeding influences taste acceptance and liking during infancy. *American Journal of Clinical Nutrition, 90,* 780–788.

Mennella, J. A., Spector, A. C., Reed, D. R., & Coldwell, S. E. (2013). The bad taste of medicines: Overview of basic research on bitter taste. *Clinical Therapeutics, 35,* 1225–1246.

Metzger, W. (2009). *Laws of seeing*. Cambridge, USA: MIT Press.

Michel, C., Velasco, C., Gatti, E., & Spence, C. (2014). A taste of Kandinsky: Assessing the influence of the artistic visual presentation of food on the dining experience. *Flavour, 3,* 7.

Mignault, A., & Chaudhuri, A. (2003). The many faces of a neutral face: Head tilt and perception of dominance and emotion. *Journal of Nonverbal Behavior, 27,* 111–132.

Minagawa-Kawai, Y., Matsuoka, S., Dan, I., Naoi, N., Nakamura, K., & Kojima, S. (2009). Prefrontal activation associated with social attachment: Facial-emotion recognition in mothers and infants. *Cerebral Cortex, 19,* 284–292.

Mitchell, D. G. V. (2011). The nexus between decision making and emotion regulation: A review of convergent neurocognitive substrates. *Behavioural Brain Research,*

217, 215–231.

Møller, A. P. (1990). Fluctuating asymmetry in male sexual ornaments may reliably reveal male quality. *Animal Behaviour*, *40*, 1185–1187.

Møller, A. P., & Thornhill, R. (1998). Bilateral symmetry and sexual selection: A meta-analysis. *The American Naturalist*, *151*, 174–192.

Morecraft, R. J., Stilwell-Morecraft, K. S., & Rossing, W. R. (2004). The motor cortex and facial expression: New insights from neuroscience. *The Neurologist*, *10*, 235–49.

Morris, M. R., Rios-Cardenas, O., Lyons, S. M., Scarlett Tudor, M., & Bono, L. M. (2012). Fluctuating asymmetry indicates the optimization of growth rate over developmental stability. *Functional Ecology*, *26*, 723–731.

Mouritsen, O. G. (2015). The science of taste. *Flavour*, *4*, 18.

Nadal, M., & Pearce, M. T. (2011). The Copenhagen Neuroaesthetics conference: Prospects and pitfalls for an emerging field. *Brain and Cognition*, *76*, 172–183.

Neely, J. G., Lisker, P., & Drapekin, J. (2014). Importance of the brow in facial expressiveness during human communication. *Otology & Neurotology*, *35*, e97-103.

Nelson, G., Chandrashekar, J., Hoon, M. A., Feng, L., Zhao, G., Ryba, N. J. P., & Zuker, C. S. (2002). An amino-acid taste receptor. *Nature*, *416*, 199–202.

Nelson, G., Hoon, M. A., Chandrashekar, J., Zhang, Y., Ryba, N. J. P., & Zuker, C. S. (2001). Mammalian sweet taste receptors. *Cell*, *106*, 381–390.

Nelson, L. S., Shih, R. D., & Balick, M. J. (2007). *Handbook of poisonous and injurious plants*. New York: Springer Science and Business Media LLC.

Ngo, M. K., Misra, R., & Spence, C. (2011). Assessing the shapes and speech sounds that people associate with chocolate samples varying in cocoa content. *Food*

Quality and Preference, *22*, 567–572.

Ngo, M. K., Piqueras-Fiszman, B., & Spence, C. (2012). On the colour and shape of still and sparkling water: Insights from online and laboratory-based testing. *Food Quality and Preference*, *24*, 260–268.

Ngo, M. K., Velasco, C., Salgado, A., Boehm, E., O'Neill, D., & Spence, C. (2013). Assessing crossmodal correspondences in exotic fruit juices: The case of shape and sound symbolism. *Food Quality and Preference*, *28*, 361–369.

Niedenthal, P. M., Augustinova, M., & Rychlowska, M. (2010). Body and mind: Zajonc's (re)introduction of the motor system to emotion and cognition. *Emotion Review*, *2*, 340–347.

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The simulation of smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *The Behavioral and Brain Sciences*, *33*, 417-433-480.

Nieh, E. H., Kim, S. Y., Namburi, P., & Tye, K. M. (2013). Optogenetic dissection of neural circuits underlying emotional valence and motivated behaviors. *Brain Research*, *1511*, 73–92.

Nitschke, J. B., Nelson, E. E., Rusch, B. D., Fox, A. S., Oakes, T. R., & Davidson, R. J. (2004). Orbitofrontal cortex tracks positive mood in mothers viewing pictures of their newborn infants. *NeuroImage*, *21*, 583–592.

Noor, F., & Evans, D. C. (2003). The effect of facial symmetry on perceptions of personality and attractiveness. *Journal of Research in Personality*, *37*, 339–347.

Northcutt, R. G. (2004). Taste buds: Development and evolution. *Brain, Behavior and Evolution*, *64*, 198–206.

Oakes, E. J., & Barnard, P. (1994). Fluctuating asymmetry and mate choice in paradise whydahs, Vidua paradisaea: An experimental manipulation. *Animal Behaviour*, *48*,

937–943.

Öngür, D., & Price, J. L. (2000). The organization of networks within the orbital and medial prefrontal cortex of rats, monkeys and humans. *Cerebral Cortex*, *10*, 206–219.

Osawa, H., & Imai, M. (2008). Towards anthropomorphized spaces: Human responses to anthropomorphization of a space using attached body parts. *Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication, RO-MAN*, 148–153.

Osawa, H., Ishii, K., Osumi, T., Ohmura, R., & Imai, M. (2009). Anthropomorphization of a space with implemented human-like features. *ACM SIGGRAPH 2009 Emerging Technologies on - SIGGRAPH '09*, 1–1.

Palmer, S. E., Schloss, K. B., & Sammartino, J. (2013). Visual aesthetics and human preference. *Annual Review of Psychology*, *64*, 77–107.

Palmer, S. E., Schloss, K. B., Xu, Z., & Prado-León, L. R. (2013). Music-color associations are mediated by emotion. *Proceedings of the National Academy of Sciences of the United States of America*, *110*, 8836–8841.

Palumbo, L., Ruta, N., & Bertamini, M. (2015). Comparing angular and curved shapes in terms of implicit associations and approach/avoidance responses. *PLoS ONE*, *10*, 1–16.

Parise, C., & Ernst, M. (2015). Correlation detection as a general mechanism for multisensory integration. *Journal of Vision*, *15*, 364.

Parise, C. V. (2015). Crossmodal correspondences: Standing issues and experimental guidelines. *Multisensory Research*, *29*, 7–28.

Parise, C. V., & Spence, C. (2012a). Assessing the associations between brand packaging and brand attributes using an indirect performance measure. *Food*

Quality and Preference, *24*, 17–23.

Parise, C. V., & Spence, C. (2012b). Audiovisual crossmodal correspondences and sound symbolism: A study using the implicit association test. *Experimental Brain Research*, *220*, 319–333.

Parise, C. V., & Spence, C. (2013). Audiovisual cross-modal correspondences in the general population. In J. Simner & E. Hubbard (Eds.), *Oxford handbook of synesthesia* (pp. 790–815). Oxford, UK: Oxford University Press.

Perrett, D. I., Burt, D. M., Penton-Voak, I. S., Lee, K. J., Rowland, D. a, & Edwards, R. (1999). Symmetry and human facial attractiveness. *Evolution and Human Behavior*, *20*, 295–307.

Phillips, M. L., Young, A. W., Senior, C., Brammer, M., Andrew, C., Calder, A. J., … David, A. S. (1997). A specific neural substrate for perceiving facial expressions of disgust. *Nature*, *389*, 495–8.

Piqueras-Fiszman, B., Velasco, C., Salgado-Montejo, A., & Spence, C. (2013). Using combined eye tracking and word association in order to assess novel packaging solutions: A case study involving jam jars. *Food Quality and Preference*, *28*, 328–338.

Poffengerger, A. T., & Barrows, B. E. (1924). The feeling value of lines. *Journal of Applied Psychology*, *8*, 187–205.

Pound, N., Lawson, D. W., Toma, A. M., Richmond, S., Zhurov, A. I., & Penton-Voak, I. S. (2014). Facial fluctuating asymmetry is not associated with childhood ill-health in a large British cohort study. *Proceedings of the Royal Society B: Biological Sciences*, *281*, 20141639–20141639.

Praticò, G., Capuani, G., Tomassini, A., Baldassarre, M. E., Delfini, M., & Miccheli, A. (2014). Exploring human breast milk composition by NMR-based metabolomics.

Natural Product Research, *28*, 95–101.

Ramachandran, V. S., & Hubbard, E. M. (2001). Synaesthesia -- A window into perception, thought and language. *Journal of Consciousness Studies*, *8*, 3–34.

Reber, R., Schwarz, N., & Winkielman, P. (2004). Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? *Personality and Social Psychology Review*, *8*, 364–382.

Reed, L. I., Zeglen, K. N., & Schmidt, K. L. (2012). Facial expressions as honest signals of cooperative intent in a one-shot anonymous Prisoner's Dilemma game. *Evolution and Human Behavior*, *33*, 200–209.

Rhodes, G. (2006). The evolutionary psychology of facial beauty. *Annual Review of Psychology*, *57*, 199–226.

Rhodes, G., Proffitt, F., Grady, J. M., & Sumich, A. (1998). Facial symmetry and the perception of beauty. *Psychonomic Bulletin & Review*, *5*, 659–669.

Riera, C. E., Vogel, H., Simon, S. A., Damak, S., & le Coutre, J. (2009). Sensory attributes of complex tasting divalent salts are mediated by TRPM5 and TRPV1 channels. *The Journal of Neuroscience*, *29*, 2654–2662.

Rikowski, A., & Grammer, K. (1999). Human body odour, symmetry and attractiveness. *Proceedings of the Royal Society B: Biological Sciences*, *266*, 869–874.

Roca, E. M., Gómez-Puerto, G., Nadal, M., & Call, J. (2015). Do great apes also prefer curved visual objects? *Perception*, *44*, 1P2M110.

Rodríguez, I., Gumbert, A., De Ibarra, N. H., Kunze, J., & Giurfa, M. (2004). Symmetry is in the eye of the "beeholder": Innate preference for bilateral symmetry in flower-naïve bumblebees. *Naturwissenschaften*, *91*, 374–377.

Rolls, E. T. (2004). Multisensory neuronal convergence of taste, somatosensory, visual,

olfactory, and auditory inputs. In *The handbook of multisensory processes* (pp. 311–331). Cambridge, MA/London, UK: MIT Press.

Rolls, E. T., & Baylis, L. L. (1994). Gustatory, olfactory, and visual convergence within the primate orbitofrontal cortex. *The Journal of Neuroscience*, *14*, 5437–5452.

Rolls, E. T., & Grabenhorst, F. (2008). The orbitofrontal cortex and beyond: From affect to decision-making. *Progress in Neurobiology*, *86*, 216–244.

Rosenstein, D., & Oster, H. (1988). Differential facial responses to four basic tastes in newborns. *Child Development*, *59*, 1555–1568.

Rosenthal, R., Rosnow, R. L., & Rubin, D. B. (2000). *Contrasts and effect sizes in behavioral research: A correlation approach*. (R. Rosenthal, R. L. Rosnow, & D. B. Rubin, Eds.) (Cambridge). Cambridge/New York/Oakleigh: Cambridge University Press. Retrieved from http://www.cambridge.org/us/academic/subjects/psychology/social-psychology/contrasts-and-effect-sizes-behavioral-research-correlational-approach

Rozin, P., Lowery, L., & Ebert, R. (1994). Varieties of disgust faces and the structure of disgust. *Journal of Personality and Social Psychology*, *66*, 870–881.

Salgado-Montejo, A., Alvarado, J. A., Velasco, C., Salgado, C. J., Hasse, K., & Spence, C. (2015). The sweetest thing: The influence of angularity, symmetry, and the number of elements on shape-taste matches. *Frontiers in Psychology*, *6*, 1382.

Salgado-Montejo, A., Marmolejo-Ramos, F., Alvarado, J. A., Arboleda, J. C., Suarez, D. R., & Spence, C. (2016). Drawing sounds: representing tones and chords spatially. *Experimental Brain Research*, *234*, 3509–3522.

Salgado-Montejo, A., Salgado, C. J., Alvarado, J., & Spence, C. (2016). Simple lines and shapes are associated with, and communicate, distinct emotions. *Cognition and Emotion*, *9931*, 1–15.

