Theoretical Article

On the Relationship(s) Between Color and Taste/Flavor

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Abstract: Experimental psychologists, psychophysicists, food/sensory scientists, and marketers have long been interested in, and/or speculated about, what exactly the relationship, if any, might be between color and taste/flavor. While several influential early commentators argued against there being any relationship, a large body of empirical evidence published over the last 80 years or so clearly demonstrates that the hue and saturation, or intensity, of color in food and/or drink often influences multisensory flavor perception. Interestingly, the majority of this research has focused on vision's influence on the tasting experience rather than looking for any effects in the opposite direction. Recently, however, a separate body of research linking color and taste has emerged from the burgeoning literature on the crossmodal correspondences. Such correspondences, or associations, between attributes or dimensions of experience, are thought to be robustly bidirectional. When talking about the relationship between color and taste/flavor, some commentators would appear to assume that these two distinct literatures describe the same underlying empirical phenomenon. That said, a couple of important differences (in terms of the bidirectionality of the effects and their relative vs. absolute nature) are highlighted, meaning that the findings from one domain may not necessarily always be transferable to the other, as is often seemingly assumed.

Keywords: color, taste, flavor, crossmodal correspondences, multisensory perception

Since the first tentative report on the topic by the British chemist H. C. Moir that appeared in the *Journal of the Society of Chemical Industry* back in 1936, several hundred published studies have subsequently investigated the influence of color on aroma, taste, and flavor (see Spence, Levitan, Shankar, & Zampini, 2010, for a review). Perhaps unsurprisingly, many of the earliest studies in this area were based squarely on practical concerns around the use of artificial food coloring in everyday food and drink products. The butter lobby, for instance, objected to the addition of a golden yellow food coloring to "naturally" white margarine, a new product around the time that Masurovsky (1939) published his article on this topic. Meanwhile, early psychologists such as Karl Duncker (1939) were interested in gauging the responses of people to unusually colored new food products, such as the then recently introduced white chocolate. By contrast, much of the interest in unusually colored foods these days (such as the increasingly popular blue foods, color-changing foods, or rainbow-colored unicorn drinks) would appear to be driven as much by concerns about how they will photograph (e.g., on Instagram; see Spence, 2018a), as by the influence that the color may have on taste and/or consumer behavior (see Spence, 2018b; Spence, Okajima, Cheok, Petit, & Michel, 2016; Stewart, 2011, for reviews).

In this review, the literature on color's influence on taste/flavor perception is briefly summarized first. Next, the literature on crossmodal correspondences between color and taste is reviewed. Thereafter, the question is addressed of how these two literatures are related to one another. Finally, two key differences between crossmodal influence of color on taste/flavor perception and color–taste correspondences are outlined in terms of the unidirectional versus bidirectional interactions/connections, and the relative versus absolute nature of the crossmodal mappings/effects involved.

Color's Influence Over Multisensory Flavor Perception

The majority of experimental studies of color's influence on tasting have tended to focus on simple situations, typically involving artificially colored liquids/drinks that are either sniffed (thus involving orthonasal cues; Zellner, Bartoli, & Eckard, 1991) and/or else tasted (so targeting retronasal olfaction; see Spence, 2016a, for a review). Colorful drinks are relatively easy to create and, what is more, do not provide many of the other cues that are normally available when we inspect a food visually. Often, however, the colors and/or flavors that have been used in the laboratory research in this area have borne little, or no, obvious relationship to the colors/flavors that one might expect to find in the drinks on supermarket shelves, say (see Zampini, Sanabria, Phillips, & Spence 2007; Zampini, Wantling, Phillips, & Spence, 2008, for a couple of examples).

Until recently, virtually all of the studies of color's influence on people's taste and flavor expectations, and thereafter on their tasting experiences (see Piqueras-Fiszman & Spence, 2015a, for a review on the influence of sensory and hedonic expectations on experience), have emerged from the fields of sensory science, food science, and/or food marketing (e.g., Garber, Hyatt, & Starr, 2001, 2003, for representative work in this area). In recent years, the interest from the marketing side has been as much been on packaging color, as well as other kinds of background color, as it has been on the color of the product itself (see Spence, 2016c; Spence & Velasco, 2018, for recent reviews). At the same time, however, it is important to stress that neither the color of the product, nor of its packaging, are constitutive of flavor perception itself (see Spence, Smith, & Auvray, 2015, on this point). As such, color sits in a rather unusual position relative to the taste/flavor of a product. When it is the color of the product that we are talking about, then it is clearly intrinsic to the product. Yet, at the same time, it is mostly not considered part of (or intrinsic to) the flavor of the food and beverage product.

The color of food and drink items is sometimes tightly linked to, or correlated with, the taste, flavor, and/or mouthfeel characteristics of the product, as in the case of variations in the color of natural products as it ripens, say (see Foroni, Pergula, & Rumiati, 2016). At other times, however, the color of a food product is understood to be unrelated to, and hence providing no necessary direct link to, the taste/flavor properties (see Velasco et al., 2016, for a number of such examples). Oftentimes, the color chosen for a given product is seemingly arbitrary (cf. Walker-Andrews, 1994, on the topic of arbitrary correspondences – think here only of the ring tone on your phone). However, if the color happens to be distinctive, the product may still soon come, through a process of associative learning, to be strongly linked in the consumer's mind with a particular taste/flavor profile (e.g., Higgins & Hayes, 2019).[1] This may even be the case when the product is experienced away from its packaging and any other branding/labeling information, etc. In this regard, it is worth noting that we start picking up color–taste/flavor associations very early in development (see Fernandez & Bahrick, 1994; Reardon & Bushnell, 1988). What is more, we do not even need to be conscious of the association, or contingency, in order for it to influence our perception/performance (see Stevenson, Boakes, & Wilson, 2000). Recently, Higgins and Hayes have shown how rapidly new color–taste associations can be picked up in adults as a result of associative learning.

The three main aspects of appearance in the food/drink space are color, both hue and intensity/saturation, and turbidity/opacity (in the case of liquids and gels). However, most of the research on visual appearance has been focused on hue (e.g., red, green, yellow), with a much smaller literature addressing questions related to the saturation/intensity of color (see Spence et al., 2010, for a review). The turbidity, opacity, sheen, and other visual appearance properties of food and drink have received surprisingly little research interest to date and so will not be discussed further here (see Barnett, Juravle, & Spence, 2017; Murakoshi, Masuda, Utsumi, Tsubota, & Wada, 2013; Okajima & Spence, 2011, for a few exceptions). Changing the hue of a drink has been shown to influence thresholds for the basic tastes when presented in solution (Maga, 1974), taste and flavor intensity ratings (e.g., Calvo, Salvador, & Fiszman, 2001; Chan & Kane-Martinelli, 1997; Clydesdale, 1993; Johnson & Clydesdale, 1982), and even flavor identification responses (e.g., DuBose, Cardello, & Maller, 1980; Stillman, 1993; Zampini et al., 2007, 2008).

It is, however, important to note that not all of the studies that have been published in this area have reported an effect of changing the color of a drink on people's taste ratings (see Alley & Alley, 1998; Chan & Kane-Martinelli, 1997; Lavin & Lawless, 1998, for null results). Part of the problem here is that the impact of color on tasting turns out to depend both on what taste/flavor expectations a color signifies in the mind of the observer but also on how close, or far, the actual tasting experience is from that visually induced expectation (cf. Piqueras-Fiszman & Spence, 2015a; Schifferstein, 2001). When visually determined taste expectations and the subsequent tasting experience itself are reasonably close (as when a dark blueish-purple drink is expected to taste of blueberry and actually tastes of blackcurrant; see also Hall, Johansson, Tärning, Sikström, & Deutgen, 2010), one often sees assimilation. By contrast, independence or perhaps even contrast may be observed when the tasting experience is too far removed from the visually induced expectation. So, unless one knows what expectations people hold in relation to a given food color (presumably acquired through experience as a result of associative learning; Higgins & Hayes, 2019), it may be hard to know quite what the consequences of changing the color of a drink, say, will be for multisensory flavor perception.

