Colour–taste correspondences: Designing food experiences to meet expectations or to surprise

Carlos Velasco, Imagineering Institute and University of Oxford

Charles Michel, University of Oxford

Jozef Youssef, Kitchen Theory

Xavier Gamez, Xavier 260

Adrian David Cheok, Imagineering Institute and City University. London

Charles Spence, University of Oxford

Abstract

Recent research demonstrates the existence of a number of surprising associations (otherwise known as crossmodal correspondences) between seemingly non-related features in different sensory modalities, such as between basic tastes and colours. These correspondences have been incorporated into a dish called 'The Four Tastes' by chef Jozef Youssef. The dish is presented with four separate elements, each having a distinctive colour. Diners are instructed to match the colour to the appropriate taste (bitter, sweet, salty and sour). After establishing the association, the modernist chef, molecular mixologist, food designer or culinary artist can then either choose to design tasting experiences that align with these crossmodal correspondences or else play against them (to create incongruency and surprise). The former strategy typically leads to increased liking, possibly as a result of the diner being able to process the sensory information more fluently. The latter, by contrast, can elicit disconfirmed

expectations, which can result in positive or negative experiences. While surprise is something that a growing number of diners are coming to expect when they visit a modernist restaurant, it tends to be a much harder approach to implement successfully in other contexts. Here, we present the literature on colour/taste correspondences, and discuss the implications of crossmodal (in)congruence in food design.

Keywords

colour

taste

vision

crossmodal correspondences

experimental experiential dining

expectations

food design

experience design

1. Introduction

Crossmodal correspondences (see Spence 2011, 2012, for reviews) are defined as the often surprising associations that people share between seemingly unrelated features, attributes or dimensions (e.g., polar dimensions; Gardner 1974; Proctor and Cho 2006) either physically present, or merely imagined, in different sensory modalities. So, for example, people match higher-pitched sounds with higher elevations in space (e.g., Parise et al. 2014; Stumpf 1883), or basic tastes with the curvilinearity of shapes, typically shown visually (Velasco et al. 2015a). Moreover, people will reliably match certain colours with specific pieces of music (this correspondence possibly based on a common affect evoked by both colours and music, see Palmer et al. 2013). They have even been shown to attribute speed to fruits – 'Just ask yourself which is faster, a lemon or a prune?' (Woods et al. 2013, evaluated the lemon/fast association).

One of the crossmodal correspondences that have intrigued both chefs and food companies alike in recent years is the surprising associations that many people seem to make between colours and tastes (see Spence et al. 2015, for a review). Here, it is important to note that we are not necessarily talking about semantic (e.g., between a ripe tomato and the colour red, e.g., Brunel et al. 2015; Velasco et al. 2015c) but rather about more abstract associations. As such, crossmodal correspondences are often a little harder to pin down in terms of there being a specific prototypical stimulus or an object out there in the environment (Deroy and Spence 2016) that embodies both the colour and the taste that people say correspond to one another. To date, the available research suggests that some of these crossmodal correspondences are broadly consistent across individuals, both within and across different cultures (at least within the few cultures that have been tested Spence et al. 2010) and across the decades (see Spence et al. 2015).

In this article, we evaluate the role of taste/colour correspondences in the context of food design. This article is divided into two main sections. In the first part, we introduce one of the ways in which colour/taste correspondences have been incorporated into the design of a specific dish by a chef. We also report the latest data from different countries assessing such correspondences in food-related settings. In particular, we present the results of two dining events, one conducted in Mexico and the other in Brazil, and a large-scale study conducted at the Science Museum in London. The results of these kinds of studies may provide inspiration for culinary artists and food experience designers. In the second part, we move on to critically evaluate the role of colour/taste congruency and the potential outcomes of congruent vs incongruent food-related colour/taste manipulations in various food-related contexts. We conclude with some general thoughts concerning taste–colour correspondences, and their applications in the world of food design.

2. Taste/colour correspondences in food design: Evidence from 'The Taste of Colour' in different countries

2.1. 'The Taste of Colour'

Inspired by the existence of robust crossmodal correspondences between colour and taste, chef Jozef Youssef introduced a dish, namely 'The Taste of Colour', served as part of a recent dining concept called *Synaesthesia* (https://kitchen-theory.com/synaesthesia-by-kitchen-theory/). For this dish, the diners are served four spherified mouthfuls of food, each having a different colour (see Figure 1A). The spherification technique (see Youssef 2013) was chosen since it effectively removes any orthonasal olfactory cues, which might otherwise bias the diner's expectations concerning the likely taste of each of the coloured liquids. What this means, in practice, is that colour is the most salient cue that the diners have to base their

taste expectations on. The balls explode when placed in the mouth, each one delivering an intense burst of taste/flavour. This usually delivers a memorable and unusual experience for diners.

INSERT FIGURE 1 ABOUT HERE

In the restaurant setting, the spheres are randomly placed on the table in front of the diners. The waitress then explains that the diners should try the four-tastes dish, starting with the salty, then the bitter, then the sour spoonful or shot glass and end, finally, on a sweet note. The diners are encouraged to align their spoons on the table, and to compare their responses with those of the other diners sitting nearby. In the *Synaesthesia* dining concept, the diners were deliberately seated along a single narrow table in order to facilitate just this kind of comparison and subsequent discussion among the diners. The waitress would note down how each diner had arranged their spoons (see Figures 1A and 1B). All things considered, with the results of experimental and experiential tasting events (such as those reported below), scientists and chefs are now in a much better position to advise which colours would work especially well (in terms of corresponding crossmodally) with which taste.

Data concerning crossmodal correspondences between colour and taste can also be collected from the audience at public talks and online, where people only get to see the coloured foods on a screen and have to judge the taste that they would be expected to be associated with each colour. Independently of the approach, the majority of people tend to be consistent in terms of the way in which they match the colours with tastes. That is, people's responses are significantly non-random. For example, people typically associate sweet with red (though the latest data suggest pink may also be a good match for sweetness, see Woods and Spence in

press). On average, people typically get a little over 70 per cent 'right' (see Spence et al. 2015; Wan et al. 2014a, 2014b). Of course, 'right' or 'correct' is not really the term that we should be using here. Instead, we are looking for the consensual response (Koriat 2008). In the end, what is key is whether and how the diner (or participant) can decode the intentions of the chef (or scientist).