Salgado-Montejo, A., Tapia Leon, I., Elliot, A. J., Salgado, C. J., & Spence, C. (2015). Smiles over frowns: When curved lines influence product preference. *Psychology & Marketing*, *32*, 771–781.

Salgado-Montejo, A., Velasco, C., Ariza, L., Salgado, R., & Moreno, A. M. (2017). The Four Moments of Experience Streamlining the process of packaging development. In *ESOMAR 70 - Visionary* (pp. 173–186). Amsterdam: ESOMAR.

Salgado-Montejo, A., Velasco, C., Olier, J. S., Alvarado, J., & Spence, C. (2014). Love for logos: Evaluating the congruency between brand symbols and typefaces and their relation to emotional words. *Journal of Brand Management*, *21*, 635–649.

Sasaki, Y., Vanduffel, W., Knutsen, T., Tyler, C., & Tootell, R. (2005). Symmetry activates extrastriate visual cortex in human and nonhuman primates. *Proceedings of the National Academy of Sciences of the United States of America*, *102*, 3159–3163.

Scharlemann, J. P., Eckel, C. C., Kacelnik, A., & Wilson, R. K. (2001). The value of a smile: Game theory with a human face. *Journal of Economic Psychology*, *22*, 617–640.

Scheib, J. E., Gangestad, S. W., & Thornhill, R. (1999). Facial attractiveness, symmetry and cues of good genes. *Proceedings of the Royal Society B: Biological Sciences*, *266*, 1913–1917.

Schiffman, S. S., Reilly, D. A., & Clark, T. B. (1979). Qualitative differences among sweeteners. *Physiology & Behavior*, *23*, 1–9.

Schug, J., Matsumoto, D., Horita, Y., Yamagishi, T., & Bonnet, K. (2010). Emotional expressivity as a signal of cooperation. *Evolution and Human Behavior*, *31*, 87–94.

Shepherd, K., & Bar, M. (2011). Preference for symmetry: Only on Mars? *Perception*, *40*, 1254–1256.

Shimamura, A. P., & Palmer, S. E. (2014). *Aesthetic Science*. New York, NY: Oxford University Press.

Silvia, P. J., & Barona, C. M. (2008). Do people prefer curved objects? Angularity, expertise, and aesthetic preference. *Empirical Studies of the Arts*, *27*, 25–42.

Spence, C. (2011). Crossmodal correspondences: A tutorial review. *Attention, Perception & Psychophysics*, *73*, 971–995.

Spence, C. (2012a). Auditory contributions to flavour perception and feeding behaviour. *Physiology and Behavior*, *107*, 505–515.

Spence, C. (2012b). Managing sensory expectations concerning products and brands: Capitalizing on the potential of sound and shape symbolism. *Journal of Consumer Psychology*, *22*, 37–54.

Spence, C. (2016). Multisensory packaging design: Color, shape, texture, sound, and smell. In P. Burgess (Ed.), *Integrating the packaging and product experience in food and beverages: A road-map to consumer satisfaction* (pp. 1–22). Oxford, UK: Woodhead Publishing.

Spence, C. (2017). Tasting in the air: A review. *International Journal of Gastronomy and Food Science*, *9*, 10–15.

Spence, C., Auvray, M., & Smith, B. (2014). Confusing Tastes with Flavours. In D. Stokes, M. Matthen, & S. Biggs (Eds.), *Perception and Its Modalities* (pp. 247–274). Oxford University Press.

Spence, C., & Deroy, O. (2013). Taste and shapes: A review of four hypotheses. *Historia Scientiae*, *25*, 42–49.

Spence, C., & Gallace, A. (2011). Tasting shapes and words. *Food Quality and Preference*, *22*, 290–295.

Spence, C., Michel, C., & Smith, B. (2014). Airplane noise and the taste of umami.

Flavour, *3*, 1–4.

Spence, C., Ngo, M. K., Percival, B., & Smith, B. (2013). Crossmodal correspondences: Assessing shape symbolism for cheese. *Food Quality and Preference*, *28*, 206–212.

Spence, C., & Piqueras-Fiszman, B. (2012). The multisensory packaging of beverages. In M. G. Kontominas (Ed.), *Food packaging: Procedures, management and trends* (pp. 187–233). Hauppauge, NY: Nova Science Publishers.

Spence, C., Puccinelli, N. M., Grewal, D., & Roggeveen, A. L. (2014). Store atmospherics: A multisensory perspective. *Psychology & Marketing*, *31*, 472–488.

Sriram, N., & Greenwald, A. G. (2009). The brief implicit association test. *Experimental Psychology*, *56*, 283–294.

Stein, B. E. (2012). *The new handbook of multisensory processing*. Cambridge, MA: MIT Press.

Steiner, J. E. (1973). The gustofacial response: observation on normal and anencephalic newborn infants. *Symposium on Oral Sensation and Perception*, 254–278.

Steiner, J. E. (1974). Discussion paper: Innate, discriminative human facial expression to taste and smell stimulation. *Annals of the New York Academy of Sciences*, *237*, 229–233.

Steiner, J. E. (1979). Human facial expressions in response to taste and smell stimulation. *Advances in Child Development and Behavior*, *13*, 257–295.

Steiner, J. E., Glaser, D., Hawilo, M. E., & Berridge, K. C. (2001). Comparative expression of hedonic impact: Affective reactions to taste by human infants and other primates. *Neuroscience & Biobehavioral Reviews*, *25*, 53–74.

Sternini, C. (2013). In search of a role for carbonation: Is this a good or bad taste? *Gastroenterology*, *145*, 500–503.

Stewart, I. (2013). *Symmetry: A very short introduction*. Gosport, UK: Oxford University Press.

Stone, L. M., Finger, T. E., Tam, P. P. L., & Tan, S.-S. (1995). Taste receptor cells arise from local epithelium, not neurogenic ectoderm. *Proceedings of the National Academy of Sciences of the United States of America*, *92*, 1916–1920.

Suwankanit, C., Dermiki, M., Kennedy, O. B., & Methven, L. (2013). Umami: Suppressed by all other tastes but itself an enhancer of salty and sweet perception. In *Poster presented at 10th Pangborn Sensory Science Symposium*. Rio de Janeiro.

Swaddle, J. P. (1996). Reproductive success and symmetry in zebra finches. *Animal Behaviour*, *51*, 203–210.

Temussi, P. A. (2009). Sweet, bitter and umami receptors: A complex relationship. *Trends in Biochemical Sciences*, *34*, 296–302.

Temussi, P. A., Lelj, F., & Tancredi, T. (1978). Three-dimensional mapping of the sweet taste receptor site. *Journal of Medicional Chemistry*, *21*, 1154–1158.

Thornhill, R. (1999). The scent of symmetry: A human sex pheromone that signals fitness? *Evolution and Human Behavior*, *20*, 175–201.

Thornhill, R., & Gangestad, S. (1999). Facial attractiveness. *Trends in Cognitive Sciences*, *3*, 452–460.

Tinga, A. M., Visser-Meily, J. M. A., van der Smagt, M. J., Van der Stigchel, S., van Ee, R., & Nijboer, T. C. W. (2016). Multisensory stimulation to improve low- and higher-level sensory deficits after stroke: A systematic review. *Neuropsychology Review*, *26*, 73–91.

Tinio, P. P. L., & Leder, H. (2009). Just how stable are stable aesthetic features? Symmetry, complexity, and the jaws of massive familiarization. *Acta Psychologica*, *130*, 241–250.

Tipples, J., Atkinson, A. P., & Young, A. W. (2002). The eyebrow frown: A salient social signal. *Emotion, 2*, 288–296.

Toet, A., & Tak, S. (2013). Look out, there is a triangle behind you! The effect of primitive geometric shapes on perceived facial dominance. *I-Perception, 4*, 53–56.

Treesukosol, Y., Smith, K. R., & Spector, A. C. (2011). The functional role of the T1R family of receptors in sweet taste and feeding. *Physiology and Behavior, 105*, 14–26.

van der Helm, P. A., & Leeuwenberg, E. L. (1996). Goodness of visual regularities: A nontransformational approach. *Psychological Review, 103*, 429–456.

Vartanian, O., Navarrete, G., Chatterjee, A., Fich, L. B., Leder, H., Modroño, C., … Skov, M. (2013). Impact of contour on aesthetic judgments and approach-avoidance decisions in architecture. *Proceedings of the National Academy of Sciences of the United States of America, 110,* 10446–10453.

Velasco, C., Salgado-Montejo, A., Elliot, A. J., Woods, A. T., Alvarado, J., & Spence, C. (2016). The shapes associated with approach/avoidance words. *Motivation and Emotion, 40*, 689–702.

Velasco, C., Salgado-Montejo, A., Marmolejo-Ramos, F., & Spence, C. (2014). Predictive packaging design: Tasting shapes, typefaces, names, and sounds. *Food Quality and Preference*, *34*, 88–95.

Velasco, C., Woods, A. T., Deroy, O., & Spence, C. (2015). Hedonic mediation of the crossmodal correspondence between taste and shape. *Food Quality and Preference, 41*, 151–158.

Velasco, C., Woods, A. T., Hyndman, S., & Spence, C. (2015). The taste of typeface. *I-Perception, 6*, 1–10.

Velasco, C., Woods, A. T., Petit, O., Cheok, A. D., & Spence, C. (2016). Crossmodal

correspondences between taste and shape, and their implications for product packaging: A review. *Food Quality and Preference*, *52*, 17–26.

Verkade, P. E. (1968). On organic compounds with a sweet and-or a bitter taste. *Il Farmaco; Edizione Scientifica*, *23*, 248–291.

Veryzer, R. W. (1993). Aesthetic response and the influence of design principles on product preferences. *Advances in Consumer Research*, *20*, 224–229.

Veryzer, R. W. (1999). A nonconscious processing explanation of consumer response to product design. *Psychology and Marketing*, *16*, 497–522.

Veryzer, R. W., & Borja de Mozota, B. (2005). The impact of user-oriented design on new product development: An examination of fundemental relationships. *The Journal of Product Innovation Management*, *22*, 128–143.

Veryzer, R. W., & Hutchinson, J. . W. (1998). The influence of unity and prototypicality. *Journal of Consumer Research*, *24*, 374–385.

Wagemans, J. (1995). Detection of visual symmetries. *Spatial Vision*.

Walker, P., Gavin Bremner, J., Mason, U., Spring, J., Mattock, K., Slater, A., & Johnson, S. P. (2010). Preverbal infants' sensitivity to synaesthetic cross-modality correspondences. *Psychological Science*, *21*, 21–25.

Wallace, D. J., Greenberg, D. S., Sawinski, J., Rulla, S., Notaro, G., & Kerr, J. N. D. (2013). Rats maintain an overhead binocular field at the expense of constant fusion. *Nature*, *498*, 65–9.

Waller, B. M., & Micheletta, J. (2013). Facial expression in nonhuman animals. *Emotion Review*, *5*, 54–59.

Wallis, J. D. (2007). Orbitofrontal cortex and its contribution to decision-making. *Annual Review of Neuroscience*, *30*, 31–56.

Wan, X., Woods, A. T., Salgado-Montejo, A., Velasco, C., & Spence, C. (2015).

Assessing the expectations associated with pharmaceutical pill colour and shape. *Food Quality and Preference*, *45*, 171–182.

Wan, X., Woods, A. T., van den Bosch, J. J. F., McKenzie, K. J., Velasco, C., & Spence, C. (2014). Cross-cultural differences in crossmodal correspondences between basic tastes and visual features. *Frontiers in Psychology*, *5*, 1–13.

Watson, D. G., Blagrove, E., Evans, C., & Moore, L. (2012). Negative triangles: Simple geometric shapes convey emotional valence. *Emotion*, *12*, 18–22.

Watson, D. G., Blagrove, E., & Selwood, S. (2011). Emotional triangles : A test of emotion-based attentional capture by simple geometric shapes, 37–41.

Waytz, A., Cacioppo, J., & Epley, N. (2010). Who sees human? *Perspectives on Psychological Science*, *5*, 219–232.

Weiland, R., Ellgring, H., & Macht, M. (2010). Gustofacial and olfactofacial responses in human adults. *Chemical Senses*, *35*, 841–853.

Westerman, S. J., Gardner, P. H., Sutherland, E. J., White, T., Jordan, K., Watts, D., & Wells, S. (2012). Product design: Preference for rounded versus angular design elements. *Psychology and Marketing*, *29*, 595–605.

Westerman, S. J., Sutherland, E. J., Gardner, P. H., Baig, N., Critchley, C., Hickey, C., … Zervos, Z. (2013). The design of consumer packaging: Effects of manipulations of shape, orientation, and alignment of graphical forms on consumers' assessments. *Food Quality and Preference*, *27*, 8–17.