In a series of experimental studies, Shankar and her colleagues demonstrated that different people, even within

[1] For example, many consumers find it hard to get their heads around the fact that Sprite, say, was once a brown beverage much like cola (Spence, 2018c).

Table 1. Summary of the percentage of color responses to the question 'Which drink look sweetest?' as a function of region in the study conducted at London's Science Museum. The column "*N*" indicates the number of participants from each region. [Table reprinted from Velasco et al. (2016), Table 3.]

Region	Color						*N*
	Blue	Green	Orange	Purple	Red	Yellow	
Africa	21.62	4.05	9.46	18.92	43.24	2.70	74
Asia	17.03	3.47	6.94	28.39	37.22	6.94	317
Europe	20.94	1.87	8.00	22.89	42.03	4.26	1,337
North America	28.61	1.77	5.31	11.21	48.08	5.01	339
Oceania	26.67	2.00	4.67	19.33	41.33	6.00	150
South America	16.51	0.00	5.50	22.02	51.38	4.59	109
UK	32.58	1.27	5.48	15.64	39.09	5.95	2,993
None	0.00	0.00	0.00	0.00	66.67	33.33	3
Total	27.81	1.62	6.22	18.21	40.68	5.47	5,322

a culture (Shankar, Simons, Levitan, et al., 2010; Shankar, Simons, Shiv, Levitan, et al., 2010; Shankar, Simons, Shiv, McClure, & Spence, 2010), and most certainly between cultures (Shankar, Levitan, & Spence, 2010), sometimes associate different flavors with one and the same color. So, for instance, to give one striking example, the majority of the young Taiwanese consumers tested in one study expected a transparent blue drink to taste of mint, whereas young British consumers expected a raspberry-flavored drink instead (see Shankar, Levitan, & Spence, 2010). By first assessing each participant's flavor expectations elicited by viewing a range of different drink's colors, Shankar, Simons, Levitan, et al. (2010), Shankar, Simons, Shiv, Levitan, et al. (2010), and Shankar, Simons, Shiv, McClure, et al. (2010) were able to predict just how much of an influence the color would likely have on their participant's judgments concerning the flavor of the drink on tasting it.

Elsewhere, in what may well be the largest study of its kind, Velasco et al. (2016) reported on the taste associations elicited by six colored drinks in a sample of more than 5,000 individuals tested as part of the Cravings Exhibition held at London's Science Museum. In this case, the results revealed, for instance, that regardless of the continent from which participants came, the sweetest of the drink's colors shown was red, closely followed by blue and then purple (see Table 1). By contrast, green, yellow, and orange were rarely chosen as colors associated with sweetness regardless of the region from which the participants came.

In terms of the intensity, or saturation, of color and its impact on the tasting experience, the results of the research that has been published to date have been somewhat mixed. Once again, significant effects have been reported in some studies, but not in others. Elsewhere, significant crossmodal effects have been reported for some color intensity manipulations but not others even within the same study (e.g., Shermer & Levitan, 2014; Zampini et al., 2007, 2008; see Spence et al., 2010, for a review). Another factor that may be relevant when thinking about the crossmodal influence of color on tasting is whether the olfactory cues are experienced orthonasally, as when we sniff, or retronasally (e.g., on swallowing). Surprisingly, Koza, Cilmi, Dolese, and Zellner (2005) reported that adding color to a drink enhanced orthonasal odor intensity ratings while, at the same time, reducing the intensity of the same odor when experienced retronasally.

Mechanistic Explanations of Color's Influence Over Taste/Flavor Perception

In terms of trying to understand the mechanism(s) by which color affects the multisensory tasting experience, the body of cognitive neuroscience literature that has been published to date that is directly relevant to this question is currently very limited (see Skrandies & Reuther, 2008, for an isolated attempt to address this question). That said, it is worth noting that when the visual appearance properties of a drink make the taster think that what they are looking at is a specific product, such as Coca-Cola or Slush Puppy Cool Blue raspberry, then this may trigger specific brand associations. Under such conditions, the mechanism by which color influences the tasting experience may well turn out to be much the same as if the participants are led to believe that they are drinking Coke, by any other means. Here, one might think, for example, of the presentation of a label, an image of product packaging flashed briefly on the screen in the brain-scanner, say (e.g., Kühn & Gallinat, 2013; McClure et al., 2004), or following the presentation of any other verbal or written descriptor (see Spence, 2016b, for a review). Note that telling blindfolded participants about the color of the food that they are about to taste (even though they cannot see it directly) has also been shown to influence taste ratings in several studies (e.g., Shankar, Levitan, Prescott, & Spence, 2009). That said, whether such crossmodal influences are more perceptual versus decisional (i.e., reflecting cognitive bias) in nature, is a question that has rarely been addressed (Hidaka & Shimoda, 2014; see Spence et al., 2010, for a review). Another distinction that may be important to consider here is whether the effect of color occurs in more of a bottom-up (perhaps automatic) manner versus in more of a top-down manner (see Spence, 2015).

Interim Summary

To summarize what we have seen thus far, there is a long history of published research concerning the influence of color, be it the color of the food (Spence et al., 2010), its packaging (see Spence & Velasco, 2018, for a review), the plateware/glassware, or even in the environment in which an individual is tasting (Spence, Velasco, & Knoeferle, 2014; see Spence, 2018b, for a review), on multisensory tasting experiences. To date, however, virtually all of the published research has assessed the effects of vision on taste and not the effect *on* color expectations/perception that may be elicited by tasting something (no matter whether that taste either familiar or unfamiliar). It is fair to say that the majority of the researchers working in this area have been much more interested in color's influence on taste, than in the visual (color) expectations that might be elicited on tasting something "sight-unseen" (e.g., as when blindfolded, though see Duncker, 1939; Wan, Zhou, et al., 2014, for a couple of exceptions in this regard).

What is more, the research shows that both the hue and the saturation of a food or drink's color, though mostly it has been the former that researchers have focused on, influences the expectations that are generated in the mind of the taster (see Piqueras-Fiszman & Spence, 2015a, for a review), and thereafter, often also the experience on tasting. That said, it is important to stress that a number of null results have also been reported in this area over the years. That is, participants/consumers have not always been observed to change how they rate a drink when its color has been changed. According to Shankar, Levitan, and Spence (2010), Shankar, Simons, Levitan, et al. (2010), Shankar, Simons, Shiv, Levitan, et al. (2010), and Shankar, Simons, Shiv, McClure, et al. (2010), this can, at least in part, be explained by particular colors being associated with different flavors by different individuals/groups of consumers. It is only when the degree of discrepancy between expectations and experience is small that the former leads to an assimilation effect with regard to the latter (Piqueras-Fiszman & Spence, 2015a; Schifferstein, 2001; cf. Hovland, Harvey, & Sherif, 1957). When the discrepancy between the two becomes too large, one may find that the visual cue is simply ignored as a predictor of the taste/flavor (i.e., it is treated as unrelated) or instead that a contrast effect is reported (see Figure 1). That said, just how much of a discrepancy is needed for this transition from assimilation to contrast to occur is currently not known.