One intriguing insight, which has emerged from working with several different chefs on their own versions of this dish, is that turbidity/opacity of food, something that is rarely considered in the academic literature on food colour (see Chylinski et al. 2015; Spence 2015a, for a review), can nevertheless impact the taste expectations (or associations) that people have with coloured foodstuffs. To illustrate the point, just think of a clear dark green liquid served in a glass and ask yourself what taste/flavour you would likely expect. Most people would suggest sour, thinking perhaps of the acidic flavour of lime (Shankar et al. 2010; see also Wan et al. 2014a, 2014b). Anecdotally, when more or less the same colour has been served as an opaque liquid, people's minds seem to wonder more towards a bitter taste instead, potentially because they are thinking of cruciferous vegetables such as cabbage (see Figure 1B). The turbidity of a liquid may influence the meaning of colour. Note how such an insight, should it be validated by subsequent research, emerged directly from the collaboration between culinary arts and psychological science. Another possible example here comes from the changing expectations, which would be generated by viewing a drink having a dark brown colour, as a function of the presence vs absence of carbonation. Perhaps people's expectations would switch between cola and coffee in this case. Obviously, the glassware and temperature of a drink (see Figure 1C) also play a role here when it comes to interpreting the meaning of a drink colour (see Wan et al. 2014a, 2014b).

2. 2. Studying 'The Taste of Colour' in Mexico and Brazil

Serving the dish in different countries helps to heighten the dining public's awareness of the taste expectations, that are induced whenever we look at a food or beverage (no matter whether it has a colour or not) through the discussion of the results of the experience/experiment with the diners. It also provides a practical challenge for the chef wanting to incorporate local ingredients into their cooking (see the Appendix for the ingredients used in the three versions of 'The Taste of Colour' dish). The hope is that the colours should be broadly, categorically, similar (given the putative cross-cultural consistency in the taste–colour mapping), while the flavours differ so as to be appropriate to the region where the study is being conducted. One of the challenges for the chef is to try to develop flavours that both represent the basic tastes and, at the same time, are pleasurable for the diners. Pure bitterness, after all, is not a particularly pleasant taste experience (e.g., Velasco et al. 2015a). At the same time, the results from such a dish being served, and the responses of diners collected in different countries, can provide useful insights in terms of any cross-cultural similarities/differences regarding the colours associated with basic tastes (see Hutchings 1999).

With the aforementioned points in mind, we conducted two experiments with 'The Taste of Colour' dish in pop-up dinners in Mexico (by Jozef Youssef; see Figure 1B) and in Porto Alegre, Brazil (with chef Xavier Gamez of restaurant Xavier260; http://xavier260.com/; see Figure 1C). The participants in Mexico (n=37) and Brazil (n=91) were presented with the dish and were asked to indicate which taste (sweet, bitter, salty, sour) would be the best match to each of its components (see Section 2.1). Intriguingly, the results (see Table 1) suggest both similarities and differences from the results that had been obtained previously by Spence et al. (2015) and Wan et al. (2014a, 2014b). Pearson's χ^2 tests were carried out in

order to assess any association between the colour responses for the different tastes both in Mexico and Brazil.

INSERT TABLE 1 ABOUT HERE

The analysis revealed a significant association between colour responses and taste words in the Mexican (χ^2 = 32.98, df=9, p<0.001, Cramer's V=0.273, p<0.001) and in the Brazilian (χ^2=75.91, df=9, p<0.001, Cramer's V=0.264, p<0.001) diners. Closer inspection of Table 1 reveals that the most frequent colour associated with sweet was red (though it did not differ significantly from white in Mexico). The next most consensual response was for salty (though interestingly the Mexican diners matched this taste with brown not white, as they did in Brazil; see Spence et al. 2015; Wan et al. 2014a, 2014b), and then sour. Intriguingly, no clear colour associations were obtained when it came to the colour of bitterness in either country (note that previous research has suggested that bitterness tends to be associated with black, Spence et al. 2015). Here it is worth noting that the taste words, in different languages, could potentially differ in terms of other non-semantic elements of words such as their sound symbolic meaning, which may explain, in part, the different matchings (e.g., Simner et al. 2010). However, although the size of this convenience sample was not especially large, the results presented nevertheless suggest the existence of cross-cultural differences (cf. Bremner et al. 2013; Hutchings 1999; Palmer et al. 2013), and would perhaps merit follow-up research with a larger sample (with the data possibly being collected online; Woods et al. 2015).

2.3. The colour of sweet taste: A large-scale study at London's Science Museum

We recently conducted a large-scale study (*N*=5322 participants) at London's Science Museum during an exhibition on the science of food called 'Cravings'.[1] In this study, we evaluated whether the association between sweetness and red would be robust, given that we could access a large sample of participants from a host of different backgrounds. A summary of the participants' demographic data is shown in Table 2. The participants responded to a single question, 'Which drink looks sweetest?', after being presented with the images of six clear plastic cups filled with liquids of different colours (see Figure 2).

INSERT TABLE 2 & FIGURE 2 ABOUT HERE

A χ^2 goodness-of-fit test revealed statistically significant differences in the overall colour selection frequencies, $\chi^2(5)=3717.71$, $p<0.001$, Cohen's $w=0.836$ (note that if there were no differences one would expect a minimum frequency of 887 for each colour, see 'Total' row in Table 3). Bonferroni-corrected χ^2 goodness-of-fit analyses were performed for each region of origin, which revealed a significantly different selection of colours for each of the different regions ($p<0.001$, for all regions). Once again, the results revealed that red was the predominant response for the sweet taste, although interestingly the percentage only exceeded 50 per cent in those participants who reported being from South America (51.38 per cent) (see Table 3). Possibly, it does not go beyond those percentages, given that the question asked and stimuli used here contrasted with the way in which previous studies assessed colour–taste correspondences (e.g., using more varied stimulus sets and/or only evaluating the matches without dealing with intensity or level of sweetness).