Winkielman, P., Berridge, K. C., & Wilbarger, J. L. (2005). Unconscious affective reactions to masked happy versus angry faces influence consumption behavior and judgments of value. *Personality and Social Psychology Bulletin*, *31*, 121–135.

Wintjens, R., Viet, T. M. V. N., Mbosso, E., & Huet, J. H. (2011). Hypothesis/review: The structural basis of sweetness perception of sweet-tasting plant proteins can be

deduced from sequence analysis. *Plant Science*, *181*, 347–354.

Yamamoto, K., & Ishimaru, Y. (2013). Oral and extra-oral taste perception. *Seminars in Cell and Developmental Biology*, *24*, 240–246.

Yamamoto, M., & Lambert, D. R. (1994). The impact of product aesthetics on the evaluation of industrial products. *Journal of Product Innovation Management*, *11*, 309–324.

Yarmolinsky, D. A., Zuker, C. S., & Ryba, N. J. P. (2009). Common sense about taste: From mammals to insects. *Cell*, *139*, 234–244.

Yeomans, M. R., Tepper, B. J., Rietzschel, J., & Prescott, J. (2007). Human hedonic responses to sweetness: Role of taste genetics and anatomy. *Physiology and Behavior*, *91*, 264–273.

Zajonc, R. B., & Markus, H. (1984). Affect and cognition: The hard interface. In C. Izard, J. Kagan, & R. B. Zajonc (Eds.), *Emotion, cognition, and behavior* (pp. 73–102). Cambridge: Cambridge University Press.

Zanna, M. P., & Fazio, R. H. (1982). The attitude-behavior relation: Moving toward a third generation of research. In *The Ontario symposium* (p. 283–301 (Vol. 2)).

Zhang, Y., Hoon, M. a., Chandrashekar, J., Mueller, K. L., Cook, B., Wu, D., … Ryba, N. J. P. (2003). Coding of sweet, bitter, and umami tastes: Different receptor cells sharing similar signaling pathways. *Cell*, *112*, 293–301.

Zhao, G. Q., Zhang, Y., Hoon, M. A., Chandrashekar, J., Erlenbach, I., Ryba, N. J. P., & Zuker, C. S. (2003). The receptors for mammalian sweet and umami taste. *Cell*, *115*, 255–266.

Appendix A Drawing sounds: Representing tones and chords spatially

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ABSTRACT

Research on the crossmodal correspondences has revealed that seemingly-unrelated perceptual information can be matched across the senses in a manner that is consistent across individuals. An interesting extension of this line of research is to study how sensory information biases action. In the present study, we investigated whether different sounds (i.e., tones and piano chords) would bias participants' hand movements in a free-movement task. Right-handed participants were instructed to move a computer mouse in order to represent three tones and two chords. They also had to rate each sound in terms of three visual analogue scales (slow-fast, unpleasant-pleasant, and weak-strong). The results demonstrate that tones and chords influence hand movements, with higher-(lower-)pitched sounds giving rise to a significant bias towards upper (lower) spatial locations. These results are discussed in terms of the literature on forward models, embodied cognition, crossmodal correspondences, and mental imagery. Potential applications sports and rehabilitation are discussed briefly.

KEYWORDS: SOUND; SPACE; MOUSE-TRACKING; MOVEMENT; VALENCE; EMBODIED COGNITION

A.1. Introduction

To date, the study of crossmodal correspondences has largely focused on documenting associations across seemingly unrelated sensory features from different sensory modalities (see Spence, 2011, for a review). These crossmodal associations would appear to be useful when it comes to predicting the likely sensory properties of stimuli. Think, for example, about how colour provides a useful cue to the ripeness, and hence sweetness, of many fruits and vegetables (Maga, 1974; Watson, 1971). As yet, less attention has been paid to the role of crossmodal correspondences in the production and understanding of action. Specifically, further research is still needed in order to understand whether crossmodal correspondences can influence motor responses and facilitate action planning. What is more, the crossmodal correspondences between auditory and spatial information (e.g., high-pitch and higher spatial positions) would seem to be of particular interest given the importance of auditory and visual information in everyday life (e.g., driving, crossing a street, or navigating through a supermarket).

Some interesting examples of audiovisual correspondences (see Eitan & Timmers, 2010; Parise, Spence, & Deroy, 2015, for reviews) include the correspondence between pitch and brightness (higher pitch ~ brighter), size (higher pitch ~ smaller), weight (higher pitch ~ lighter), thickness (higher pitch ~ thinner), and sharpness (higher pitch ~ sharper). Other correspondences involving pitch (but not necessarily visual information) include softness / roughness (higher pitch ~ softer), gender (higher pitch ~ female), age (higher pitch ~ younger), and to a specific valence (higher pitch ~ positive valence). Perhaps the latter association between pitch and valence might also explain why some musical chords are associated with a specific emotional valence. For instance, major chords[18] tend to be

[18] Note here that a chord is composed of three notes: a base or root note, a third, and a perfect fifth. What determines whether a chord is major or minor depends on whether the third is four (major chord) or three (minor chord) semitones higher than the root note (see Bakker & Martin, 2014; Parker, 2009).

associated with a positive emotional valence whereas minor chords are associated with a negative valence instead (Bakker & Martin, 2014; Scherer & Oshinsky, 1977). However, as yet, no one has probed whether these chords are intuitively localized higher in space as compared to minor chords or whether they can influence the direction of body movements (e.g., the hand, see D'Ausilio, Brunetti, Delogu, Santonico, & Belardinelli, 2010, for evidence regarding how auditory information influences motor performance).

Perhaps one of the strongest matches between auditory and visual information that has been documented thus far is between pitch and spatial elevation (Parise, 2016). Numerous studies have demonstrated that low- and high-pitched sounds are more easily associated with lower and higher spatial positions, respectively (e.g., Evans & Treisman, 2010; Melara & O'Brien, 1987; Pratt, 1930; Rigas & Alty, 2005; Stumpf, 1883). What is more, the associations made by participants between the positions in space of a sound as a function of its pitch are not culturally mediated (see Deroy, Fernandez-Prieto, Navarra, & Spence, in press; Treitler, 1982, for discussion of the spatial representation of music). Spatial connotations of auditory pitch would seem to be explained by an embodied representation of sound. The embodied mechanism of space-pitch representations seems, in turn, to be facilitated by the statistical properties of the stimulus (i.e., by how often a sound with a specific pitch is presented in a particular region of space, see Parise, Knorre, & Ernst, 2014). Mudd (1963) reported that high-pitched sounds were associated with upper and rightward locations, whereas low-pitch sounds were matched to lower and leftward positions.

The consistency in the spatial localization of sounds could be taken to suggest that at least some sounds can induce a bias in people's motor responses. However, as Rusconi, Kwan, Giordano, Umiltà, and Butterworth (2006) have pointed out, those tasks that have sought to evaluate how pitch is matched to spatial location have typically had their participants

explicitly match a sound to a location. Rusconi et al. provided evidence that pitch and space are associated spontaneously, by demonstrating a reaction time (RT) advantage for high- and low-pitched sounds when pressing a key located in the upper and lower portion of the keyboard, respectively. One interesting hypothesis that could be used to explain why it is that we associate low frequency sounds with the lower visual field could be related to the fact that we sometimes "feel" these sounds through our feet and lower abdomen (e.g., as in a party or concert; DeChaine, 2002; Henriques, 2003)[19]. However, it is still not clear whether associations between space and pitch also occur automatically (without a direct instruction to do so). What is more, while changes in pitch can clearly be localized spatially, it is not yet clear whether sound biases the direction of motion.

A first step in determining whether sound influences a participant's movement patterns is to evaluate whether there is any consistency in terms of how simple auditory stimuli are intuitively localized spatially. Penfield and Rasmussen (1950) had already suggested that meaningful actions require a somatotopic representation of the body. It is possible that this representation can be extended to other senses and be used not just for proprioception but also for spatial navigation (see Aglioti & Pazzaglia, 2010, for a review on the sonic representation of action, see also King, Schnupp, & Doubell, 2001). Perception and movement, then, could be tightly linked and thus influence one another. The latter suggestion, that auditory information can influence movement, is further supported by evidence (see Maeda, Kanai, & Shimojo, 2004; Deroy et al., in press) showing that high and low pitch frequencies can influence the perceived motion of gratings presented in a computer screen (i.e., upwards and downwards, respectively).

[19] These sensations can be related to the mechanical response of tissues to vibration. The range of natural frequencies for different body parts (e.g., hands, eyes, abdominal mass, chest) range from two to 200Hz. Above 250Hz, Pacini receptors are unresponsive and no longer represent sinusoidal frequencies as vibrations (Chaffin, Andersson, & Martin, 2006; Makous, Friedman, & Vierck, 1995).

There is growing evidence that the traditional view of perception and action as being governed by separate neural circuitry is incorrect. Specifically, the discovery of the so-called "double duty" mirror neurons suggests that perceptual information and motor actions may share the same neural circuitry (Buccino et al., 2001; Gazzola & Keyser, 2009). Even more surprising is the evidence demonstrating that there are neurons sensitive to both actions and to the sounds that accompany, or that result from, the action itself (e.g., the sound produced when scratching a surface or tearing a piece of paper, see Kohler et al., 2002; see also Keyser et al., 2003). It is clear, then, that actions and the sounds elicited by those actions are processed together. It would be interesting to study whether sounds can not only be associated with actions/motor responses but also influence the dynamics of the response itself. The focus is on evaluating participants' hand movements via mouse tracking, given that they are a commonly used mode of responding (Barca & Pezzulo, 2015; Freeman, Dale, & Farmer, 2011). No previous study has used mouse tracking as a free movement response tool in order to evaluate how sensory information (in this case, sound) is spontaneously represented by people in terms of movement.

It is now more than 70 years since Karwoski, Odbert, and Osgood (1942) had their participants draw whatever was suggested by a series of 15-second pieces of music using coloured pencils. These researchers presented their participants with different clarinet compositions including gruppettos, staccatos, and glissandos, as well as some stimuli that consisted of just a crescendo or diminuendo on a single note. While the participants drew very different representations, certain commonalties were nevertheless still observed, such as relating the thickness of the lines drawn to the intensity of the sound. It seems the participants were trying to represent similar attributes (e.g., speed or intensity) but used different visual representations to do so. To our knowledge, this is the only study of its

kind to have attempted to and assess whether hand movements can be biased by the properties of sound. There is also evidence to suggest that ascending and descending tones can bias the interpretation of ambiguous (hard to predict) motion (Harris & Carnevale, 2016). The latter studies by Karwoski et al. and Harris and Carnevale suggest that sounds can be matched to visual information and represented using bodily movement.

The purpose of the present study was to determine whether tones and chords would bias the direction of hand movements. It was also of interest to determine whether those participants who are not asked to represent sound in terms of a spatial location are able to produce similar movements to those reported in the aforementioned literature. The experimental procedure presented in this study can further disentangle the semantic association between pitch and spatial location and could potentially help determine if other mechanisms facilitate these matches. While Rusconi et al. have already conducted a study that involved implicit measures (i.e. RTs); the instructions of the task were clearly explicit. Therefore, it is unclear whether sound and space are merely associated or whether sound can actually bias spatial localization. The present study continues the interesting work of the aforementioned authors and provides instructions that are more implicit. Specifically, the fact that the participants will be focused on drawing whatever comes to mind as they hear each sound and not focused on localizing could reduce the influence of any explicit associations.

There were three expectations regarding the present studies. First, it was expected that the major and minor chords presented to the participants would also bias their hand movements upwards and downwards, respectively. Second, Furthermore, it was of interest to study whether movement patterns would be influenced by how weak/strong, fast/slow, and by the valence that the participants associated with each sound. Third,

exploring whether the angle of motion could help elucidate some more complex movement patterns. In particular, whether it could help to determine there were any patterns across participants in how they graphically represented each or some of the sounds. Determining whether tones and chords spontaneously influence the direction of motion (i.e., the spatial location in which participants move their hand) can shed light on the implicitness of the associations between sounds and spatial location. If the participants are actually biased and move their hand toward a specific location on the screen, then it is possible that these associations are automatic and implicit. However, because most tasks so far have been of an explicit nature (i.e., asking participants to localize a sound spatially) it is not clear if these matches are always mediated by a semantic component or if they can occur without conscious awareness and are governed by more basic structural mechanisms. Additional research on how auditory information can influence movement may be relevant for sensorimotor learning in sports and neuropsychological rehabilitation.