Varying the saturation/intensity of color has also been shown to influence tasting but again does not always. In the latter case, once again, the suggestion is that null results might perhaps reflect there being a mismatch between the expected and perceived taste. Without more research, though, it is hard to know whether crossmodal effects go in both directions, and if so, whether the effects are equally strong: that is, do taste/flavor cues influence visual appearance, as much as visual appearance so clearly affects various aspects of the tasting experience? The visual dominance that is so often seen in human information processing (e.g., Posner, Nissen, & Klein, 1976; Spence, Shore, & Klein, 2001) would certainly lead to the suggestion that the strength of crossmodal effects might well be asymmetrical. Note here, by contrast, that the crossmodal correspondences reviewed in the next section are thought to go in both directions. Furthermore, the strength of the association (or crossmodal correspondence) is often implicitly assumed to reflect the strength of any ensuing crossmodal effect that will be observed.

Crossmodal Correspondences Between Color and Taste

I now want to switch to a consideration of those studies of the associations between color and taste that have started to appear outside of the literature on flavor perception. In particular, a number of researchers interested in crossmodal correspondences (defined as the often surprising associations that people often seem to experience between stimulus attributes/dimensions of experience in different senses that are often seemingly unrelated; see Spence, 2011, for a review) have also started to become interested in the crossmodal associations that people experience between color and taste. Here, associations between colors and tastes or vice versa (remember that correspondences are claimed to be bidirectional or "transitive") may be elicited by asking people to match taste words such as "sweet," "sour," and "bitter" with color descriptors (e.g., "red," "green," and "blue") or, on occasion, a pre-defined set of color patches (see Heller, 1999; Koch & Koch, 2003; O'Mahony, 1983; Tomasik-Krótki & Strojny, 2008; Wan, Woods, et al., 2014). Note here that in contrast to the literature on multisensory flavor perception, those

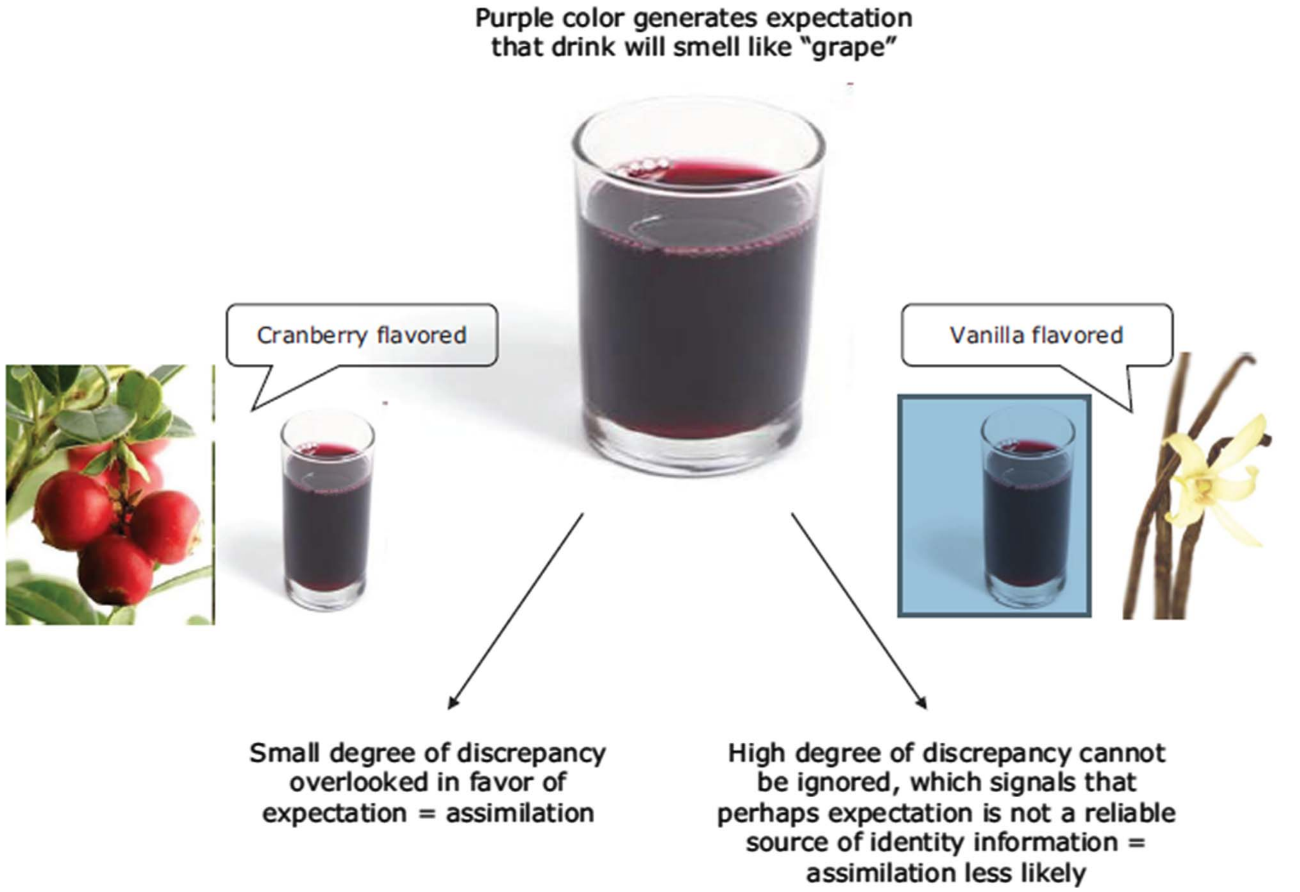

Figure 1. People typically see the color of a drink prior to smelling it (except in the case of drinking from a can). This color can set-up a strong expectation as to what the drink's flavor will most likely be. This expectation can either be confirmed or disconfirmed through experience of the actual stimulus. The prediction is that if the degree of perceptual discordance between the expected and actual stimuli is small, differences may be overlooked in favor of a response that is consistent with this expectation. If, on the other hand, the discrepancy between the expected and actual stimuli is too large, differences may be too great to overlook and to still consider the expectation a reliable predictor of the drink's identity. As a result, assimilation may be less likely to occur. [Figure reprinted with permission from Shankar, Simons, Shiv, Levitan, et al. (2010).]

interested in crossmodal correspondences are seemingly just as likely to ask about the colors that people associate with tastes, as about the tastes that they associate with specific colors (or color words). Crossmodal correspondences are, after all, thought to be robustly bidirectional or transitive (Mesfin, Hussain, Covaci, & Ghinea, 2018; see Deroy & Spence, 2013, for a review). At the same time, however, one might well legitimately ask how such bidirectional crossmodal correspondences link to the crossmodal effects of color on taste documented in the preceding section.

The concern is sometimes raised that any crossmodal correspondences that have been established on the basis of words describing sensations, such as the word "sweet" might give rise to a different pattern of results than when actual sensory stimuli (e.g., tastants) are used (e.g., Simner, Cuskley, & Kirby, 2010; Velasco, Woods, Deroy, & Spence, 2015; Wang, Wang, & Spence, 2016, on this point). On the flip side, however, the problem when using actual tastants is that it may be hard to know just how generalizable a particular crossmodal correspondence is beyond the specific stimulus involved (and/or its intensity). Furthermore, one other potential problem emerges just as soon as one starts to think about the challenges facing someone who might be interested in assessing the color associated with bitterness, given the multiple different bitterants that give rise to the same taste description "it tastes bitter" (see Belitz, 1985; Higgins & Hayes, 2019).