INSERT TABLE 3 ABOUT HERE

---

2. 4. Taste–colour correspondences in the context of multisensory flavour perception

From the dining events/experiments, which were held in Mexico and Brazil, as well as the London study, it is possible to assert that taste–colour associations occur in a non-random manner. Moreover, even though there is a certain degree of variability as a function of the background of the participants, it appears that some associations appear more often than others. Note, for example, that a specific taste need not have just one match and could, potentially, have a set of colours that better represent it in the general population (sweet with red and blue in the experiment in London's Science Museum). Potentially, future studies may look at ranges of chroma, hue and brightness for each taste quality.

One potential criticism of the line of research outlined here is that the focus on taste–colour correspondences is a little reductionist in its approach (given the different multisensory inputs that are known to influence flavour perception, see Prescott 2015; Spence 2015c). After all, it is commonly stated that the olfactory component contributes mightily to the tasting experience (i.e., 75-95% of the experienced; see Spence 2015b, for a review). Hence, one might wonder why we do not focus on aroma–colour or flavour–colour correspondences instead. This is certainly a fair point. However, it is important to highlight that one of the problems here is that it is simply much harder to agree on what the appropriate basic categories of aroma or flavour are, than it is in the case of basic tastes. Perhaps here, then, it would be best to adapt a categorization scheme from a specific product category. One possibility here, although perhaps a little specialized, would be to use the wine aroma wheel, since it has seven categories. Although note that the colour wheel already has colours implicitly associated with it (e.g., see http://winearomawheel.com/; see also Lee et al. 2001).

Taking the research in a different direction, what we have done for colour (i.e., determining the correspondences with taste), could certainly also be extended to shape in future research (Salgado et al. 2015; Velasco et al. 2015b). In fact, that had been the initial suggestion for 'The Four Tastes' dish – that is, each taste would have both a specific colour and be presented in a particular shape. However, discussion with the chef soon revealed that it would be hard to find a technique other than spherification to produce foods in several shapes, without affecting the perceived texture of the food. Hence, the dish worked better with the surprise delivered by the explosion of each of the spherified balls in the mouth (see Youssef 2013). That said, the unusual taste/texture experience that is offered by one of these egg-yolk-like textural experiences, is probably something that again works better as curated experience than when taken out of context (https://thepsychologist.bps.org.uk/sensory-trickery-kitchen; see also https://www.youtube.com/watch?v=juhN_exBbHM).

One of the limitations of the spherification technique is that (as its name suggests) it is not possible to change the shape properties of one's creations. This is salient given that previous research has documented that there is a strong relationship between tastes and shapes varying in their roundness vs angularity, symmetry vs asymmetry, and number of elements (sweet is round, symmetrical, and is associated to shapes with fewer elements than is sour, e.g., Salgado et al. 2015; Velasco et al. 2015a, 2015b). Taste/curvature correspondences can influence the processing of taste and shape information (Liang et al. 2013; Spence 2014; Velasco et al. 2015b). While the association between colours and shapes has been researched elsewhere (see Chen et al. 2015, for one such study), additional research is still needed in order to see how colours and shapes work in conveying taste information.

One other intriguing suggestion here for future tasting/testing, when the dish is next served in a large-scale format, is first to ask the people which taste they expect, and then how much they enjoyed the taste experience. Whether people are 'right' about the taste should, at least

according to the theory of disconfirmed expectations, carry over to influence the subsequent tasting experience: if you taste what you expected to taste, then you should like the experience more (see Piqueras-Fiszman and Spence 2012; Schifferstein 2001).

Although beyond the scope of the current endeavour, if one knows the colour that makes taste, then one could also think about coordinating the colour of plateware and/or cutlery to deliver optimal colour contrast (Harrar and Spence 2013; Lyman 1989; Spence and Piqueras-Fiszman 2014). That said, there are alternative strategies and also challenges when it comes to optimally combining plate colour with the colour of the food (see Woods and Spence in press). In the next section, we move on to discuss the role, and potential outcomes, of taste–colour congruency in the context of food design.

3. The role of crossmodal congruency in the restaurant setting

3.1. Congruence vs incongruence

When thinking about the use of colour congruency in combining colours with tastes, it is worth noting that its effect may depend on the taster, context of tasting and on the person who happens to be delivering the food (see Desmet and Schifferstein 2008; Spence et al. 2015). So, for example, if you are tricked by the use of incongruent colour–taste combinations in an experimental dining event, a modernist restaurant, or by a pop-up culinary artist, you may be pleasantly surprised. By contrast, if the drink that you happen to buy in the supermarket, or from a street vendor in a foreign country, is coloured incongruently, the response is likely to be negative (or at least, may influence the way you attend to it, see Velasco et al. 2015c). What if you really want a sweet drink and buy something red and it turns out not to be sweet? Every one of us can probably remember an unpleasant experience

where the colour did not correctly signify the right taste (see also Ludden et al. 2007). Certainly, the use of incongruent colour failed spectacularly in the marketplace for the clear cola drinks like Clear Tab Pepsi (see Triplett 1994).

Given these examples, it is interesting to note that that congruency is not always the optimal solution when it comes to developing products in the marketplace (Ludden et al. 2008, 2012). While not talking specifically about foods, Mandler (1982) suggested that neither perfect congruency nor incongruency was desirable when it comes to value judgements. Rather, according to Mandler's theory of incongruity, something between congruency and incongruency may be optimal, assuming that consumers are provided with the appropriate tools to resolve the small degree of incongruency (or discrepancy, see also Meyers-Levy and Tybout 1989; Stayman et al. 1992). The idea here is that positive feelings will follow the consumer's process of finding a way to make sense of, or resolve, the incongruency (Miller and Kahn 2005). As we will see below, it is not always immediately obvious as to what constitutes congruency in the world of colour–taste/flavour matching, especially when it comes to artificial and/or unusual natural products (e.g., it could change over time).