In the context of sports there is already evidence that acoustic feedback can influence the timing and synchronicity of motor response (e.g., in rowing, see Schaffert, Mattes, & Effenberg, 2011). For instance, research shows that sound can help rowers improve their stroke (Harfield, Halkon, Mitchell, Phillips, & May, 2014; Schaffert & Mattes, 2015) and that auditory feedback providing real-time heart-rate information could potential enhance performance (Stahl & Thoshkahna, 2016). Bood, Nijssen, van der Kamp, and Roerdink (2013) have shown that coupling movement with specific songs or beats can also enhance the performance of an athlete. However most of the aforementioned research has focused on explicit cues to guide actions, the present study may further our understanding on how perception can implicitly bias movement patterns.

In neuropsychological rehabilitation there is already interesting work showing successful rehabilitation using audio-visual cues in hemianopia and spatial neglect (e.g., Bolgonini, Rasi, Coccia, & Làdavas, 2005; Frassinetti, Pavani, & Làdavas, 2002; see also Tinga et al., 2015, for a review on multisensory interventions after stroke). Given that the present study seeks to determine whether different sounds can be located in space spontaneously, our findings could be useful to validate existing procedures and perhaps develop more implicit cues to aid in the rehabilitation process of patients that have attentional or spatial neglect.

A.2. STUDY A1

A.2.1. Methods

Participants: Twenty-nine participants (15 males, M_{age} = 28.21 years, SD_{age} = 7.58, $range_{age}$ = 18-55 years) volunteered to take part in this study. They were invited to participate in the study via the Crossmodal Research Lab database. All of the participants signed a standard consent form; the study was reviewed and approved by the Central University Research Ethics Committee at the University of Oxford (MS-IDREC-C1-2015-218). All of the participants were right-handed by self-report. The study took approximately 15 minutes to complete, and the individuals received £5 in return for their participation.

Apparatus and materials: E-Prime 2.0 software (Psychology Software Tools, Inc.) and Mouse Tracker (MT) software (Freeman & Ambady, 2010) were used to present the stimuli, and to record the participants' responses. The participants sat in front of a 14"

LED monitor, with a screen resolution of 1024x768 pixels, and a screen refresh rate of 60 Hz. The mouse was located on a table and all of the participant's hand movements were executed in a horizontal plane. Signal Generator in Pro Tools 11 was used to generate the sine tones. EW Pianos Gold was used to generate the piano chords and tones. All chords were at -10dB per tone and the total sum of the three tones that made the triad was -3.5dB. Three tones were created by combining three frequencies which are made from the harmonic series of the fundamental: high (2000Hz - 3000Hz – 5000Hz); medium (1000Hz – 1500Hz – 2500Hz); and low pitch (80Hz – 120Hz – 200Hz). The major piano chord was generated using the notes A2, E3, and C#4. The minor chord was produced using the notes A2, E3, and C4. The tones and chords had equal duration and were presented for 1000 ms.

Given that the range of human hearing extends from 20Hz to 20 KHz (in the ideal case, i.e., without any hearing loss), the tones presented to the participants cover the complete range. The low-pitched tone starts two octaves above the lowest hearing range (20*2*2), which sets the lowest frequency at 80 Hz. The highest frequency of the high-pitched sound starts two octaves below the maximum hearing range (20000/2/2), which is 5000 Hz. Finally, given that the 5000Hz and 80Hz frequencies are not in the same octaves, the mid-pitched tone is set approximately two octaves below 5000Hz and three octaves above 80Hz. The piano chords are set from A 220; they are in open disposition, meaning the third is always the highest note, which facilitates their identification. What is more, the chords used in the present study are prototypical musical chords (i.e., they are commonly used in musical instruction).

Procedure: The participants were presented with two tasks. In one, they had to listen to each of the chords and tones and were instructed to move the mouse freely in any way and for as long as they considered appropriate in order to represent each of the sounds

that they heard. The participants could start moving as soon as they heard the sound and had to click the mouse to terminate the trial. Each of the five sounds was presented at random three times, giving rise to three blocks of trials (15 trials per participant). The participants could move their hand at stimulus onset and could not see what they were drawing, as only the mouse cursor was visible. The latter was located at the centre of the screen at the start of each trail. Hand movements were registered every 70ms; the latter sampling frequency is sufficient to study gross motor responses (see Freeman & Ambady, 2010). The participants could move until they had finished their "drawing" pattern, there was no time restriction. The maximum time registered was seven seconds; the total duration of each trial was divided into a maximum of 100 bins. In the second task, they were presented with a series of horizontal VA scales and were asked to rate the tones and chords in terms of how fast/slow, strong/weak, pleasant/unpleasant each of them was. The participants rated each of the sounds four times. The sounds and the scales were presented in a random order. The two tasks were counterbalanced across participants. The scales and the drawing task were presented separately so that the participants did not have fresh in their memory what they had scored or drawn. This helped control for the possibility that the participants would intuitively associate their responses on the two tasks.

Data analysis: The data in both tasks were analysed via high breakdown and high efficiency robust linear regression modelling (see Yohai, 1987) implemented in the 'lmRob' function in the 'robust' R package. For the rating data, the independent variables were participant (P) and sound (B) and were entered in this order. For the mouse-tracking task, the independent variables were participant (P), trial (T), sound (S), and bins (B) and were hierarchically entered in this order. Note that adding the covariate T, allowed us to account for any potential trial-by-trial effects. The dependent variables were the locations

in terms of X and Y coordinates and angle of hand displacements on the plane (mouse-tracking task) and the ratings of the tones and chords in terms of how fast/slow, strong/weak, pleasant/unpleasant each of them was (rating task). For each hierarchical model, the variability accounted for was estimated as R^2•100. The models' fits were compared via analysis of variance (ANOVA) and robustified *F*-tests (*Fr*). Shifting boxplots (Marmolejo-Ramos & Tian, 2010) were used to represent the distribution of specific results in both tasks and to help visualise comparisons of interest. The results of the mouse-tracking task were represented via three dimensional point clouds. The Agresti-Pendergast test (F_{AP}) implemented in the R function 'apanova' (see Wilcox, 2005) was used to compare dependent groups. Although pairwise comparisons can be graphically obtained by the degree of overlap between the confidence intervals shown in the boxplots, the percentile bootstrap method was used to confirm visual inspection and the *p*-values were adjusted via the sequentially rejective method (p_{srm}, see Wilcox, 2005, p. 313). The latter correction is achieved by setting the option 'hoch = FALSE' in the 'rmmcppb' R function.

A.2.2. Results

The results revealed that the participants produced consistent patterns of movement both for the tones and for the chords, as well as biases towards specific spatial locations when moving their hand in response to each of the sounds. Overall, there were minor changes in x-axis positions and no perceivable differences between the sound conditions (see Figure A.1). In contrast, the tones and chords had an effect on the spatial localization of the participants' drawings in the vertical axis of the computer screen (see Figure A.1).

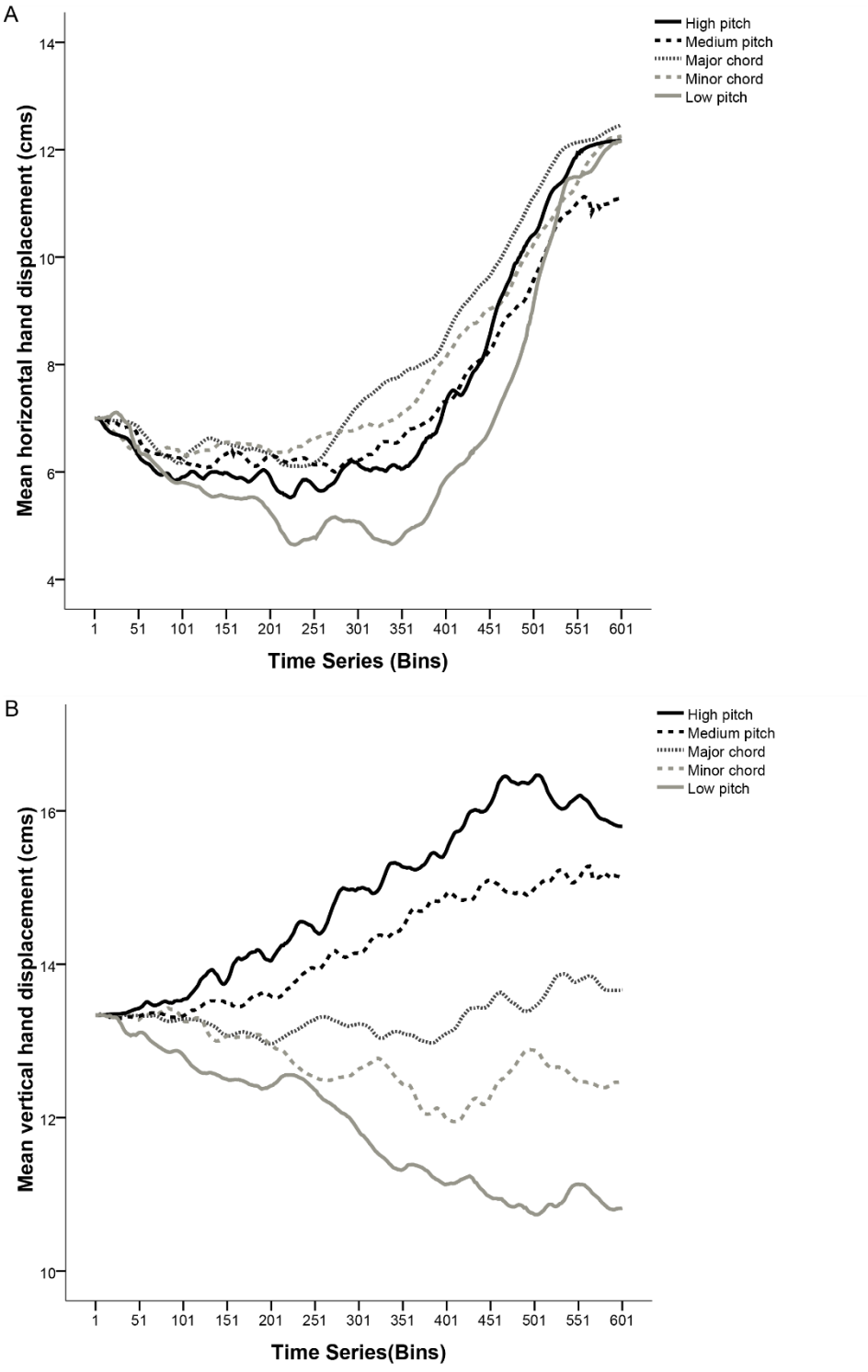


Figure A.1. Plots showing the average location of the hand (cm) across time bins (ms) in the horizontal (A) and vertical (B) axes of the computer screen in Study A1. Time bins were calculated by dividing the total time each participant took to draw each sound into 600 segments. Notice how the hand movements tend to move towards the right-hand side of the screen with no marked differences between the sound conditions. By contrast, vertical hand movements appear to be affected by the sound condition with higher (lower) pitched tones yielding more hand movements in the upper (lower) portion of the screen as time progressed during the trial.

Order effects were analysed using a Generalized Estimating Equations Model (hybrid estimation model and interchangeable matrix) by adding the previously presented sound (S-1) as an additional independent variable. The previous sound was not a significant predictor of the mean Y position of the current sound, Wald χ^2 (5) = 4.88, p = 0.43. The interaction between the previous and current sound in the y-axis was significant, Wald χ^2 (16) = 55.24, p < .001. Bonferroni corrected pairwise comparisons revealed that when the high-pitched sound was presented during the first trial; the values in the y-axis were overall higher in the following trials. However, the randomization algorithm of the Mouse Tracker Software only produced two trials that present the high-pitched sound in the first trial. The latter together with the fact that a *Fr* (i.e., a robust ANOVA, which is less sensitive to outliers) was used suggests that our results are not significantly influenced by the aforementioned two trials.

The variability accounted for by each model was 0.01% (P), 0.01% (P + T), 0.1% (P + T + S), and 0.6% (P + T + S + B). Hand movements in the x-axis displayed significant differences for the participants variable F_r = 10.20, p =.001, as well as when this variable was paired in the model with the trial and the sounds presented to the participants F_r = 11.98, p =.014. These results indicate that there were individual differences in the participants' horizontal hand movements and that the overall movement in the x-axis associated with the sounds showed some differences (see Figure A.1).