Relevant here, Saluja and Stevenson (2018) recently tested 50 Australian participants with the five basic tastes delivered at three different stimulus intensities (cf. Wang et al., 2016). The participants were given a broad color palate to choose from (they could also pick white, gray, or black; e.g., achromatic colors), and they were instructed to pick the color that matched the taste that they were experiencing. The participants subsequently had to do the same in

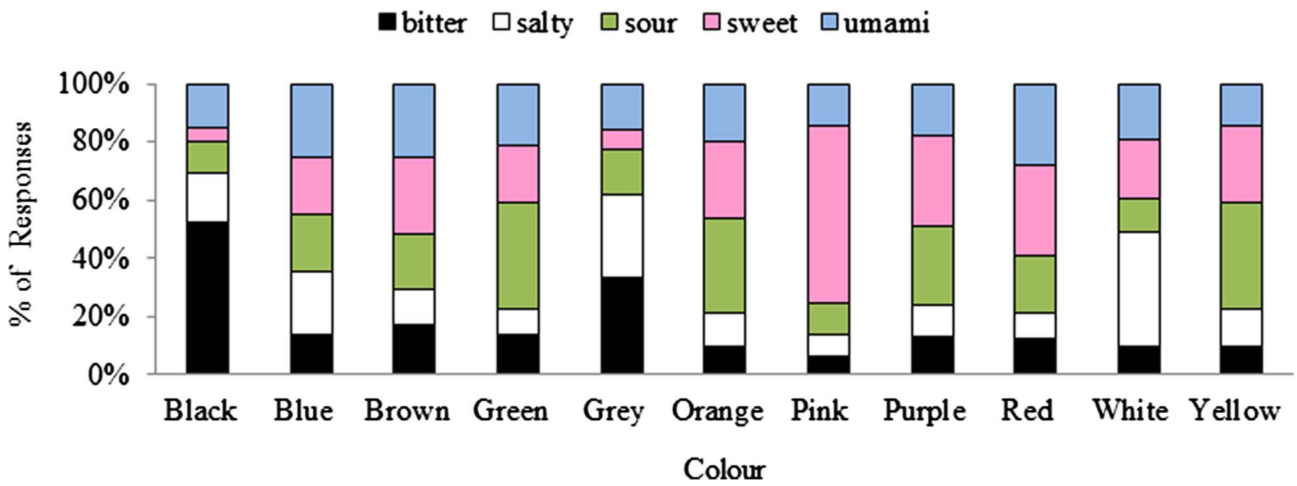

Figure 2. The taste–color correspondences documented by Wan, Woods, et al. (2014). The percentage of bitter, salty, sour, sweet, and umami taste terms chosen for each of the color patches are represented by the colors black, white, green, pink, and blue, respectively. [Figure reprinted from Spence, Wan, et al. (2015).]

response to taste words rather than actual tastants. The results were fairly consistent no matter whether tastants or taste words were used. In both cases, the results were consistent with the majority of the previous research. Summarizing the research on such crossmodal correspondences between colors and tastes that had been published to date, Spence, Wan, et al. (2015) concluded that pink and red were most strongly associated with sweetness, yellow and green with sour, white and blue with salty, and browny/black and purple (or possibly green) with bitter (see Figure 2). The colors associated with the taste of umami have been less intensively investigated thus far and, what is more, have not yet led to especially clear results (see Tomasik-Krótki & Strojny, 2008; Wan, Woods, et al., 2014, for the only two studies to have assessed the color associated with umami). Meanwhile, the piquant/spicy sensation associated with eating chiles, for instance, is also associated with the color red (see Spence, 2018d, for a review).

In the first instance, the interest in any crossmodal correspondences between tastes and colors comes not from food science or food marketing, but rather from a growing curiosity among researchers about the surprising connections that people experience/share between a whole host of seemingly unrelated stimulus features/dimensions, such as between shapes and tastes/flavors (Spence & Deroy, 2013) or aromas (Deroy, Crisinel, & Spence, 2013). In his early work, for instance, O'Mahony (1983) assessed not only the colors of taste but also the days of the week, the states of the USA, etc. that people tend to associate with the four basic taste words. Color was, in other words, treated as a feature/stimulus much like any other (seemingly ignoring color's role as a potentially product-intrinsic cue; see also Chan, Tong, Tan, & Koh, 2013). That said, the discovery of such robust crossmodal correspondences clearly also feeds into the literature on food marketing (e.g., for those considering the best combination of colors to reflect a particular taste or flavor; e.g., see Favre & November, 1979) as well as the marketing of various other products ranging from perfumes (e.g., Jacquot, Velasco, Spence, & Maric, 2016) to paints (Tastecolors, 2015). Indeed, similar crossmodal matching studies have also been conducted with colors and fragrances (Gilbert, Martin, & Kemp, 1996; Jacquot et al., 2016; Levitan, Ren, Woods, Boesveldt, Chan, et al., 2014), though reviewing this literature falls beyond the scope of this review.

Of course, when thinking about correspondences in the abstract, we can start to combine colors and ask whether they connote a specific taste, aroma/fragrance, or flavor better than any individual color patch (see Favre & November, 1979; Jacquot et al., 2016). Woods and colleagues conducted a series of experiments to address this specific question. They had online participants pick which of the four basic tastes they associated with colored squares having one of eight different hues (green, yellow, red, pink, blue, white, black, and purple). The participants were also asked to rate pairs of colors when either presented side by side (Woods & Spence, 2016) or else when one small color square was placed in front of another larger one (Woods, Marmolejo-Ramos, Velasco, & Spence, 2016). Intriguingly, when the stimuli were organized as foreground–background color pairs (e.g., pink on a white background, say), then the associated taste ("sweet") was classified more consistently than when the best of the individual colors was used.

Interim Summary

Separate from the literature that has investigated color's crossmodal influence on multisensory flavor perception (summarized earlier), another, currently much smaller body of research has focused on the relationship between color and taste/aroma from the point of view of the literature on crossmodal correspondences. Relevant here, a number of studies conducted over the last 30–40 years have demonstrated that there are robust associations between tastes and colors and vice versa.[2] That said, different kinds of relationship between the senses may underlie the bidirectional crossmodal correspondence between color and taste/flavor.

Explaining Color–Taste Correspondences

At this point, it is necessary to introduce a distinction between *prothetic* and *metathetic* continua. Prothetic stimulus dimensions can be arranged along a less-to-more continuum (e.g., from less-to-more intense), whereas no such arrangement can be made for metathetically organized colors (hues) or taste qualities.[3] The crossmodal correspondence between hue and taste quality, for instance, is based on a metathetic relationship, whereas the relationship between color saturation and taste/flavor intensity is based on a correspondence between prothetic stimulus dimensions instead (e.g., Spence, 2011; Stevens, 1957).

There are also many polar correspondences where polar opposite pairs of terms, such as "good-bad" and "high-low" are placed on the opposite ends of different continua (e.g., Gardner, 1974; Proctor & Cho, 2006; Schietecat, Lakens, IJsselsteijn, & de Kort, 2018). In the case just mentioned, the polar dimensions would be aligned such that the correspondence was between "high and good" at one end and "low and bad" at the other. Relevant here, some researchers have been tempted to arrange pairs of taste qualities (such as "bitter" and "sweet") at either end of a scale (e.g., see Crisinel et al., 2012, for one such example). It is, however, unclear whether bitter and sweet should be considered as polar opposites, given that one could just as plausibly argue for sweet and sour as opposites instead (Höchenberger & Ohla, in press). As such, it may be better to treat the intensity of individual tastants as prothetic dimensions rather than as a polar correspondence between opposing pairs of taste qualities, as has sometimes been done in the literature.