As a chef wanting to serve a dish in a restaurant, one might legitimately wonder what the benefits of getting the colour 'right' might be expected to be. Being aware of the correspondences allows the chef/designer either to go for congruency or else for surprise by deliberately choosing incongruent combinations of colour and taste (this obviously applies not only to colour/taste but also to the other correspondences, see Spence 2012, for additional examples such as the dish name, shape, etc.). The simple fact of being aware of the important role of expectations (both set explicitly, and present implicitly) in modelling the flavour experience can be a great source of inspiration for optimal food experience design. Furthermore, generally speaking, congruent multisensory cues are likely to be processed more easily. In turn, such increased 'perceptual fluency' typically leads to increased liking

(e.g., Labroo et al. 2008; Reber et al. 1998). The simplest solution here, then, would always be to let go of artificial colourings and try to match the colour to the taste, given that our sensory systems tend to match stimuli across the senses, when examining our environments in the search for nutritious foods (Allman 2000).

On the other hand, however, the chef/designer can also go for sensory incongruity (e.g., Ludden et al. 2012). This occurs when colours are deliberately chosen to set the wrong (or misleading) taste expectations. While the latter approach is likely to elicit surprise from the diner/drinker/audience, something that a growing number of modernist chefs, or for that matter diners in their restaurants, are increasingly coming to expect (Spence and Piqueras-Fiszman 2014), it is sometimes a much more challenging approach to pull off successfully (see Piqueras-Fiszman and Spence 2012; Spence and Piqueras-Fiszman 2014). That is, people simply just find it harder to process incongruent stimulus combinations. What is more, given that they are ingesting something that could potentially be harmful (see Koza et al. 2005), they need to have confidence in the creator (be they chef/mixologist/experience designer) in order to know that this incongruity is a purposefully designed part of the experience. This being said, it is worth considering the fact that incongruent, or surprising, colour–taste–flavour combinations have appeared in the restaurant setting for decades. Indeed, incongruent combinations have not always been used to deliver enjoyable experience to their diners though, but also for innovation purposes.

3.2. Playing with sensory incongruency: Unpleasant outcomes

Examples of incongruency include F. T. Marinetti's (blue wine, orange-coloured milk and red mineral water; see Anon. n.d.; Marinetti and Colombo 1930/1989) and Alfred

Hitchcock's use of blue food dye when hosting dinners at London's Trocadero back in the 1960s'. As the director put it,

> And all the food I had made up was blue! Even when you broke your roll. It looked like a brown roll but when you broke it open it was blue. Blue soup, thick blue soup. Blue trout. Blue chicken. Blue ice cream. (Gottlieb 2003: 76)

In these cases the strangely coloured food was not meant to be appealing for whoever was 'lucky enough' to be dining! Indeed, there are many examples of people's distaste for foods that have been coloured in an unusual manner (Moir 1936; Wheatley 1973; Wilson 2009). Poon (2014) documented some of the deeply unappealing results of inappropriate food colouring, which have been deliberately created by Lawrie Brown (http://lawriebrown.com/foodpage.html, see Figure 3, for an example). Sometimes though it is the very weirdness of the colours that is what is appealing, or that captures our attention (see also Greenspan 2009; Vanderbilt 2015). With the aforesaid in mind, one may wonder what individual differences may arise when it comes to the acceptance of congruence vs incongruence (e.g., perhaps, people that are looking for novelty may be more keen to accept incongruences as compared with food neophobics).

INSERT FIGURE 3 ABOUT HERE

3.3. Playing with sensory incongruency: Pleasant outcomes

A classic example of colour–flavour incongruity (Blumenthal 2007; Piqueras-Fiszman and Spence 2012) in the restaurant setting is the 'Beetroot and orange jelly' dish, which was, for a number of years, on the tasting menu at The Fat Duck restaurant in Bray (though it is not on the menu currently; see Malvern 2015). In this case, the use of golden beetroots and blood-red oranges allows the chef to mislead by eye (and confound the diner's expectations), but still deliver an authentic taste experience. It is interesting to note here that the same purple colour would be found in the intense-flavoured blackcurrant pastille served at the end of the meal. Here, the presence of food acids (malic/citric) helps the diner's brain to interpret the colour as either fruit or vegetable (see Zampini et al. 2008). Importantly, in this case, the real colour of the natural ingredients was respected, using a variety of beetroot that is naturally orange (not purple), and a variety of oranges that are not orange in colour (but dark red). The surprise is then induced by novelty in using an unusual ingredient, rather than by 'hacking' the colour of the food in an arbitrary way. Moreover, surprise was also accompanied by very high expectations set by the context, and a highly refined and carefully designed flavour experience in terms of texture, aroma, presentation and storytelling. If different taste–colour combinations had been used (such as, e.g., colouring the beetroot green), then it is probable that the dish would be less liked and perhaps the connection with natural colouring, which was so important to the culinary team in this case, would have been lost. Another surprisingly coloured food is the completely white chocolate sorbet, which uses distilled coco bean essence created by the famous Spanish chef, Jordi Roca (see Anon. 2015). The dessert was completely white but tasted of dark chocolate. Notice how, in these two cases, the intention of the modernist chef was very much to make something delicious, not only surprising (see Spence and Piqueras-Fiszman 2014). It is perhaps worth noting that the use of compounds and essences, and especially of distillation, allows the chef to separate colours from flavours.

3.4. Different types of colour–taste incongruency

There is an interesting angle here about those foods, dishes or drinks that we can see are unusually coloured, but which we do not know whether they are incongruent or not until we taste them – think here only of the red and the black beef-burgers sold by Burger King in Asia (Anon. 2015; Cook 2012). Is this an example of food that is incongruently coloured or not? The answer would seem to depend. In the Burger King case, the idea was apparently driven by a limited marketing budget combined with a desire to whip up the shock factor in the hope that this would lead to increased media attention (which indeed it did). Here, while red and black are not necessarily colours that we normally associate with a hamburger, it turns out that the actual flavours are not that incongruent – black sesame (that works for a burger bun, which is normally covered in sesame seeds anyway) and tomato powder (again, tomato is by no means a foreign ingredient to burgers); so it is more the colour incongruity (though the brand's corporate colour) rather than the actual flavour that is the issue. It is an interesting question as to how important the ultimate surprising congruency of colour and taste played to the ultimate consumer proposition, also bearing in mind that the discussion here has been built around a fine-dining context/intention, and fast food would seem to be at the other end of the spectrum, and addressed to a different type of public.