For the y-axis, the variability accounted for by each model was 0.001% (P), 0.003% (P + T), 0.17% (P + T + S), and 0.93% (P + T + S + B). A comparison of the models indicated there were significant displacements in the y-axis only when sound was added to the model (P + T + S): F_r = 25.90, p<.001 (see Figure A.1). The F_{AP} test showed that the means of the sounds differed significantly (F_{AP} (4, 35996) = 697.84, p < .0001). Only one

pairwise comparison failed to reach statistical significance, 'minor chord' vs. low pitch tone, $p_{srm} > .05$. The means and standard deviations (SD) of the sounds were $M_{major\ chord} = -0.18$, $SD = 2.84$; $M_{minor\ chord} = -0.71$ $SD = 3.02$; $M_{medium\text{-}pitch} = 0.53$, $SD = 3.91$; $M_{high\text{-}pitch} = 1.60$, $SD = 4.62$; $M_{low\text{-}pitch} = -1.60$, $SD = 3.73$. Overall, for the y-axis, the participants moved their hand more in the upper portion of the screen when presented with a high-pitch tone and produced more movements towards the bottom of the screen when presented with the low-pitched tone (see Figures A.2A and A.2C). The mid-pitched tone seemed to produce upper-middle movements (see Figure A.2B); while the major chord seems to have generated more hand movements in the upper part of the display as compared to the minor chord (see Figures A.2D and A.2E).

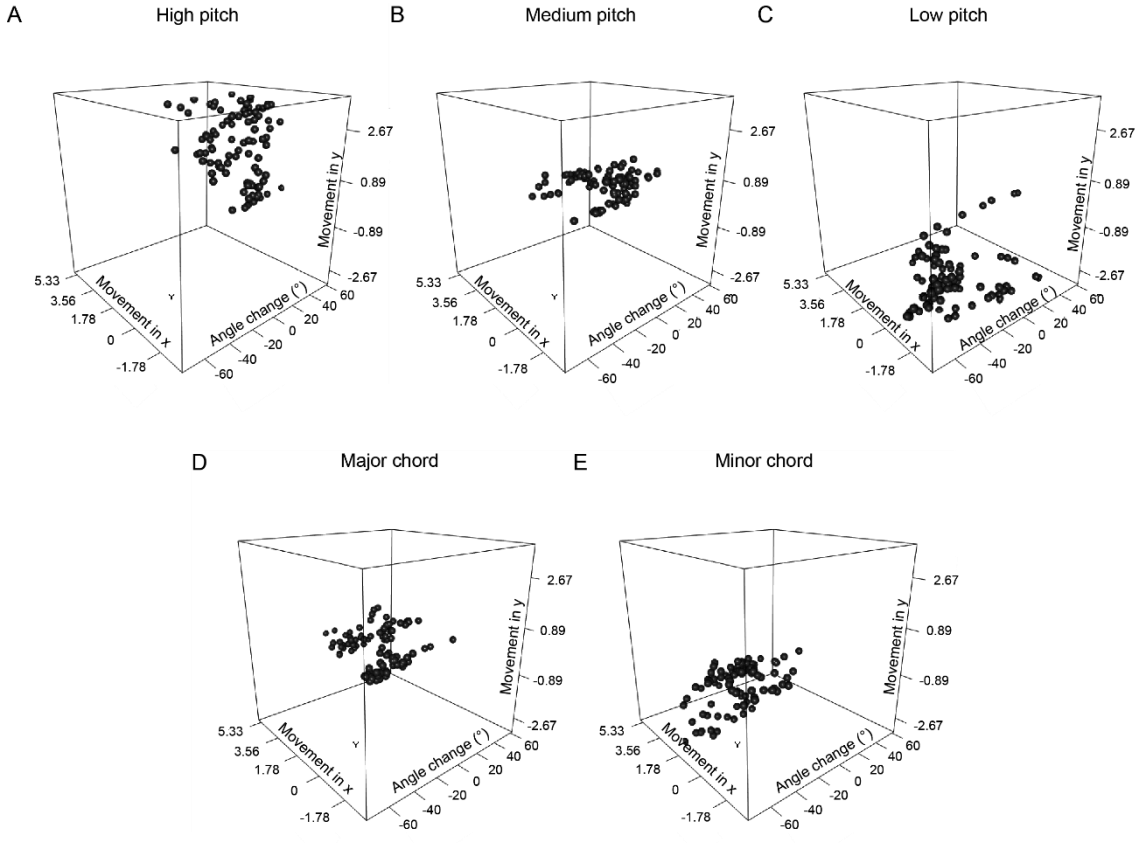


Figure A.2. Plots showing the mean location of the participant's hand in the horizontal (x) and vertical plane (y) of the computer screen, as well as the mean changes in the angle of movement (in degrees) for the (A) high frequency; (B) the mid frequency; (C) the low frequency; (D) the major chord; and (E) the minor chord in Study A1. The graph highlights the overall consistency of the responses made by participants. The different graphs also show that pitch has an influence on the vertical movements of the participant's hand (i.e., higher pitch is represented in the upper

portion of the plot and lower pitch toward the bottom). Finally, the tones yielded more changes in the direction (angle) of hand movements than chords.

The angle, which reflects the direction of the hand at a given point in time, also presented significant differences. The variability accounted for by each model was 0.14% (P), 0.19% (P + T), 3.58% (P + T + S), and 4.03% (P + T + S + B). A comparison of the models indicated significant effects of participants (P), trials (P + T), and sound (P + T + S) on 'angle': F_r = 18.87, p = .001, F_r = 5.65, p = .01, and F_r = 107.12, p <.001, respectively. The effect of the participant variable on the model reflects individual differences which are also manifested in terms of trial differences. The F_{AP} test showed that the means of the sounds differed significantly (F_{AP} (4, 35996) = 3306.59, p < .0001). All pairwise comparisons were significant at the level of p_{srm} < .001 ($M_{major\ chord}$ = -10.62, SD = 110.23; $M_{minor\ chord}$ = -33.55, SD = 104.57; $M_{medium\text{-}pitch}$ = 1.86, SD = 111.71; $M_{high\text{-}pitch}$ = 13.94, SD = 111.55; $M_{low\text{-}pitch}$ = -40.12, SD = 109.45, see also Figure A.2). Regarding the VA scales, sound had an effect on the slow-fast ratings, F_r = 57.75, p < .001 (the variability accounted for by each model was 0.71% - P - and 57.17% - P + S). Nine pairwise comparisons were significant when comparing the slow-fast ratings made by the participants (p_{srm} < .01, see Figure A.3). The only ratings that were not significant were 'major chord' ($M_{major\ chord}$ = 37.29, SD = 13.12) vs. 'minor chord' ($M_{minor\ chord}$ = 37.89, SD=13.31). The high frequency sound resulted in the highest ratings ($M_{high\text{-}pitch}$ = 75.67, SD=22.10) while the lower frequency gave rise to the lowest ratings ($M_{low\text{-}pitch}$ = 23.25, SD=17.75).

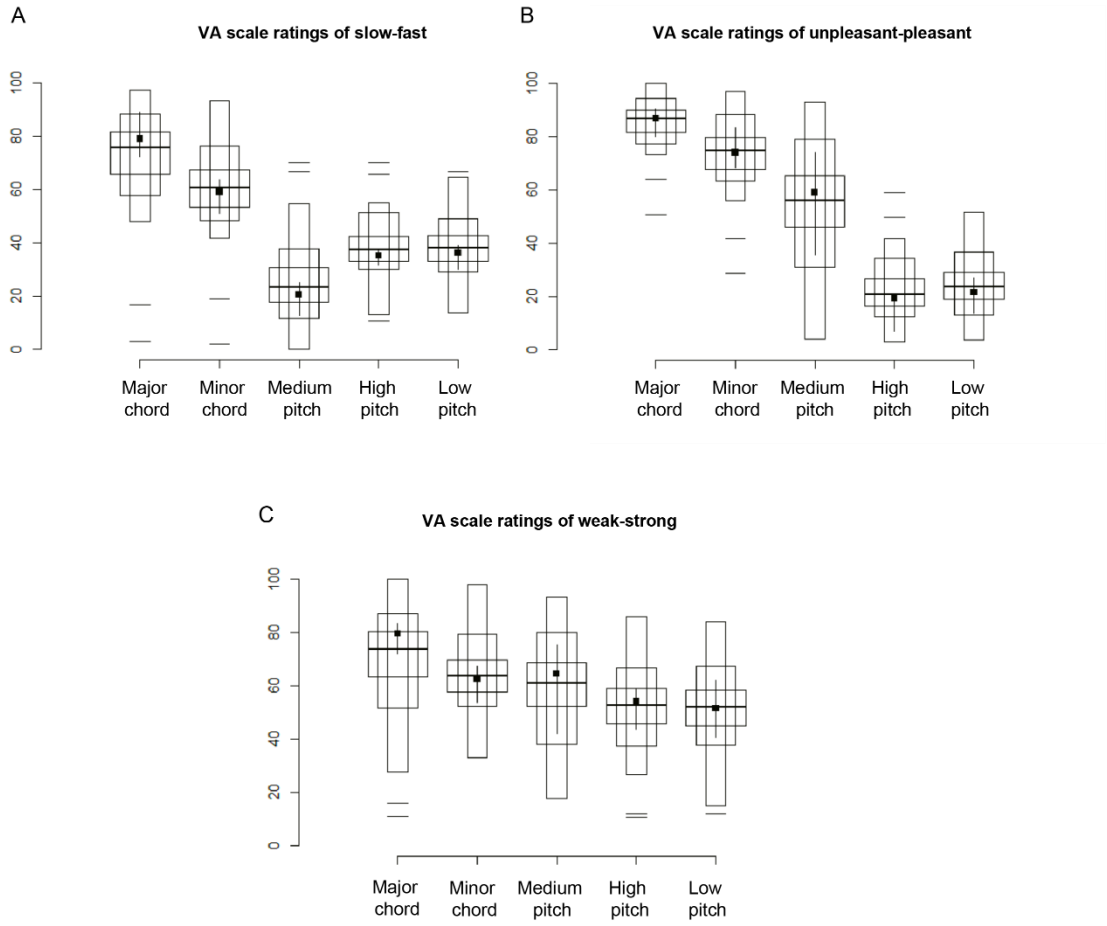


Figure A.3. Shifting boxplots presenting the mean ratings for each of the scales in terms of (A) the fast-slow VA scale; (B) the unpleasant-pleasant VA scale; and (C) the weak-strong VA scale in Study A1. VA = visual analogue. In this type of boxplot observations lying ± 2 *SD* beyond the mean are represented by dashes, observations between -2 and +2 *SD* are represented by the longest and thinnest box. Observations that fall between the mean of the first half of the data and the mean of the second half of the data are represented by the intermediate box. The middle thickest and longest horizontal line represents the mean of the data and its 95% bootstrap bias-corrected and accelerated confidence intervals (95% CI_{BCa}) are represented by the outermost box. The median and its 95% CI_{BCa} are represented by a solid small square and whiskers around it (see Marmolejo-Ramos & Tian, 2010, for details). The y-axis presents the VA scores for each scale and sound ranging from 0 to 100. Y-axis presents the mean scores for the VA scales ranging from 0 to 100. VA = visual analogue.

There were no significant effects for the weak-strong ratings, F_r = .43, p =.50 (P) and F_r = 7.61, p =.09 (P + S). The variability accounted for by each model was 0.34% (P) and 17.00% (P + S). Although a comparison of the models indicated that no factor had a significant effect on the 'weak-strong' ratings, 'sound' did have a marginal effect and the F_{AP} test revealed that the means for the various sounds differed significantly (F_{AP} (4, 112) = 6.53, p < .001). Five out of the ten pairwise comparisons revealed significant

differences; ‘major chord’ ($M_{major\ chord}$ = 52.55, *SD*=19.21) and F2000Hz ($M_{F2000Hz}$ = 73.56, *SD* = 23.35), ‘minor chord’ ($M_{minor\ chord}$ = 51.98, *SD*=18.75) and F2000Hz, F1000Hz ($M_{F1000Hz}$ = 63.51, *SD*=17.55) and F2000Hz, ‘major chord’ and F1000Hz, and F2000Hz and F80Hz (M_{F80Hz}=61.01, *SD*=23.71) were all significant, $p_{srm} < .01$ (see Figure A.3B).

The variability accounted for by the model for the unpleasant-pleasant ratings was 0.34% (P) and 69.13% (P + S). A comparison of the models indicated that only ‘sound’ (P + S) had significant effects on the ‘unpleasant-pleasant’ ratings: F_r = 78.22, $p < .001$. The effect of sound in the ratings is shown in Figure A.3C. The F_{AP} test showed that the means of the sounds differed significantly (F_{AP} (4, 112) = 50.82, $p < .0001$), such that all pairwise comparisons were significant ($p_{srm} < .01$). The means and SDs of the remaining sounds were $M_{major\ chord}$ = 20.68, *SD* = 13.81; $M_{minor\ chord}$ = 23.51, *SD* = 14.28; $M_{F1000Hz}$ = 74.58, *SD* = 16.30; $M_{F2000Hz}$ = 86.72, *SD* = 11.32; M_{F80Hz} = 55.84, *SD*=26.90.