People's choice of the most appropriate matching taste quality when viewing abstract color patches, or vice versa, might well be mediated by the emotional valence associated with the component stimuli (see Gilbert, Fridlund, & Lucchina, 2016; Karp & Karp, 2001). Emotional mediation has been reported to play some small, but significant, role in explaining people's matching behavior for a number of the crossmodal correspondences reported to date (e.g., see Palmer, Schloss, Xu, & Prado-León, 2013; Schifferstein & Tanudjaja, 2004; Velasco et al., 2015; Wang & Spence, 2017, for a few representative examples).[4] That said, when Saluja and Stevenson (2018) asked their participants on what basis they were making their color choices when matching to tastants or taste words: 72% of participants claimed that they had based one or more of their choices on real-world associations, a couple of the participants (4%) said that they had responded on the basis of valence (read "emotional mediation"), while the remaining 24% of the participants were unable to say on what basis they had made their decisions. Of course, that said, it is possible that statistical analysis might well reveal that emotional mediation is playing a significant role in modulating the crossmodal correspondences that people make between tastes and colors, without the former necessarily being consciously aware that this is what is going on (Wardle, Mitchell, & Lovibond, 2007).[5]

A priori, another possibility is that participants might base their color–taste associations on some kind of perceptual similarity between the sensations involved. However, as argued long ago by Helmholtz, this would seem not to be the case for colors and tastes. As the eminent early psychophysicist once put it:

"The distinctions among sensations which belong to different modalities, such as the differences among blue,

[2] Interestingly, such an association was hinted at much earlier in the writings of novelist Borges (see Borges & Bioy-Casares, 1993).

[3] Adding to the potential confusion here, color categories (Ludwig & Simner, 2013) can also be meaningfully arranged as a circular distribution (see Gilbert et al., 2016). Note that this is not possible for taste qualities.

[4] Given the emotional mediation account mentioned earlier, it is worth noting that some have argued that the relationship between color and emotion may not, itself, be transitive (see Gilbert et al., 2016).

[5] Potentially relevant here, consider only the fact that, when asked in the abstract, most people, regardless of culture, typically mention blue and green as their most preferred colors (e.g., Palmer & Schloss, 2010; though see also Taylor, Clifford, & Franklin, 2013). However, when people are asked about their favorite colors as far as food and/or drink are concerned, then blue and green tend to drop right down in terms of people's rankings. Instead, pinks and reds start to come to the fore (e.g., Spence, 2018a; Walsh, Toma, Tuveson, & Sondhi, 1990). As such, one might imagine that any emotional mediation of color–taste correspondences would likely be sensitive to a range of contextual factors (Schloss & Heck, 2017).

warm, sweet, and high-pitched, are so fundamental as to exclude any possible transition from one modality to another and any relationship of greater or less similarity. For example, one cannot ask whether sweet is more like red or more like blue. Comparisons are possible only within each modality; we can cross over from blue through violet and carmine to scarlet, for example, and we can say that yellow is more like orange than like blue!" (Helmholtz, 1878/1971, p. 77).[6]

This lack of phenomenal/perceptual similarity between color and taste (cf. Marks, 1989, 1995; Melara, 1989) brings into focus the point that crossmodal correspondences need not necessarily imply any kind of phenomenal/perceptual similarity (even if sometimes perceptual similarity may be the basis on which a match is made).

On the Relationship Between Crossmodal Correspondences and Crossmodal Influences

Having briefly summarized the literature on crossmodal influences of color on multisensory flavor perception and the literature on bimodal crossmodal correspondences linking colors with tastes/flavors, what remains to be determined is the relationship between them. If, for instance, people experience a particular correspondence between color and taste, does that necessarily mean that there will also be a crossmodal influence of that color on that specific taste or *vice versa*? At one level, these two literatures appear to be talking about the same thing, namely the relationship between color and taste. Indeed, this is certainly the way in which a number of researchers write (e.g., see Piqueras-Fiszman & Spence, 2015b). Similarly, Higgins and Hayes (2019, p. 362) also appear to conflate these literatures. However, as this review has hopefully already started to make clear, the crossmodal influence of food color on taste that has been demonstrated in food/sensory science and marketing studies may be importantly different from the bidirectional (or transitive) association between taste and color tapped, say, by the literature concerned with crossmodal correspondences. In fact, a closer analysis immediately reveals two potentially important differences (see below). As such, one needs to be careful in jumping from one literature to the other.

Differences Between Crossmodal Influences and Crossmodal Correspondences

(1) Unidirectional Versus Bidirectional Nature of the Relationship

According to the literature published to date, the crossmodal influence of vision on tasting appears to be much stronger than any crossmodal effects that have been documented in the opposite direction (i.e., effects of taste on color perception). This, as we have seen already, certainly fits with the literature demonstrating the visual dominance that characterizes so much of multisensory information processing in human beings (e.g., Posner et al., 1976; Spence et al., 2001). By contrast, crossmodal correspondences are commonly considered to be robustly bidirectional (Parise, 2016; see Deroy & Spence, 2013, for a review). What this means, in practice, is that the crossmodal association between a sweet taste and a pinkish-red color is widely considered to be just as strong as the association between pinkish-red and sweet. Hence, while both literatures support the existence of a relationship between colors and tastes, they diverge with respect to the precise nature of this relationship. As such, the existence of a crossmodal influence of taste on color, or vice versa, cannot be assumed simply because a crossmodal correspondence between the stimuli has been demonstrated.

(2) Relative Versus Absolute Mappings Between the Senses

In the case of stimulus intensity, crossmodal influences on tasting appear to be more absolute than relative or at least that is the way in which several researchers argue in the literature (e.g., Shermer & Levitan, 2014; Zampini et al., 2007).[7] By contrast, prothetic crossmodal correspondences are typically argued to be more relative than absolute (e.g., Brunetti, Indraccolo, Del Gatto, Spence, & Santangelo, 2018; see Deroy & Spence, 2013, for a review). It is, for instance, the higher pitched of two sounds that will be matched with the larger, higher, and lighter of two objects. Crucially, though, there is no precise one-to-one mapping between a specific auditory pitch and a particular size of object, say (see Parise & Spence, 2013). To be clear, the

[6] Note, though, that there is an interesting contrast case here with olfactory–gustatory crossmodal correspondences, where statistical co-occurrence (e.g., in food and drink) does appear to enhance the perceived similarity of the component stimuli, as when smells take on sweet qualities after having co-occurred in foods (e.g., Baeyens, Eelen, Van den Bergh, & Crombez, 1990; Blank & Mattes, 1990; Jones, Roberts, & Holman, 1978; see Stevenson & Boakes, 2004, for a review).

[7] Specifically, when a change in intensity/saturation of color does not modify taste/flavor ratings, researchers often explain the null result in terms of there being too much of a mismatch between the senses, thus implying more of an absolute mapping.

suggestion that emerges from the literature on crossmodal correspondences is that it will be the more intensely colored stimulus that will be matched with the more intense taste/flavor. The actual taste intensity and color saturation values are not thought to matter all that much. Consequently, depending on the stimuli presented, one might therefore expect to find a correspondence without there necessarily being a crossmodal influence on tasting. Remember that in order for the latter to occur, one needs the component stimuli to be close enough for assimilation to occur, rather than, say, contrast or possibly independence (see Piqueras-Fiszman & Spence, 2015a).