There is an important distinction to be drawn here between hidden and visible incongruency (Schifferstein and Spence 2008). The red and black burgers constitute examples of visible incongruency. Simply by looking at the burger one knows that there is something surprising going on. By contrast, the two chef-inspired gastronomic dishes, the beetroot and orange jelly and Roca's white chocolate sorbet, constitute examples of hidden incongruency. One is only surprised on actually tasting the food, and even then with visual dominance being what it is, some of the diners at The Fat Duck may remain unaware of the incongruency until the waiter alerts them to what is going on. Similar cases can also be observed when it comes to mass

consumption products. For example, it turns out that the colour of gummy bears does not always correspond to their actual flavour (Kentish 2015).

A final category of seemingly incongruently coloured foods, which should perhaps be mentioned here, includes all those exotic fruits and vegetables (see Piqueras-Fiszman and Spence 2012; see also Becker 2015; Bry 2015). In the United Kingdom, for example, most people would want to say that purple carrots, purple sprouting broccoli, purple cauliflower, purple potatoes, purple corn, white aubergines, white strawberries (pineberries) and white carrots are incongruent (though that is not necessarily the case, see Poulter 2011), but not necessarily less pleasant – though the expectations set by the colour might change the flavour experience of the fruit/vegetable. One can only wonder how such unusually coloured vegetables play with all those suggestions that one finds in the press advising that by carefully picking the colours of one's fruit and vegetables, one can, potentially, achieve a healthier diet (Gupta 2015)!

4. Conclusions

According to Peirce (1868),

> Sight by itself informs us only of colors and forms. No one can pretend that the images of sight are determinate in reference to taste. They are, therefore, so far general that they are neither sweet nor non-sweet, bitter nor non-bitter, having savor nor insipid.

In contrast to what the scientist of the nineteenth century would have had us believe, the latest research clearly shows that colours are reliably associated with tastes. In fact, a growing body of empirical research has now started to help uncover and document these correspondences, showing their generalizability or variability across countries/cultures, and even suggesting a degree of consistency across the decades (see Spence et al. 2015, for a review).

This correspondence is particularly consistent between the colour red (and/or pinky-red) and sweetness. While some cross-cultural differences have emerged, thus far it is unclear whether these result from genuine differences in the associations learned in different cultures, correspondences between hue and taste engrained in our evolutionary path or, for example, slight differences in the turbidity of the foods served (or perhaps both, see Spence et al. 2015 for further discussion on the psychological mechanisms that may underlie colour/taste correspondences). Moreover, a number of additional questions remain to be answered. For instance, how do individual differences (i.e., whether a diner, or consumer, is a foodie vs a neophobe; Henriques et al. 2009), context (a Michelin-Star restaurant vs a local market; King et al. 2004) and culture influence people's reactions to congruence vs incongruence?

Apart from these questions, having been made aware of such colour–taste correspondences, the chef, molecular mixologist, food product designer, culinary artist or experience designer can either choose to follow the correspondences, or else they may go down the path of challenging them, and by so doing potentially surprise their diners/audience (while taking into account the way in which context may contribute to the such an effect). It should, though, be noted in closing that the latter approach is much harder to pull off successfully (Piqueras-Fiszman and Spence 2012; Spence and Piqueras-Fiszman 2014). Either way, colour/taste congruency should be an integral part of the design of food/drink, its name, flavour and the design of the overall experience of eating and drinking.

References

Allman, J. M. (2000), *Evolving Brains*, New York, NY: Scientific American Library.

Anon. (2012), 'Delicious science', http://harvardmagazine.com/2012/09/delicious-science. Accessed 14 December 2015.

____ (2015), 'Burger King Japan to sell "red" burgers', http://blogs.wsj.com/japanrealtime/2015/06/17/burger-king-japan-to-sell-red-burgers/. Accessed 4 September 2015.

____ (n.d.), 'Futurist cooking: Was molecular gastronomy invented in the 1930s?', http://www.thestaffcanteen.com/editorial/futurist-cooking-was-molecular-gastronomy-invented-in-the-1930s. Accessed 1 September 2015.

Becker, E. (2015), 'Surreal still lifes of genetically modified fruit', http://thecreatorsproject.vice.com/blog/surreal-still-lifes-of-genetically-modified-fruit. Accessed 16 December 2015.

Borges, J. L. and Bioy-Casares, A. (1993), 'An abstract art', in L. Golden (ed.), *A Literary Feast*, New York, NY: The Atlantic Monthly Press, pp. 70–73.

Bremner, A., Caparos, S., Davidoff, J., de Fockert, J., Linnell, K. and Spence, C. (2013), 'Bouba and Kiki in Namibia? A remote culture make similar shape-sound matches, but different shape-taste matches to Westerners', *Cognition*, 126:2, pp. 165–72.

Brunel, L., Carvalho, P. F. and Goldstone R. L. (2015), 'It does belong together: Cross-modal correspondences influence cross-modal integration during perceptual learning', *Frontiers in Psychology*, 6:358.

Bry, D. (2015), 'Orange is the new yuck: Why autumn foods make me sick', www.theguardian.com/lifeandstyle/2015/oct/01/why-orange-food-is-disgusting-pumpkins-carrots. Accessed 16 December 2015.

Chen, N., Tanaka, K. and Watanabe, K. (2015), 'Color-shape associations revealed with implicit association tests', *PLoS ONE*, 10:1, p. e0116954.

Chylinski, M., Northey, G. and Ngo, L. V. (2015), 'Cross-modal interactions between color and texture of food', *Psychology & Marketing*, 32:9, pp. 950–66.

Cook, W. (2012), 'Would you eat a "gourmet" burger made with charred bamboo and squid ink?', http://www.dailymail.co.uk/news/article-2208321/Burger-King-black-burger-Japan-bamboo-charcoal-squid-ink.html. Accessed 4 September 2015.