In order to assess whether there were any correlations between the angle of motion and scores derived from the VA scales, the angle data was transformed into frequencies (number of changes per participant and per trial). Pearson correlations between changes in the angle of motion and the scores of the VA scales only revealed what seem to be spurious correlations (fast-slow: r = -0.18, $p < .05$; pleasant-unpleasant: r = 0.19, $p < .05$; weak-slow: no effect was found).

A.2.3. Discussion

The present study was designed to evaluate the spontaneous hand movements made by participants in response to each of five different sounds (i.e., high, medium, low pitch, major chord, and minor chord). VA ratings were also collected on three scales. Vertical

movements on the computer screen, as well as changes in the angle of movement, were influenced by the sounds that were presented. Specifically, the participants generated more hand movements in the upper portion of the screen when representing the high frequency sound in terms of their hand movements. By contrast, the lower frequency sound produced more hand movements toward the lower part of the screen. The sounds did not, however, seem to produce any significant effect on the horizontal axis that was not best explained simply by inter-subject variability. The angle measurement reflects the number of changes in direction and can be an indicator of the jaggedness of the participant's hand movements after hearing each sound. The participants produced the largest and smallest changes in the angle of movement when "drawing" the highest and lowest frequencies, respectively. This result suggests that the drawings associated with the high frequency sound gave rise to more jagged hand movements, whereas the lower frequency sound gave rise to less.

As revealed by these results, the high- and low-pitched sounds produced the greatest changes in the angle of motion. Plotting the hand movements made by the participants reveals an even more interesting relationship between the high-pitched and low-pitched tones, as well as between the minor chord and the angle of motion.

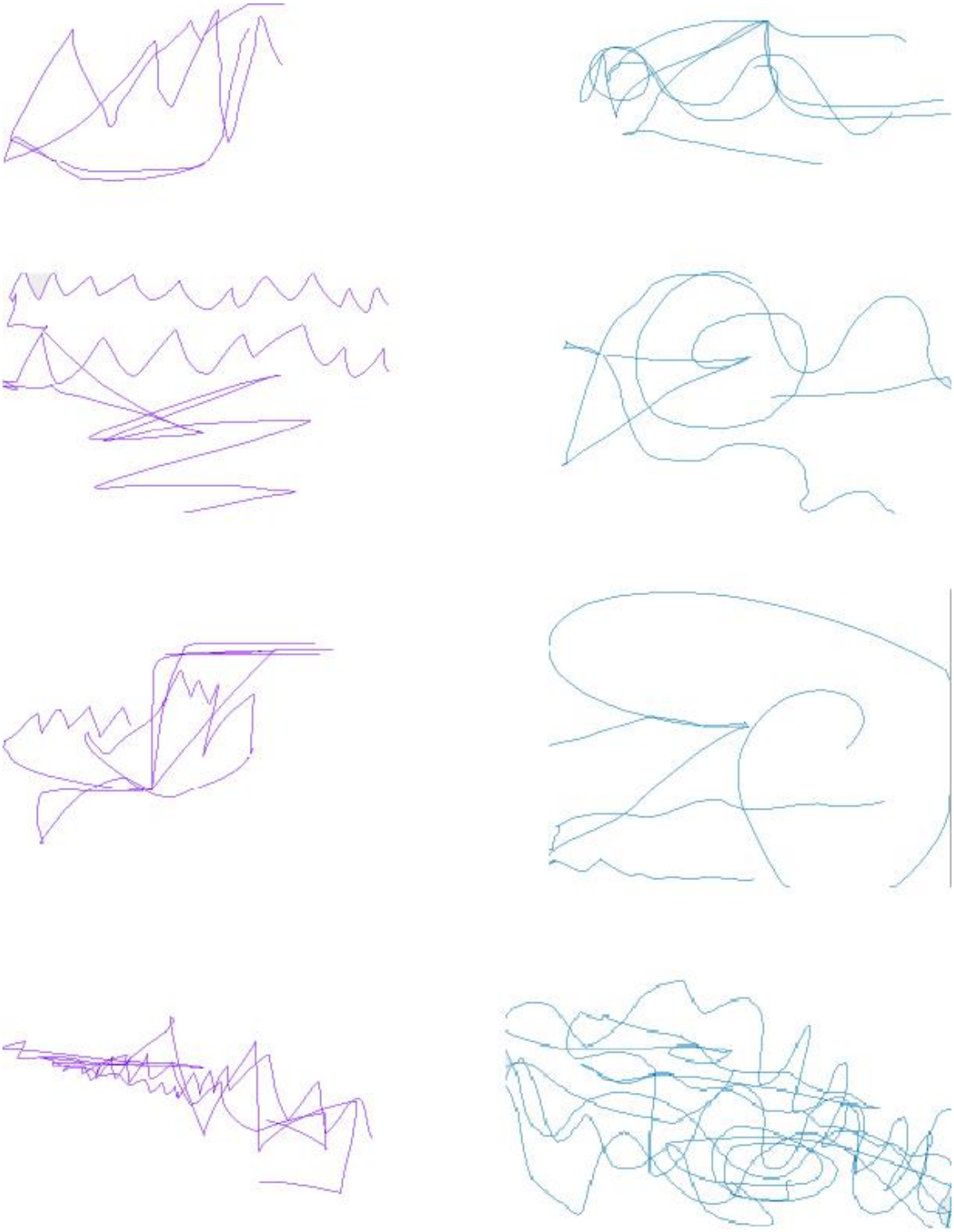


Figure A.4. Plots of some of the participants' hand movements after hearing a high-pitched tone (left-hand side), and either a low-pitched tone or a minor chord (right-hand side) in Studies A1 and A2. It can be seen that the high-pitched drawings are more jagged and angular whereas those drawings depicting low-pitched tones or minor chords tend to be rounder in form.

As can be observed in the examples in the previous figure (see Figure A.4), high-pitched sounds are jagged and, in general, more angular than low-pitched tones and minor chords. In fact, it seems that the low-pitched tone and the minor chord gave rise to rounder motion patterns. The number of spikes produced by the participants while moving their hands could be explained by the perceived complexity of each of the sounds. Sherman, Grabowecky, and Suzuki (2013) have demonstrated that more cluttered visual scenes are matched with faster auditory rhythms (i.e., faster amplitude modulation). The angle of motion, then, is an interesting candidate to further analyse how different sensory modalities can be represented using drawings or by means of visual information (e.g., shapes or lines). The patterns presented earlier (see Figure A.4) could become a plausible starting point to link auditory information to those studies focused on the crossmodal associations that have been documented between shapes and tastes (see Spence & Deroy, 2013, for a review). Though more research is needed in order to determine whether different frequencies are construed as more "complex", "dense", or "cluttered" or if other mechanisms explain why some sounds produced more jagged or rounded movements. Additionally, it is important to note that all of our participants were right-handed (by self-report). While it is possible that this could have influenced the right-sided tendency that we report, there is no reason to think that handedness would have an influence on vertical spatial orientation.

Concerning the VA scale scores, the 2000Hz sound consistently produced higher scores (i.e., it was rated as more pleasant and faster). In comparison, the 80Hz sound yielded scores that were significantly lower (i.e., it was rated as more unpleasant and slower). Given that the (2000Hz) sound produced higher valence ratings and was also rated as "faster" than the 80Hz sound, this may suggest that it is associated with a positive valence and perhaps with a high state of arousal. With the latter in mind, it is possible that

movement patterns could be influenced by emotional information (e.g., valence and arousal), which in turn supports the evidence showing that emotion and motor systems are interrelated (Holstege, 2013). The link between affective processing and spatial representation is also supported by work showing that the emotional valence of a sound can influence the perception of interpersonal distance (Tajadura-Jiménez, Pantelidou, Rebacz, Västfjäll, & Tsakiris, 2011), peripersonal space (Ferri, Tajadura-Jimenez, Väljamäe, Vastano, & Constantini, 2015), size (Meier, Robinson, & Caven, 2008; see also Tajadura-Jiménez, Larsson, Väljamäe, Västfjäll, & Kleiner, 2010), and spatial localization on the vertical axis (Meier & Robinson, 2004; Montoro, Contreras, Elosúa, & Marmolejo-Ramos, 2015; Sasaki, Yamada, & Miura, 2016).

One important thing to note about the results of Study A1 is that since the participants could observe the mouse cursor as they "drew" each sound, it is hard to disentangle the influence of visual and auditory perception in the mouse tracker task. In practical terms it is unlikely that sound could bias one without the other in the context of our task. It is possible that crossmodal associations between sound and spatial location are indeed a mechanism through which sound influences the direction of motion. Nevertheless, in order to determine whether the visual feedback from the screen and the fact that the mouse was placed in a horizontal plane had an effect in the responses made by the participants, a second study was conducted.

A.3. STUDY A2

In Study 2 the mouse was placed on a vertical plane and the participants were blindfolded throughout the study. We expected no change in the effects reported in Study A1 given that visual processing is an inherent part of spatial mapping and suggests that the

participants would have a visual image of space even if they are blindfolded (Thinius-Blanc & Gaunet, 1997).

A.3.1. Methods

Participants: Fifteen participants (9 females, M_{age} = 20.47 years, SD_{age} = 3.36, $range_{age}$ = 18-28 years) volunteered to take part in this study.

Apparatus and materials: A Logitech G600 MMO mouse (1000Hz response rate and 200dpi sensitivity) was placed on a vertical wooden board 100 cm. × 25 cm. The participants were blindfolded throughout the Study. A researcher helped each of the participants find the centre of the board after each trial and the computer reset the position of the mouse cursor at the beginning of each trial so that all the participants started exactly from the same position. All other conditions were the same as for Study A1.

A.3.2. Results

The variables for the statistical model were participant (P), trial (T), sound (S), and bins (B) and were entered hierarchically in the aforementioned order. The variability accounted for by the model in the x-axis was 0.19% (P), 0.21% (P + T), 0.72% (P + T + S), and 2.59% (P + T + S + B). Consistent with what had been found in Study A1, hand movements in the x-axis displayed significant differences for the "P" variable, F_r = 283.18, p < .001, when the "T" variable was entered, F_r = 7.82, p = .004, and when the variable "S" was added to the model, F_r = 199.9, p < .001. Robust one-way ANOVAs for dependent measures (via the Agresti-Pendergast test; F_{AP} test) revealed that mean hand location differed significantly according to the sound that was presented on each trial (F_{AP} (4, 95996) = 4332.16, p < .0001). Percentile bootstrap pairwise comparisons

showed that only the comparisons of 'major vs. medium-pitch' and 'medium-pitch vs. low-pitch' did not reach significance. Overall, hand movements in the x-axis in Studies A1 and A2 are very similar and show a slight rightward tendency. The means for the x-axis hover around 0.09, that is, close to the starting point in the centre of the screen.

For the y-axis, the variability accounted for by the model was 0.002% (P), 0.06% (P + T), 0.32% (P + T + S), and 1.17% (P + T + S + B). Hand movements in the y-axis displayed significant differences when the "T" variable (F_r = 92.35, p < .001) and the "S" variable (F_r = 91.05, p < .001) were added. Robust one-way ANOVAs for dependent measures (via the Agresti-Pendergast test; F_{AP} test) revealed that the mean location in the y-axis differed significantly (F_{AP} (4, 95996) = 3853.77, p < .0001). Percentile bootstrap pairwise comparisons revealed that all comparisons except for the 'minor chord vs. the low-pitch' frequency reached statistical significance. The low-pitch frequency produced the lowest mean position (M = 0.56, SD = 0.29), followed by the minor chord (M = 0.67, SD = 0.28). On average, hand movements were located in mid-portion of the screen when the major chord was presented (M = 0.77, SD = 0.27). Hand movements for medium- (M = 0.82, SD = 0.26) and high-pitched frequencies (M = 0.83, SD = 0.28) were located on average on the upper portion of the screen, with the high-pitched sound presenting, on average, a slightly higher position in the vertical plane.