Conclusions

As this review of the literature has hopefully made clear, researchers from a wide range of disciplines have been interested in the relation, or association, between colors and tastes/flavors. Over the last 80 years or so, there has undoubtedly been a great deal of interest from food scientists, sensory scientists, and food marketers interested in how best to capture the consumer's attention and deliver the best taste experience by optimizing the color of the product and/or its packaging. Meanwhile, in recent years, a separate empirical literature has emerged documenting the crossmodal correspondences that exist between colors and tastes, flavors, and aromas/fragrances. As yet, however, we have little insight into the neural mechanism(s) underpinning such crossmodal influences and associations (cf. Österbauer et al., 2005). Nor, it has to be said, do we know the exact relationship between the crossmodal influences and connections established by these two literatures. That said, as has just been highlighted, there are undoubtedly some important differences between them, meaning that one certainly cannot make strong predictions from one literature with regard to what will happen (or be found) in the other domain. Looking to the future, it will likely be helpful to use cognitive neuroscience findings in order to try and discriminate more clearly between perceptual versus decisional effects in the case of color's crossmodal influence over taste/flavor (cf. Hidaka & Shimoda, 2014).

At the same time, however, it is also worth highlighting the fact that color-flavor associations sit in a somewhat uneasy/unusual place with regard to the crossmodal correspondences more generally. This is because people can often point to specific stimuli that embody both the color and taste/flavor, thus making this kind of correspondence somewhat different from other crossmodal correspondences where no such obvious co-occurrence of features underlying the association can be postulated (Saluja & Stevenson, 2018).[8] At the same time, however, food color also sits in a somewhat unusual position with respect to multisensory flavor perception – being intrinsic to the food but not constitutive of its flavor. Or, as C. S. Peirce (1868) put it 150 years ago:

> "Sight by itself informs us only of colors and forms [and that] No one can pretend that the images of sight are determinate in reference to taste."

However, that said, just because color is not determinate in terms of taste (i.e., as might be expected to be the case if the two sensory cues were picking up on the same amodal environmental property), one should not take from that that these sensory features are unrelated. Instead, it would appear that color and taste (or perhaps the underlying nutritional properties that are signaled by gustatory stimulus properties) are more-or-less highly correlated in the environment (Foroni et al., 2016; Reinoso Carvalho, Moors, Wagemans, & Spence, 2017; Spence, 2010; Stewart, 2011; Velasco et al., 2016). Though, as was first highlighted by Helmholtz so many years ago, this kind of predictive coding (of taste on the basis of food color) does not imply, nor necessarily even give rise to, any kind of phenomenal similarity (see Kemp & Gilbert, 1997; Marks, 1989). This is one of the key ways in which odor–taste correspondences can be said to differ from color–taste correspondences. While color–taste crossmodal correspondences (especially in the case of food and drink) might well be based on the statistical co-occurrence of features in the environment (see Foroni et al., 2016; Parise, Knorre, & Ernst, 2014; Spence, 2011), it is important to note that emotional mediation also plays some role (especially when the color is presented in the abstract as a color patch or color word). Ultimately, therefore, given that there would appear to be multiple possible relationships between color and taste, establishing the underlying mechanism(s) will likely benefit from further cognitive neuroscience research.

Future Research Questions

- Is the crossmodal influence of color over taste/flavor more perceptual or decisional in nature?
- To what extent, if any, do gustatory stimuli influence color perception?
- To what extent are color–taste correspondences similar to/different from other types of crossmodal

[8] In the case of taste- or smell-shape correspondences, for instance, no one suggests that sweet and round or the smell of black pepper and angularity correspond because they co-occur in some specific environmental object (see Deroy et al., 2013; Spence & Deroy, 2013).

correspondence (such as the correspondence between shape and taste)?
- Are there any meaningful links to be made between color–taste correspondences and synesthesia?
- To what extent do the neural mechanisms underpinning crossmodal correspondences between color and taste overlap with those responsible for color's influence over tasting?

References

Alley, R. L., & Alley, T. R. (1998). The influence of physical state and color on perceived sweetness. *Journal of Psychology: Interdisciplinary and Applied, 132*, 561–568. https://doi.org/10.1080/00223989809599289

Baeyens, F., Eelen, P., Van den Bergh, O., & Crombez, G. (1990). Flavor-flavor and color-flavor conditioning in humans. *Learning and Motivation, 21*, 434–455.

Barnett, A., Juravle, G., & Spence, C. (2017). Assessing the impact of finings on the perception of beer. *Beverages, 3*, 26.

Belitz, H. D. (1985). Bitter compounds: Occurrence and structure-activity relationships. *Food Reviews International, 1*, 271–354.

Blank, D. M., & Mattes, R. D. (1990). Sugar and spice: Similarities and sensory attributes. *Nursing Question, 39*, 290–293.

Borges, J. L., & Bioy-Casares, A. (1993). An abstract art. In L. Golden (Ed.), *A literary feast* (pp. 70–73). New York, NY: The Atlantic Monthly Press.

Brunetti, R., Indraccolo, A., Del Gatto, C., Spence, C., & Santangelo, V. (2018). Are crossmodal correspondences absolute or relative? Sequential effects on speeded classification. *Attention, Perception, & Psychophysics, 80*, 527–534. https://doi.org/10.3758/s13414-017-1445-z

Calvo, C., Salvador, A., & Fiszman, S. (2001). Influence of color intensity on the perception of color and sweetness in various fruit-flavored yoghurts. *European Food Research and Technology, 213*, 99–103.

Chan, K. Q., Tong, E. M. W., Tan, D. H., & Koh, A. H. Q. (2013). What do love and jealousy taste like? *Emotion, 13*, 1142–1149.

Chan, M. M., & Kane-Martinelli, C. (1997). The effect of color on perceived flavor intensity and acceptance of foods by young adults and elderly adults. *Journal of the American Dietetic Association, 97*, 657–659.

Clydesdale, F. M. (1993). Color as a factor in food choice. *Critical Reviews in Food Science and Nutrition, 33*, 83–101.

Crisinel, A.-S., Cosser, S., King, S., Jones, R., Petrie, J., & Spence, C. (2012). A bittersweet symphony: Systematically modulating the taste of food by changing the sonic properties of the soundtrack playing in the background. *Food Quality and Preference, 24*, 201–204.

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.

Deroy, O., & Spence, C. (2013). Weakening the case for "weak synaesthesia": Why crossmodal correspondences are not synaesthetic. *Psychonomic Bulletin & Review, 20*, 643–664.

DuBose, C. N., Cardello, A. V., & Maller, O. (1980). Effects of colorants and flavorants on identification, perceived flavor intensity, and hedonic quality of fruit-flavored beverages and cake. *Journal of Food Science, 45*, 1393–1399.

Duncker, K. (1939). The influence of past experience upon perceptual properties. *American Journal of Psychology, 52*, 255–265.

Favre, J.-P., & November, A. (1979). *Color and communication*. Zurich, Switzerland: ABC-Verlag.

Fernandez, M., & Bahrick, L. E. (1994). Infants' sensitivity to arbitrary object-odor pairings. *Infant Behavior and Development, 17*, 471–474.

Foroni, F., Pergola, G., & Rumiati, R. I. (2016). Food color is in the eye of the beholder: The role of human trichromatic vision in food evaluation. *Scientific Reports, 6*, 1–6. https://doi.org/10.1038/srep37034

Garber, L. L. Jr., Hyatt, E. M., & Starr, R. G. Jr. (2001). Placing food color experimentation into a valid consumer context. *Journal of Food Products Marketing, 7*, 3–24.

Garber, L. L. Jr., Hyatt, E. M., & Starr, R. G. Jr. (2003). Reply to commentaries on: "Placing food color experimentation into a valid consumer context". *Food Quality and Preference, 14*, 41–43.