Deroy, O. and Spence, C. (2016), 'Crossmodal correspondences: Four challenges', *Multisensory Research*, 29:1–3, pp. 29–48.

Desmet, P. M. and Schifferstein, H. N. (2008), 'Sources of positive and negative emotions in food experience', *Appetite*, 50:2, pp. 290–301.

Gardner, H. (1974), 'Metaphors and modalities: How children project polar adjectives onto diverse domains', *Child Development*, 45:1, pp. 84–91.

Gottlieb, S. (ed.) (2003), *Alfred Hitchcock: Interviews*, Jackson, MS: University of Mississippi Press.

Greenspan, S. (2009), '11 strange, and often wrong, colored foods and drinks', 'http://www.11points.com/Food-Drink/11_Strange,_and_Often_Wrong,_Colored_Foods_and_Drinks. Accessed 4 September 2015.

Gupta, S. (2015), '6 coloured foods that you should be eating for a long and healthy life', http://www.indiatimes.com/health/healthyliving/6-coloured-foods-that-you-should-be-eating-for-a-long-and-healthy-life-243998.html. Accessed 4 September 2015.

Harrar, V. and Spence, C. (2013), 'The taste of cutlery', *Flavour*, 2:21.

Henriques, A. S., King, S. C. and Meiselman, H. L. (2009), 'Consumer segmentation based on food neophobia and its application to product development', *Food Quality and Preference*, 20:2, pp. 83–91.

Hutchings, J. B. (1999), *Food Colour and Appearance*, 2nd ed., New York, NY: Plenum Publishers.

Kentish, F. (2015), 'Green gummy bears are all a lie and it's messing with our heads', http://metro.co.uk/2015/09/03/green-gummy-bears-are-all-a-lie-and-its-messing-with-our-heads-5374004/. Accessed 16 December 2015.

King, S. C., Weber, A. J., Meiselman, H. L. and Lv, N. (2004), 'The effect of meal situation, social interaction, physical environment and choice on food acceptability', *Food Quality & Preference*, 15:7, pp. 645–53.

Koriat, A. (2008), 'Subjective confidence in one's answers: The consensuality principle', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34:4, pp. 945–59.

Koza, B. J., Cilmi, A., Dolese, M. and Zellner, D. A. (2005), 'Color enhances orthonasal olfactory intensity and reduces retronasal olfactory intensity', *Chemical Senses*, 30:8, pp. 643–49.

Labroo, A. A., Dhar, R. and Schwartz, N. (2008), 'Of frog wines and frowning watches: Semantic priming, perceptual fluency, and brand evaluation', *Journal of Consumer Research*, 34:6, pp. 819–31.

Lee, K. Y. M., Paterson, A. and Piggott, J. R. (2001), 'Origins of flavor in whiskies and a revised flavor wheel: A review', *Journal of the Institute of Brewing*, 107:5, pp. 287–313.

Liang, P., Roy, S., Chen, M. L. and Zhang, G. H. (2013), 'Visual influence of shapes and semantic familiarity on human sweet sensitivity', *Behavioural Brain Research*, 253, pp. 42–47.

Ludden, G. D., Schifferstein, H. N. and Hekkert, P. N. (2007), 'Surprising the senses', *The Senses and Society*, 2:3, pp. 353–62.

____ (2008), 'Surprise as a design strategy', *Design Issues*, 24:2, pp. 28–38.

Ludden, G. D., Kudrowitz, B. M., Schifferstein, H. N. and Hekkert, P. (2012), 'Surprise and humor in product design', *Humor*, 25:3, pp. 285–309.

Lyman, B. (1989), *A Psychology of Food, more than a Matter of Taste*, New York: Avi, van Nostrand Reinhold.

Malvern, J. (2015), 'Heston's next trick is mindblowing', http://www.thetimes.co.uk/tto/life/food/article4536244.ece. Accessed 16 December 2015.

Mandler, G. P. (1982), 'The structure of value: Accounting for taste', in M. S. Clark and S. T. Fiske (eds), *Affect and cognition. The 17th Annual Carnegie Symposium on Cognition*, Hillsdale: Lawrence Erlbaum, pp. 3–36.

Marinetti, F. T. and Colombo, L. (1930/1998), *La cucina futurista: Un pranzo che evitò un suicidio*/'The Futurist kitchen: A meal that prevented suicide', Milan: Christian Marinotti Edizioni.

Meyers-Levy, J. and Tybout, A. M. (1989), 'Schema congruity as a basis for product evaluation', *Journal of Consumer Research*, 16:1, pp. 39–54.

Miller, E. G. and Kahn, B. E. (2005), 'Shades of meaning: The effect of color and flavor names on consumer choice', *Journal of Consumer Research*, 32:1, pp. 86–92.

Moir, H. C. (1936), 'Some observations on the appreciation of flavour in foodstuffs', *Journal of the Society of Chemical Industry: Chemistry & Industry Review*, 14:8, pp. 145–48.

Palmer, S. E., Schloss, K. B., Xu, Z. and Prado-León, L. R. (2013), 'Music-color associations are mediated by emotion', *Proceedings of the National Academy of Sciences of the USA*, 110:22, pp. 8836–41.

Parise, C. V., Knorre, K. and Ernst, M. O. (2014), 'Natural auditory scene statistics shapes human spatial hearing', *Proceedings of the National Academy of Sciences of the USA*, 111:16, pp. 6104–08.

Peirce, C. S. (1868), 'Some consequences of four incapacities', *Journal of Speculative Psychology*, 2:3, pp. 140–57.

Piqueras-Fiszman, B. and Spence, C. (2012), 'Sensory incongruity in the food and beverage sector: Art, science, and commercialization', *Petits Propos Culinaires*, 95:1, pp. 74–118.

Poon, L. (2014), 'Tasting with our eyes: Why bright blue chicken looks so strange', http://www.npr.org/sections/thesalt/2014/04/16/303215873/tasting-with-our-eyes-why-bright-blue-chicken-looks-so-strange. Accessed 4 September 2015.