A.3.3. Discussion

The results of Study A2 validate our initial findings showing that the effects reported here in terms of vertical spatial location persist regardless of whether the mouse is placed in a horizontal or vertical plane and even when the participants are blindfolded. What is more, it would, of course, be wrong to assume that if the participants are blindfolded they are

not able to form a mental image of the space their hand is moving on. There is evidence that even in blind patients the visual cortex is involved in the spatial mapping and that visual areas are activated during tasks that would appear to be solely spatial (Farah, Hammond, Levine, & Calvanio, 1988; Thinius-Blanc & Gaunet, 1997). The similarity between our findings in Studies 1 and 2 suggests that there does indeed seems to be some visuo-spatial reference regarding the position of the hand in space regardless of the presence/absence of direct visual feedback. It would be interesting to replicate our study in congenitally blind participants.

Our results are certainly consistent with the aforementioned literature that demonstrates that visual areas are involved in the coding of spatial information. An alternate view that was put-forward by Ricciardi et al. (2009) is that action representation systems are supramodal and can be adapted depending on the modality that is dominant or available (in this particular case sound, as there was no visual input). The latter study demonstrated that those systems involved in action imitation and understanding can develop in the absence of visual input (i.e., in blind individuals). The latter evidence may suggest that in sighted individuals, systems involved in action can still map actions into space using only auditory feedback. Nevertheless, the fact that there is no visual feedback does not necessarily imply the absence of mental imagery. Spence and Deroy (2012) have put forward the possibility that mental imagery can extend to other sensory modalities with varying degrees of vividness. The evidence that blind individuals can have mental imagery also seems to stack-up (see Bértolo, 2014; Cattaneo et al., 2008; De Volder et al., 2001; Lambert, Sampaio, Mauss, & Scheiber, 2004, for examples). After observing our results for Study 2, it is possible that mental imagery can be used as a tool to enhance the accuracy of motor responses and can help compensate when one sensory input (i.e., vision) is not available.

A.4. General Discussion

The results reported here confirm that despite the variations between the actual "drawings" that each participant made; tones and chords can bias hand movements and can be mapped in terms of specific spatial locations. What is more, the results of the present study demonstrate that the associations between pitch and spatial location can occur even in the absence of directed instructions to map each sound to a specific location. Moreover, the results of the VA scales may suggest that the valence of the stimulus can influence spatial location. Our results are consistent with findings suggesting that the valence attributed to an action can influence action perception (Wilke, Synofzik, & Lindner, 2012). The latter emphasises that affective information can play an important role in action planning. Hence, the aforementioned mechanisms (i.e., affective and embodied) should not be viewed as mutually exclusive but rather as a compound system that facilitates the matching of auditory information to a location in space. Our study further contributes to the growing literature that at least some crossmodal correspondences are likely to be mediated, at least to a degree, by the valence of the stimulus (see Palmer, Schloss, Xu, & Prado-León, 2013; Salgado-Montejo et al., 2015; Velasco, Woods, Deroy, & Spence, 2014, for examples).

Furthermore, this study strengthens Parise et al.'s (2014) claim suggesting that embodied cognition plays a role in how sounds and spatial locations are associated with each other. The findings presented here underscore the notion that the body aids in the matching of sensory information across different sensory modalities. Embodied cognition, then, could be an interesting mechanism to expand our understanding of crossmodal correspondences from the domain of perception, where it has been mostly studied to date (see Spence, 2011, for a review), through to the world of action. More research is clearly needed in order to determine whether the biases caused by tones and chords that are reported here

are caused by relative or absolute pitch. Research that does not prime the participants into thinking about space may shed light onto whether it is relative or absolute pitch that facilitates the associations reported between space and sound.

The growing body of evidence highlighting the existence of neurons sensitive to both perceptual and motor information underscores the relationship between sensory information and action. Moreover, the link between action and perception seems to be inherently crossmodal, underscoring the importance of studying other senses aside from vision. Indeed, Aglioti and Pazzaglia (2010) have stressed the fact that studies evaluating the multisensory nature of action preparation and organization are scarce. What is more, these researchers also highlight how experience can influence perception and action, and perhaps even how perceptual information is utilised to guide motor responses.

As was demonstrated by Maeda et al. (2004), auditory information can influence how participants perceive the direction of a moving object. Moreover, the results presented here are aligned with the notion that sensory experience can influence and inform motor responses. For example, the pitch of a sound could help prepare for head turns or eye gaze shifts towards the most likely location of the object that is generating the sound. These basic relationships between motor and sensory systems could then give rise to more complex interactions that allow the brain to interpret sensory information in terms of actions. Furthermore, understanding how different senses are involved in the planning and execution of motor responses could shed new light on the multisensory nature of action. For example, transforming auditory spatial maps into visual coordinates which, in turn, direct eye movements (see Arnott & Alain, 2011; Heffner & Heffner, 1992a, b), and finally produce a path for an organized reaching movement is altogether a multisensory process.

According to the forward model theory, information derived from sensorimotor systems possess an inherent delay (i.e., from the afferent fibres that carry sensory information to the brain and from the muscles that execute the motor commands generated by the brain). The latter delay causes our brain to "live in the past" (Franklin & Wolpert, 2011, p. 426, see also Dimitriou, Wolpert, & Franklin, 2013) and presents a fundamental challenge as to how to accurately respond in the present. Hence, throughout evolution, it was necessary to develop predictive models in order for the brain to be able to compensate any delays in the processing of sensory information or in the execution of motor commands; this is known as a forward model (Wolpert & Flanagan, 2001). Another way of thinking about this phenomenon is that a forward model can take into account the current state of a body part (e.g., a limb or the head), the velocity and acceleration that will be generated during the movement (transition state), and the final state of the body-part after the motor command has ended. In addition, forward models may also be involved in distinguishing between sensory information generated by external cues (i.e., information derived from the world around us) and produced by our own movement (see Miall & Wolpert, 1996, for a discussion of forward models and their relevance). There is already evidence to show that actions and action preparation have an influence on sensory processing (Press, Gherri, Heyes, & Eimer, 2009), while our study shows that sensory information can be involved in action preparation.

The challenge now is, on the one hand, to understand motor processes not as a final output but as part of the process of understanding actions, sensory information, and perhaps even as a facilitator of sensory integration. Zajonc and Marcus (1984, see also Niedenthal et al., 2010) have already underscored the importance of motor processes in cognitive representations and were part of what they referred to as the "hard" interface of cognition. It is not implausible, then, to assume that sensory information may have a motor correlate

and that any relationship that exists is bidirectional. If the latter were to be true, then it might be expected that sensory information from different modalities could modify motor expression in interesting ways.

So far, in the context of sports, there has been a steady focus on how sounds can explicitly influence motor responses. There is, for example, research showing that sounds can help synchronize actions (e.g., rowing) and make them more effective (Schaffert et al., 2011; Schaffert & Mattes, 2015, see also Sigrist, Rauter, Marchal-Crespo, Riener, & Wolf, 2015). The present study shows sounds can also bias the direction of motion even in the absence of explicit instructions and could therefore potentially be used to prepare athletes or influence their performance. Given that we found a hierarchical organization of the sounds that were presented to the participants, it would be possible to create graded responses to different spatial locations. More research is needed to integrate our findings to the context of sports. The spatial organization reported in the present study could also be used to rehabilitate those patients that have suffered some loss in spatial navigation (e.g., stroke patients, see Tinga et al., 2015). For example, tones and chords could be presented to patients while performing spatial tasks to facilitate spatial mapping.

Crossmodal correspondences between sounds and movement may also open up some interesting possibilities for the understanding of music as more than just a "sonic event" (Bergeron & Lopes, 2009). For one, we know that body movements can influence auditory processing (Phillips-Silver & Trainor, 2005, 2007). The latter studies suggest that movement is intrinsically associated with how we understand sound. Furthermore, there is evidence to show the importance of visual information and actions in the perception of sounds (i.e., from gestures, to the movements when conducting an orchestra, see Vuoskoski, Thompson, Clarke, & Spence, 2014; Vuoskoski, Spence, Thompson, & Clarke, in press). In the end, the same mechanisms that facilitate our

understanding of sound and its representation via movement could also be involved in defining how we express and produce music. Evidence from mirror neuron studies suggest that brain areas involved in action generation are also involved in action understanding. The movement produced while playing music (or signing) may be as important to the experience as the sound that is being produced. The bodily expressions that accompany the production of sounds can actually correspond to the structure of sound (e.g., its strength or speed, see Cesar et al., 2014; Stern, 2010). Hence, it would seem that the understanding of music as it unfolds is intimately tied to its production; something like a circular event where production and understanding need each other to exist.

The present study, demonstrating that auditory information can influence action (i.e., the direction of motion and spatial location), is also relevant to understanding how people produce music. As suggested by Zatorre, Chen, and Penhune (2007), the production of music requires, among other things, timing, sequencing, and the spatial organization of movement. It is possible that the movement biases reported here could be tied to the same mechanisms that facilitate spatial organization in the production of music. After all, notes are spatially grouped according to their frequency in many instruments.

Finally, the possibility that sound-space correspondences could influence the direction of motion requires further research and offers new and interesting potential applications for audiovisual correspondences. For example, in directing gaze and affordances in consumer behaviour, guiding motor actions to prevent driving accidents, and in therapies seeking to rehabilitate those patients who have suffered a stroke and have some degree of motor impairment.

REFERENCES

Aglioti, S. M., & Pazzaglia, M. (2010). Representing actions through their sound. *Experimental Brain Research*, *206*, 141-151.

Arnott, S. R., & Alain, C. (2011). The auditory dorsal pathway: Orienting vision. *Neuroscience and Biobehavioral Reviews*, *35*, 2162-2173.

Bakker, D. R., & Martin, F. H. (2014). Musical chords and emotion: Major and minor triads are processed for emotion. *Cognitive, Affective & Behavioral Neuroscience*, *15*, 15-31.

Barca, L., & Pezzulo, G. (2015). Tracking second thoughts: Continuous and discrete revision processes during visual lexical decision. *PLoS ONE*, *10*, e0116193.

Bergeron, V., & Lopes, D. (2009). Hearing and seeing musical expression. *Philosophy and Phenomenological Research*, *78*, 1-16.

Bértolo, H. (2014). Visual imagery without visual perception: lessons from blind subjects. In M. F. P. C. Martins Costa & R. N. Nogueira (Eds.), *Second International Conference on Applications of Optics and Photonics* (p. 92862K). International Society for Optics and Photonics.

Bolognini, N., Rasi, F., Coccia, M., & Làdavas, E. (2005). Visual search improvement in hemianopic patients after audio-visual stimulation. *Brain*, *128*, 2830-2842.

Bood, R. J., Nijssen, M., van der Kamp, J., & Roerdink, M. (2013). The power of auditory-motor synchronization in sports: Enhancing running performance by coupling cadence with the right beats. *PLoS ONE*, *8*; e70758.

Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., Seitz, R. J., Zilles, K., Rizzolatti, G., & Freund, H. J. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: An fMRI study. *European Journal of Neuroscience*, *13*, 400-404.

Cattaneo, Z., Vecchi, T., Cornoldi, C., Mammarella, I., Bonino, D., Ricciardi, E., & Pietrini, P. (2008). Imagery and spatial processes in blindness and visual impairment. *Neuroscience and Biobehavioral Reviews, 32,* 1346-1360.

Chaffin, D. B., Andersson, G., & Martin, B. J. (2006). *Occupational biomechanics*. Hoboken, NJ: Wiley-Interscience.

D'Ausilio, A., Brunetti, R., Delogu, F., Santonico, C., & Belardinelli, M. O. (2010). How and when auditory action effects impair motor performance. *Experimental Brain Research, 201,* 323-330.

DeChaine, D. R. (2002). Affect and embodied understanding in musical experience. *Text and Performance Quarterly, 22,* 79-98.

Deroy, O., Fernandez-Prieto, I., Navarra, J., & Spence, C. (in press). Unravelling the paradox of spatial pitch. To appear in T. L. Hubbard (Eds.), *Spatial biases in perception and cognition*. Cambridge, UK: Cambridge University Press.

De Volder, A. G., Toyama, H., Kimura, Y., Kiyosawa, M., Nakano, H., Vanlierde, A, Wanet-Defalque, M. C., Mishina, M., Oda, K., Ishiwata, K., Senda, M. (2001). Auditory triggered mental imagery of shape involves visual association areas in early blind humans. *Neuroimage, 14,* 129-139.

Dimitriou, M., Wolpert, D. M., & Franklin, D. W. (2013). The temporal evolution of feedback gains rapidly update to task demands. *Journal of Neuroscience, 33,* 10898-10909.

Evans, K. K., & Treisman, A. (2010). Natural cross-modal mappings between visual and auditory features. *Journal of Vision, 10,* 1-12.