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

Gilbert, A. N., Fridlund, A. J., & Lucchina, L. A. (2016). The color of emotion: A metric for implicit color associations. *Food Quality & Preference, 52*, 203–210.

Gilbert, A. N., Martin, R., & Kemp, S. E. (1996). Cross-modal correspondence between vision and olfaction: The color of smells. *American Journal of Psychology, 109*, 335–351.

Hall, L., Johansson, P., Tärning, B., Sikström, S., & Deutgen, T. (2010). Magic at the marketplace: Choice blindness for the taste of jam and the smell of tea. *Cognition, 117*, 54–61. https://doi.org/10.1016/j.cognition.2010.06.010

Heller, E. (1999). *Wie Farben wirken. Farbpsychologie, Farbsymbolik, kreative Farbgestaltung* [How color works. Color psychology, color symbolism, working creatively with color]. Reinbek bei Hamburg, Germany: Rowohlt Taschenbuch Verlag.

Helmholtz, H. (1878/1971). *Treatise on physiological optics* (Vol. II). New York NY: Dover Publications.

Hidaka, S., & Shimoda, K. (2014). Investigation of the effects of color on judgments of sweetness using a taste adaptation method. *Multisensory Research, 27*, 189–205.

Higgins, M. J., & Hayes, J. E. (2019). Learned color taste associations in a repeated brief exposure paradigm. *Food Quality and Preference, 71*, 354–365.

Höchenberger, R., & Ohla, K. (in press). A bittersweet symphony: Evidence for taste-sound correspondences without effects on taste quality-specific perception. *Journal of Neuroscience Research*. https://doi.org/10.1002/jnr.24308

Hovland, C., Harvey, O., & Sherif, M. (1957). Assimilation and contrast effects in reactions to communication and attitude change. *Journal of Abnormal & Social Psychology, 55*, 244–252.

Jacquot, M., Velasco, C., Spence, C., & Maric, Y. (2016). On the colors of odors. *Chemosensory Perception, 9*, 79–93.

Johnson, J., & Clydesdale, F. M. (1982). Perceived sweetness and redness in colored sucrose solutions. *Journal of Food Science, 47*, 747–752.

Jones, F. N., Roberts, K., & Holman, E. W. (1978). Similarity judgments and recognition memory for some common spices. *Perception & Psychophysics, 24*, 2–6.

Karp, E. M., & Karp, H. B. (2001). Color associations of male and female fourth-grade school children. *The Journal of Psychology, 122*, 383–388.

Kemp, S. E., & Gilbert, A. N. (1997). Odor intensity and color lightness are correlated sensory dimensions. *American Journal of Psychology, 110*, 35–46.

Koch, C., & Koch, E. C. (2003). Preconceptions of taste based on color. *Journal of Psychology: Interdisciplinary and Applied, 137*, 233–242. https://doi.org/10.1080/00223980309600611

Koza, B. J., Cilmi, A., Dolese, M., & Zellner, D. A. (2005). Color enhances orthonasal olfactory intensity and reduces retronasal olfactory intensity. *Chemical Senses, 30*, 643–649.

Kühn, S., & Gallinat, J. (2013). Does taste matter? How anticipation of cola brands influences gustatory processing in the brain. *PLoS One, 8*, e61569. https://doi.org/10.1371/journal.pone.0061569

Lavin, J. G., & Lawless, H. T. (1998). Effects of color and odor on judgments of sweetness among children and adults. *Food Quality and Preference, 9*, 283–289.

Levitan, C. A., Ren, J., Woods, A. T., Boesveldt, S., Chan, J. S., McKenzie, K. J., . . . van den Bosch, K. J. (2014). Cross-cultural color-odor associations. *PLoS One, 9*, e101651.

Ludwig, V. U., & Simner, J. (2013). What colour does that feel? Tactile-visual mapping and the development of cross-modality. *Cortex, 49*, 1089–1099.

Maga, J. A. (1974). Influence of color on taste thresholds. *Chemical Senses and Flavor, 1*, 115–119.

Marks, L. E. (1989). On cross-modal similarity: The perceptual structure of pitch, loudness, and brightness. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 586–602.

Marks, L. E. (1995). Intermodal similarity and cross-modality matching: Coding perceptual dimensions. In R. D. Luce, D. D. Hoffman, M. D'Zmura, G. Iverson, & A. K. Romney (Eds.), *Geometric representations of perceptual phenomena: Papers in honor of Tarow Indow on his 70th birthday* (pp. 207–233). Hove, UK: Erlbaum.

Masurovsky, B. I. (1939). How to obtain the right food color. *Food Industries, 13*, 55–56.

McClure, S. M., Li, J., Tomlin, D., Cypert, K. S., Montague, L. M., & Montague, P. R. (2004). Neural correlates of behavioral preference for culturally familiar drinks. *Neuron, 44*, 379–387.

Melara, R. D. (1989). Similarity relations among synesthetic stimuli and their attributes. *Journal of Experimental Psychology: Human Perception & Performance, 15*, 212–231.

Mesfin, G., Hussain, N., Covaci, A., & Ghinea, G. (2018). *Inverse and transitivity of cross-modal correspondence in mulsemedia*. IEEE International Conference on Multimedia & Expo Workshops (ICMEW 2018), 23–27 July 2018, San Diego, California, USA.

Moir, H. C. (1936). Some observations on the appreciation of flavor in foodstuffs. *Journal of the Society of Chemical Industry: Chemistry & Industry Review, 14*, 145–148.

Murakoshi, T., Masuda, T., Utsumi, K., Tsubota, K., & Wada, Y. (2013). Glossiness and perishable food quality: Visual freshness judgment of fish eyes based on luminance distribution. *PLoS One, 8*, e58994.

Okajima, K., & Spence, C. (2011). Effects of visual food texture on taste perception. *i-Perception, 2*, 966. https://doi.org/10.1068/ic966

O'Mahony, M. (1983). Gustatory responses to nongustatory stimuli. *Perception, 12*, 627–633.

Österbauer, R. A., Matthews, P. M., Jenkinson, M., Beckmann, C. F., Hansen, P. C., & Calvert, G. A. (2005). Color of scents: Chromatic stimuli modulate odor responses in the human brain. *Journal of Neurophysiology, 93*, 3434–3441. https://doi.org/10.1152/jn.00555.2004

Palmer, S. E., & Schloss, K. B. (2010). An ecological valence theory of human color preference. *Proceedings of the National Academy of Sciences of the United States of America, 107*, 8877–8882. https://doi.org/10.1073/pnas.0906172107

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. https://doi.org/10.1073/pnas.1212562110

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. https://doi.org/10.1073/pnas.1322705111

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

Peirce, C. S. (1868). Some consequences of four incapacities. *Journal of Speculative Psychology, 2*, 140–157.

Piqueras-Fiszman, B., & Spence, C. (2015a). Sensory expectations based on product-extrinsic food cues: An interdisciplinary review of the empirical evidence and theoretical accounts. *Food Quality & Preference, 40*, 165–179.

Piqueras-Fiszman, B., & Spence, C. (2015b). Color correspondences in chemosensation: The case of food and drink. In A. Hirsch (Ed.), *Nutrition and Chemosensation* (pp. 139–158). Boca Raton, FL: CRC Press.

Posner, M. I., Nissen, M. J., & Klein, R. M. (1976). Visual dominance: An information-processing account of its origins and significance. *Psychological Review, 83*, 157–171.

Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin, 132*, 416–442.