Poulter, S. (2011), 'The purple potato that lowers blood pressure', http://www.dailymail.co.uk/news/article-2049294/Purple-potato-helps-lower-blood-pressure-doesnt-make-weight.html. Accessed 15 December 2015.

Prescott, J. (2015), 'Multisensory processes in flavour perception and their influence on food choice', *Current Opinion in Food Science*, 3, pp. 47–52.

Proctor, R. W. and Cho, Y. S. (2006), 'Polarity correspondence: A general principle for performance of speeded binary classification tasks', *Psychological Bulletin*, 132:3, pp. 416–42.

Reber, R., Winkielman, P. and Schwartz, N. (1998), 'Effects of perceptual fluency on affective judgments', *Psychological Science*, 9:1, pp. 45–48.

Salgado-Montejo, A., Alvarado, J., Velasco, C., Salgado, C. J., Hasse, K. and 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: Perception Science*, 6:1382.

Schifferstein, H. N. J. (2001), 'Effects of product beliefs on product perception and liking', in L. Frewer, E. Risvik and H. Schifferstein (eds), *Food, People and Society: A European Perspective of Consumers' Food Choices*, Berlin: Springer Verlag, pp. 73–96.

Schifferstein, H. N. J. and Spence, C. (2008), 'Multisensory product experience', in H. N. J. Schifferstein and P. Hekkert (eds), *Product Experience*, London: Elsevier, pp. 133–61.

Shankar, M. U., Levitan, C. and Spence, C. (2010), 'Grape expectations: The role of cognitive influences in color-flavor interactions', *Consciousness & Cognition*, 19:1, pp. 380–90.

Simner, J., Cuskley, C. and Kirby, S. (2010), 'What sound does that taste? Cross-modal mappings across gustation and audition', *Perception*, 39:4, pp. 553-569.

Spence, C. (2011), 'Crossmodal correspondences: A tutorial review', *Attention, Perception, & Psychophysics*, 73:4, pp. 971–95.

____ (2012), 'Managing sensory expectations concerning products and brands: Capitalizing on the potential of sound and shape symbolism', *Journal of Consumer Psychology*, 22:1, pp. 37–54.

____ (2014), 'Assessing the influence of shape and sound symbolism on the consumer's response to chocolate', *New Food*, 17, pp. 59–62.

____ (2015a), 'On the psychological impact of food colour', *Flavour*, 4:21.

____ (2015b), 'Just how much of what we taste derives from the sense of smell?', *Flavour*, 4:30.

____ (2015c), 'Multisensory flavour perception', *Cell*, 161:1, pp. 24–35.

Spence, C., Levitan, C., Shankar, M. U., and Zampini, M. (2010). Does food color influence taste and flavor perception in humans? *Chemosensory Perception*, 3:68-84.

Spence, C. and Piqueras-Fiszman, B. (2014), *The Perfect Meal: The Multisensory Science of Food and Dining*, Oxford: Wiley-Blackwell.

Spence, C., Wan, X., Woods, A., Velasco, C., Deng, J., Youssef, J. and Deroy, O. (2015), 'On tasty colours and colourful tastes? Assessing, explaining, and utilizing crossmodal correspondences between colours and basic tastes', *Flavour*, 4:23.

Stayman, D. M., Alden, D. L. and Smith, K. H. (1992), 'Some effects of schematic processing on consumer expectations and disconfirmation judgments', *Journal of Consumer Research*, 19:2, pp. 240–55.

Stumpf, K. (1883), *Tonpsychologie/Psychology of Tones*, Leipzig: S. Hirzel.

Triplett, T. (1994), 'Consumers show little taste for clear beverages', *Marketing News*, 28:11, pp. 1–2.

Vanderbilt, T. (2015), 'The colors we eat: Food color does more than guide us – it changes the experience of taste', http://nautil.us/issue/26/color/the-colors-we-eat. Accessed 4 September 2015.

Velasco, C., Woods, A. T., Deroy, O. and Spence, C. (2015a), 'Hedonic mediation of the crossmodal correspondence between taste and shape', *Food Quality and Preference*, 41, pp. 151–58.

Velasco, C., Woods, A. T., Marks, L. E., Cheok, A. D. and Spence, C. (2015b), 'The semantic basis of taste-shape associations', *PeerJ*, 4:e1687.

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

Wan, X., Velasco, C., Michel, C., Mu, B., Woods, A. T. and Spence, C. (2014a), 'Does the shape of the glass influence the crossmodal association between colour and flavour? A cross-cultural comparison', *Flavour*, 3:3.

Wan, X., Woods, A. T., van den Bosch, J., McKenzie, K. J., Velasco, C. and Spence, C. (2014b), 'Cross-cultural differences in crossmodal correspondences between tastes and visual features', *Frontiers in Psychology*, 5:1365.

Wheatley, J. (1973), 'Putting colour into marketing', *Marketing*, October, pp. 24–29, 67.

Wilson, B. (2009), *Swindled: From Poison Sweets to Counterfeit Coffee – The Dark History of the Food Cheats*, London, UK: John Murray.

Woods, A. T. and Spence, C. (in press), 'Using single colours and colour pairs to communicate basic tastes', *i-Perception* (accepted for publication December 2015).

Woods, A. T., Spence, C., Butcher, N. and Deroy, O. (2013), 'Fast lemons and sour boulders: Testing the semantic hypothesis of crossmodal correspondences using an internet-based testing methodology', *i-Perception*, 4:6, pp. 365–69.

Woods, A.T., Velasco, C., Levitan, C. A., Wan, X., and Spence, C. (2015), Conducting perception research over the internet: A tutorial review, *PeerJ*, 3:e1058.

Youssef, J. (2013), *Molecular Cooking at Home: Taking Culinary Physics out of the Lab and into your Kitchen*, London, UK: Quintet Publishing.

Zampini, M., Wantling, E., Phillips, N. and Spence, C. (2008), 'Multisensory flavor perception: Assessing the influence of fruit acids and color cues on the perception of fruit-flavored beverages', *Food Quality & Preference*, 19:3, pp. 335–43.