Farah, M. J., Hammond, K. M., Levine, D. N., & Calvanio, R. (1988). Visual and spatial mental imagery: Dissociable systems of representation. *Cognitive Psychology, 20,* 439-462.

Ferri, F., Tajadura-Jiménez, A., Väljamäe, A., Vastano, R., & Costantini, M. (2015). Emotion-inducing approaching sounds shape the boundaries of multisensory peripersonal space. *Neuropsychologia, 70*, 468-475.

Franklin, D. W., & Wolpert, D. M. (2011). Computational mechanisms of sensorimotor control. *Neuron, 72*, 425-442.

Frassinetti, F., Pavani, F., Làdavas, E. (2002). Acoustical vision of neglected stimuli: Interaction among spatially converging audiovisual inputs in neglect patients. *Journal of Cognitive Neuroscience, 14*, 62-69.

Freeman, J. B., & Ambady, N. (2010). MouseTracker: Software for studying real-time mental processing using a computer mouse-tracking method. *Behavior Research Methods, 42*, 226-241.

Freeman, J. B., Dale, R., & Farmer, T. A. (2011). Hand in motion reveals mind in motion. *Frontiers in Psychology, 2*:59.

Gazzola, V., & Keysers, C. (2009). The observation and execution of actions share motor and somatosensory voxels in all tested subjects: Single-subject analyses of unsmoothed fMRI data. *Cerebral Cortex, 19*, 1239-1255.

Harfield, P., Halkon, B., Mitchell, S., Phillips, I., & May, A. (2014). A novel, real-time biomechanical feedback system for use in rowing. *Procedia Engineering, 72*, 126-131.

Harris, L. R., & Carnevale, M. J. (2016). Which direction is up for a high pitch? *Multisensory Research, 29*, 113-132.

Heffner, R. S., & Heffner, H. E. (1992a). Evolution of sound localization in mammals. In D. B. Webster, R. R. Fay, & A. N. Popper (Eds.), *The evolutionary biology of hearing* (pp. 691-715). New York, NY: Springer-Verlag.

Heffner, R. S., & Heffner, H. E. (1992b). Visual factors in sound localization in mammals. *Journal of Comparative Neurology*, *317*, 219-232.

Henriques, J. (2003). Sonic dominance and the reggae sound system session. In M. Bull & L. Black (Eds.), *The auditory culture reader* (pp. 451-480). Oxford, UK: Berg.

Holstege, G., & Huynh, H. K. (2013). Emotions studied by imaging of the human brain: The somatic and emotional motor systems. In D. W. Pfaff (Ed.), *Neuroscience in the 21st century: From basic to clinical* (pp. 2045-2068). New York, NY: Springer.

Karwoski, T. F., Odbert, H. S., & Osgood, C. E. (1942). Studies in synesthetic thinking: II. The role of form in visual responses to music. *Journal of General Psychology*, *26*, 199-222.

Keysers, C., Kohler, E., Umilta, M. A., Nanetti, L., Fogassi, L., & Gallese, V. (2003). Audiovisual mirror neurons and action recognition. *Experimental Brain Research*, *153*, 628-636.

King, A. J., Schnupp, J. W. H., & Doubell, T. P. (2001). The shape of ears to come: Dynamic coding of auditory space. *Trends in Cognitive Sciences*, *5*, 261-270.

Kohler, E., Keysers, C., Umiltà, M. A., Fogassi, L., Gallese, V., & Rizzolatti, G. (2002). Hearing sounds, understanding actions: Action representation in mirror neurons. *Science*, *297*, 846-848.

Lambert, S., Sampaio, E., Mauss, Y., & Scheiber, C. (2004). Blindness and brain plasticity: Contribution of mental imagery? An fMRI study. *Cognitive Brain Research*, *20*, 1-11.

Maeda, F., Kanai, R., & Shimojo, S. (2004). Changing pitch induced visual motion illusion. *Current Biology*, *14*, R990-R991.

Maga, J. A. (1974). Influence of color on taste thresholds. *Chemical Senses and Flavor*, *1*, 115-119.

Makous, J. C., Friedman, R. M., & Vierck, C. J. (1995). A critical band filter in touch. *The Journal of Neuroscience, 15,* 2808-2818.

Marmolejo-Ramos, F., & Tian, U. (2010). A simple method for the detection of outliers. *Electronic Journal of Applied Statistical Analysis*, *2*, 67-76.

Meier, B. P., & Robinson, M. D. (2004). Why the sunny side is up: Associations between affect and vertical position. *Psychological Science*, *15*, 243-247.

Meier, B. P., Robinson, M. D., & Caven, A. J. (2008). Why a Big Mac is good Mac: Associations between affect and size. *Basic and Applied Social Psychology*, *30,* 46-55.

Melara, R. D., & O'Brien, T. P. (1987). Interaction between synesthetically corresponding dimensions. *Journal of Experimental Psychology: General*, *116*, 323-336.

Miall, R. C., & Wolpert, D. M. (1996). Forward models for physiological motor control. *Neural Networks*, *9*, 1265-1279.

Montoro, P., Contreras, M. J., Elosúa, M. J., & Marmolejo-Ramos, F. (2015). Cross-modal metaphorical mapping of spoken emotion words onto vertical space. *Frontiers in Psychology, 6*:1205.

Mudd, S. A. (1963). Spatial stereotypes of four dimensions of pure tone. *Journal of Experimental Psychology, 66,* 347-352.

Niedenthal, P. M., Augustinova, M., & Rychlowska, M. (2010). Body and mind: Zajonc's (re)introduction of the motor system to emotion and cognition. *Emotion Review, 2,* 340-347.

Palmer, S. E., Schloss, K. B., Xu, Z., & Prado-León, L. R. (2013). Music-color associations are mediated by emotion. *Proceedings of the National Academy of Sciences of the United States of America, 110,* 8836-8841.

Parise, C. V. (2016). Crossmodal correspondences: Standing issues and experimental guidelines. *Multisensory Research, 29,* 7-28.

Parise, C. V, Knorre, K., & Ernst, M. O. (2014). Natural auditory scene statistics shapes human spatial hearing. *Proceedings of the National Academy of Sciences of the United States of America, 111,* 6104-6108.

Parise, C., Spence, C., & Deroy, O. (2015). Understanding the correspondences: Introduction to the special issue on crossmodal correspondences. *Multisensory Research, 29,* 1-6.

Parker, B. (2009). *Good vibrations: The physics of music*. Baltimore, MD: John Hopkins University Press.

Penfield, W., & Rasmussen, T. (1950). *The cerebral cortex of man*. New York, NY: MacMillan.

Phillips-Silver, J., & Trainor, L. J. (2005). Feeling the beat: Movement influences infants' rhythm perception. *Science, 308,* 1430.

Phillips-Silver, J., & Trainor, L. J. (2007). Hearing what the body feels: Auditory encoding of rhythmic movement. *Cognition, 105,* 533-546.

Pratt, C. C. (1930). The spatial character of high and low tones. *Journal of Experimental Psychology, 13,* 278-285.

Press, C., Gherri, E., Heyes, C., & Eimer, M. (2009). Action preparation helps and hinders perception of action. *Journal of Cognitive Neuroscience, 22,* 2198-2211.

Rigas, D., & Alty, J. (2005). The rising pitch metaphor: An empirical study. *International Journal of Human-Computer Studies, 62,* 1-20.

Rusconi, E., Kwan, B., Giordano, B. L., Umiltà, C., & Butterworth, B. (2006). Spatial representation of pitch height: The SMARC effect. *Cognition, 99,* 113-129.

Salgado-Montejo, A., Alvarado, J. A., Velasco, C., Salgado, C. J., Hasse, K., & Spence, C. (2015). The sweetest thing: The influence of angularity, symmetry, and the number of elements on shape-taste matches. *Frontiers in Psychology, 6:*1382.

Sasaki, K., Yamada, Y., & Miura, K. (2016). Emotion biases voluntary vertical action only with visible cues. *Acta Psychologica, 163,* 97-106.

Schaffert, N., & Mattes, K. (2015). Effects of acoustic feedback training in elite-standard para-rowing. *Journal of Sports Sciences, 33,* 411-418.

Schaffert, N., & Mattes, K. (2015). Interactive sonification in rowing: Acoustic feedback for on-water training. *IEEE MultiMedia, 22,* 58-67.

Schaffert, N., Mattes, K., & Effenberg, A. O. (2011). An investigation of online acoustic information for elite rowers in on-water training conditions. *Journal of Human Sport and Exercise, 6,* 392-405.

Sherman, A., Grabowecky, M., & Suzuki, S. (2013). Auditory rhythms are systemically associated with spatial-frequency and density information in visual scenes. *Psychonomic Bulletin & Review, 20,* 740-746.

Sigrist, R., Rauter, G., Marchal-Crespo, L., Riener, R., & Wolf, P. (2014). Sonification and haptic feedback in addition to visual feedback enhances complex motor task learning. *Experimental Brain Research, 233,* 909-925.

Spence, C. (2011). Crossmodal correspondences: A tutorial review. *Attention, Perception & Psychophysics, 73,* 971-995.

Spence, C., & Deroy, O. (2013). Crossmodal mental imagery. In S. Lacey & R. Lawson (Eds.), *Multisensory Imagery* (pp. 157-183). New York, NY: Springer.

Spence, C., & Deroy, O. (2013). Taste and shapes: A review of four hypotheses. *Historia Scientiae, 25,* 42-49.

Stahl, B., & Thoshkahna, B. (2016). Design and evaluation of the effectiveness of a sonification technique for real time heart-rate data. *Journal on Multimodal User Interfaces, 10*, 207-219.

Stumpf, K. (1883). *Tonpsychologie [Psychology of tones]*. Leipzig: S. Hirzel.

Tajadura-Jiménez, A., Larsson, P., Väljamäe, A., Västfjäll, D., & Kleiner, M. (2010). When room size matters: Acoustic influences on emotional responses to sounds. *Emotion, 10*, 416-442.

Tajadura-Jiménez, A., Pantelidou, G., Rebacz, P., Västfjäll, D., & Tsakiris, M. (2011). I-space: The effects of emotional valence and source of music on interpersonal distance. *PLoS One, 6*:e26083.

Thinus-Blanc, C., & Gaunet, F. (1997). Representation of space in blind persons: Vision as a spatial sense? *Psychological Bulletin, 121*, 20-42.

Tinga, A. M., Visser-Meily, J. M. A., van der Smagt, M. J., van der Stigchel, S., van Ee, R., & Nijboer, T. C. W. (2015). Multisensory stimulation to improve low- and higher-level sensory deficits after stroke: A systematic review. *Neuropsychology Review*, 26, 73-91.

Treitler, L. (1982). The early history of music writing in the West. *Journal of the American Musicological Society, 35*, 237-279.

Velasco, C., Woods, A. T., Deroy, O., & Spence, C. (2015). Hedonic mediation of the crossmodal correspondence between taste and shape. *Food Quality and Preference, 41*, 151-158.

Vuokowski, J., Spence, C., Thompson, M., & Clarke, E. F. (2016). Interaction of sight and sound in the perception and experience of musical performance. *Music Psychology, 33*, 457-471.

Vuoskoski, J. K., Thompson, M. R., Clarke, E. F., & Spence, C. (2014). Crossmodal interactions in the perception of expressivity in musical performance. *Attention, Perception & Psychophysics*, *76*, 591-604.

Watson, L. (1971). *The omnivorous ape*. New York, NY: Coward, McCann, & Geohhegan.

Wilcox, R. R. (2005). *Introduction to robust estimation and hypothesis testing*. San Diego, CA: Elsevier.

Wilke, C., Synofzik, M., & Lindner, A. (2012). The valence of action outcomes modulates the perception of one's actions. *Consciousness and Cognition*, *21*, 18-29.

Wolpert, D. M., & Flanagan, J. R. (2001). Motor prediction. *Current Biology*, *11*, R729-R732.

Yohai, V. (1987). High breakdown-point and high efficiency estimates for regression. *Annals of Statistics, 15*, 642-656.

Zajonc, R. B., & Markus, H. (1984). Affect and cognition: The hard interface. In C. Izard, J. Kagan, & R. B. Zajonc (Eds.), *Emotion, cognition, and behavior* (pp. 73-102). Cambridge, UK: Cambridge University Press.

Zajonc, R. B., Pietromonaco, P., & Bargh, J. (1982). Independence and interaction of affect and cognition. In M. S. Clark & S. T. Fiske (Eds.), *Affect and cognition: The seventeenth annual Carnegie symposium on cognition* (pp. 211-228). Hillsdale, NJ: Erlbaum.