FIGURE LEGENDS

Figure 1: Versions of 'The Taste of Colour': (A) The spherified starter created by chef Jozef Youssef in his Synaesthesia *pop-up in Maida Vale Place, London, UK; (B) 'The Taste of Colour', Mexico City, Mexico. Chef Jozef Youssef; (C) 'The Taste of Colour', Porto Alegre, Brazil. Chef Xavier Gamez.*

Figure 2: Visual display of the experiment conducted at a digital platform at London's Science Museum, and online.

*Figure 3: Blue chicken anyone? Incongruently colouring can be most unappealing (*Courtesy of *Lawrie Brown, http://lawriebrown.com/foodpage.html, coloured food series; [Poon 2014]).*

APPENDIX

‘The Taste of Colour’: Recipes, Ingredients.

London

Green, sour, lime spheres: Water, simple syrup, lime juice, calcium gluconate, xanthan gum and green food colouring.

Red, sweet, cranberry and rose spheres: Cranberry juice, rose compound, xanthan gum, and calcium gluconate.

White, salty, yoghurt spheres: Full fat yoghurt, water and salt.

Black, bitter, Guinness spheres: Simple syrup, Guinness, xanthan gum, calcium gluconate and black food colour.

Alginate bath: Distilled water, sodium alginate.

Mexico

Green, bitter, cucumber and pipicha herb spheres: Cucumber, pipicha herb, burnt tortilla powder, water, xanthan gum and calcium gluconate.

Red, sour, aqua chilli spheres: Chilli, lemon juice, coriander, onion, water, red food colour, salt, simple syrup, xanthan gum and calcium gluconate.

White, sweet, res con leche spheres: Rice, milk, sugar and calcium gluconate.

Brown/black, salty, mole ‘mancha manteles’ aspheres: Mancha manteles mole sauce (25+ ingredients; including chilies, fruits, nuts and mixed veg), and calcium gluconate.

Alginate bath: Filtered water, sodium alginate.

Porto Allege, Brazil, chef Xavier Gamez

4 creams, served in a same dish with transparent glass (like shot) and tea-spoon.

2 cold creams

Deep red: Beet root ‘Salmorejo’ (‘Salmorejo’=a kind of creamy ‘gazpacho’, ingredients: Raw tomatoes and cooked beet roots (very sweet), bread, garlic, olive oil, salt and vinegar).

White: ‘Ajoblanco’ (a kind of ‘salmorejo’, but with crushed almonds, not red vegetables): Almonds, bread, olive oil, salt and vinegar.

2 hot creams

Black: Black pudding (‘morcilla’) cream, with potatoes purée, and coffee expresso.

Green: Garlic chives (Oriental garlic) and spinach cream with potatoes purée, and fresh goat cheese.

Contributor details

Dr Carlos Velasco is a postdoctoral researcher at the Imagineering Institute, Iskandar, Malaysia. He obtained his D.Phil. in Experimental Psychology at Oxford University in 2015. His research focuses on crossmodal perception, in particular, on documenting, understanding and applying crossmodal correspondences. He has worked with a number of local and multinational companies in multisensory experience design. Further information http://carlosvelasco.co.uk/.

Charles Michel is a professional chef who graduated from Institut Paul Bocuse cookery school in Lyon, France in 2006. After a classical training in kitchens in France and Italy, including two years at the three Michelin-starred restaurant Dal Pescatore, his work as a cook took a turn in a collaborative research with Professor Charles Spence, applying insights from sensory and psychological science to culinary creations. He is now chef in Residence at the Crossmodal Research Laboratory, University of Oxford.

Jozef Youssef, Kitchen Theory founder and chef patron, has been on a culinary odyssey to find out about all things related to food and science, multisensory experiences, kitchen management and kitchen design, restaurants. Jozef is also the author of molecular

gastronomy at home, a simple introduction to the science behind modernist culinary techniques.

Xavier Gamez is the founder of Xavier260, the only Catalan restaurant on Brazilian ground – a place where senses are sharpened by the flavours that arise from the combination of Catalan roots cuisine, molecular gastronomy technique and the introduction of Brazilian ingredients.

Adrian David Cheok is a Full Professor of Pervasive Computing in the City University London and Director of the Imagineering Institute, Malaysia. He worked in real-time systems, soft computing and embedded computing in Mitsubishi Electric Research Labs. He has been working on research covering mixed reality, human–computer interfaces, wearable computers and ubiquitous computing, fuzzy systems, embedded systems and power electronics.

Professor Charles Spence is the head of the Crossmodal Research Laboratory. He is interested in how people perceive the world around them. In particular, how our brains manage to process the information from each of our different senses (such as smell, taste, sight, hearing and touch) to form the extraordinarily rich multisensory experiences that fill our daily lives. His research focuses on how a better understanding of the human mind will lead to the better design of multisensory foods, products, interfaces and environments in the future.

Contact:

Carlos Velasco, Imagineering Institute, Anchor 5, Mall of Medini, No.4 Lebuh Medini Utara, Medini, Iskandar, Nusajaya, 79250, Johor, Malaysia.

E-mail: carlos@imagineeringinstitute.org

Charles Michel, Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, S Parks Rd, Oxford OX1 3UD, United Kingdom.

Email: charles.michel@psy.ox.ac.uk

Jozef Youssef,

Email: jozef@kitchen-theory.com

Xavier Gamez,

Email: chef@xavier260.com

Adrian David Cheok, Imagineering Institute, Anchor 5, Mall of Medini, No.4 Lebuh Medini Utara, Medini, Iskandar, Nusajaya, 79250, Johor, Malaysia.

E-mail: adrian@imagineeringinstitute.org

Charles Spence, Crossmodal Research Laboratory, Department of Experimental Psychology, University of Oxford, S Parks Rd, Oxford OX1 3UD, United Kingdom.

Email: charles.spence@psy.ox.ac.uk

Note

[1] http://www.sciencemuseum.org.uk/visitmuseum/Plan_your_visit/exhibitions/cravings/cravings-experiment.aspx.