Reardon, P., & Bushnell, E. W. (1988). Infants' sensitivity to arbitrary pairings of color and taste. *Infant Behavior and Development, 11*, 245–250.

Reinoso Carvalho, F., Moors, P., Wagemans, J., & Spence, C. (2017). The influence of color on the consumer's experience of beer. *Frontiers in Psychology, 8*, 2205. https://doi.org/10.3389/fpsyg.2017.02205

Saluja, S., & Stevenson, R. J. (2018). Cross-modal associations between real tastes and colors. *Chemical Senses, 43*, 475–480.

Schietecat, A. C., Lakens, D., IJsselsteijn, W. A., & de Kort, Y. A. W. (2018). Predicting context-dependent cross-modal associations with dimension-specific polarity attributions part 1 – Brightness and aggression. *Collabra: Psychology, 4*, 14.

Schifferstein, H. N. J. (2001). Effects of product beliefs on product perception and liking. In L. Frewer, E. Risvik, & H. Schifferstein (Eds.), *Food, people and society: A European perspective of consumers' food choices* (pp. 73–96). Berlin, Germany: Springer.

Schifferstein, H. N. J., & Tanudjaja, I. (2004). Visualizing fragrances through colors: The mediating role of emotions. *Perception, 33*, 1249–1266.

Schloss, K. B., & Heck, I. A. (2017). Seasonal changes in color preferences are linked to variations in environmental colors: A longitudinal study of fall. *i-Perception, 8*, 6. https://doi.org/10.1177/2041669517742177

Shankar, M. U., Levitan, C. A., Prescott, J., & Spence, C. (2009). The influence of color and label information on flavor perception. *Chemosensory Perception, 2*, 53–58.

Shankar, M. U., Levitan, C., & Spence, C. (2010). Grape expectations: The role of cognitive influences in color-flavor interactions. *Consciousness & Cognition, 19*, 380–390.

Shankar, M., Simons, C., Levitan, C., Shiv, B., McClure, S., & Spence, C. (2010). An expectations-based approach to explaining the crossmodal influence of color on odor identification: The influence of temporal and spatial factors. *Journal of Sensory Studies, 25*, 791–803.

Shankar, M., Simons, C., Shiv, B., Levitan, C., McClure, S., & Spence, C. (2010). An expectations-based approach to explaining the influence of color on odor identification: The influence of degree of discrepancy. *Attention, Perception, & Psychophysics, 72*, 1981–1993.

Shankar, M., Simons, C., Shiv, B., McClure, S., & Spence, C. (2010). An expectation-based approach to explaining the crossmodal influence of color on odor identification: The influence of expertise. *Chemosensory Perception, 3*, 167–173.

Shermer, D. Z., & Levitan, C. A. (2014). Red hot: The crossmodal effect of color intensity on piquancy. *Multisensory Research, 27*, 207–223.

Simner, J., Cuskley, C., & Kirby, S. (2010). What sound does that taste? Cross-modal mapping across gustation and audition. *Perception, 39*, 553–569.

Skrandies, W., & Reuther, N. (2008). Match and mismatch of taste, odor, and color is reflected by electrical activity in the human brain. *Journal of Psychophysiology, 22*, 175–184.

Spence, C. (2010). The color of wine – part 2. *The World of Fine Wine, 29*, 112–119.

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

Spence, C. (2015). On the psychological impact of food color. *Flavor, 4*, 21.

Spence, C. (2016a). The crucial role of color in the perception of beverages. In T. Wilson & N. Temple (Eds.), *Beverage impacts on nutrition and health* (pp. 305–316). Totowa, NJ: Humana Press.

Spence, C. (2016b). The neuroscience of flavor. In B. Piqueras-Fiszman & C. Spence (Eds.), *Multisensory flavor perception: From fundamental neuroscience through to the marketplace* (pp. 235–248). Oxford, UK: Elsevier.

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

Spence, C. (2018a). What is so unappealing about blue food and drink? *International Journal of Gastronomy & Food Science, 14*, 1–8. https://doi.org/10.1016/j.ijgfs.2018.08.001

Spence, C. (2018b). Background color & its impact on food perception & behaviour. *Food Quality & Preference, 68*, 156–166.

Spence, C. (2018c). What exactly do consumers see in clear drinks? In *LS:N Global*. July 17th. Retrieved from https://www.lsnglobal.com/opinion/article/22436/what-exactly-do-consumers-see-in-clear-drinks

Spence, C. (2018d). Crossmodal contributions to the perception of piquancy/spiciness. *Journal of Sensory Studies, 2018*, e12476.

Spence, C., & Deroy, O. (2013). Tasting shapes: A review of four hypotheses. *Theoria et Historia Scientiarum, 10*, 207–238.

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

Spence, C., Okajima, K., Cheok, A. D., Petit, O., & Michel, C. (2016). Eating with our eyes: From visual hunger to digital satiation. *Brain & Cognition, 110*, 53–63. https://doi.org/10.1016/j.bandc.2015.08.006

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multimodal prior entry. *Journal of Experimental Psychology: General, 130*, 799–832.

Spence, C., Smith, B., & Auvray, M. (2015). Confusing tastes and flavors. In D. Stokes, M. Matthen, & S. Biggs (Eds.), *Perception and its modalities* (pp. 247–274). Oxford, UK: Oxford University Press.

Spence, C., & Velasco, C. (2018). On the multiple effects of packaging color on consumer behaviour and product experience in the "food and beverage" and "home and personal care" categories. *Food Quality & Preference, 68*, 226–237.

Spence, C., Velasco, C., & Knoeferle, K. (2014). A large sample study on the influence of the multisensory environment on the wine drinking experience. *Flavor, 3*, 8.

Spence, C., Wan, X., Woods, A., Velasco, C., Deng, J., Youssef, J., & Deroy, O. (2015). On tasty colors and colorful tastes? Assessing, explaining, and utilizing crossmodal correspondences between colors and basic tastes. *Flavor, 4*, 23.

Stevens, S. S. (1957). On the psychophysical law. *Psychological Review, 64*, 153–181.

Stevenson, R. J., & Boakes, R. A. (2004). Sweet and sour smells: Learned synaesthesia between the senses of taste and smell. In G. A. Calvert, C. Spence, & B. E. Stein (Eds.), *The handbook of multisensory processing* (pp. 69–83). Cambridge, MA: MIT Press.

Stevenson, R. J., Boakes, R. A., & Wilson, J. P. (2000). Resistance to extinction of conditioned odor perceptions: Evaluative conditioning is not unique. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*, 423–440.

Stewart, J. (2011). Cooking up color. *Gastronomica, 11*, 53–59.

Stillman, J. (1993). Color influences flavor identification in fruit-flavored beverages. *Journal of Food Science, 58*, 810–812.

Tastecolors. (2015). *Colora*. Retrieved from http://www.colora.be/nl-BE/Collecties/Tastecolors on 28/02/2015

Taylor, C., Clifford, A., & Franklin, A. (2013). Color preferences are not universal. *Journal of Experimental Psychology: General, 142*, 1015–1027. https://doi.org/10.1037/a0030273

Tomasik-Krótki, J., & Strojny, J. (2008). Scaling of sensory impressions. *Journal of Sensory Studies, 23*, 251–266.

Velasco, C., Michel, C., Youssef, J., Gamez, X., Cheok, A. D., & Spence, C. (2016). Color-taste correspondences: Designing food experiences to meet expectations or to surprise. *International Journal of Food Design, 1*, 83–102.

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

Walker-Andrews, A. (1994). Taxonomy for intermodal relations. In D. J. Lewkowicz & R. Lickliter (Eds.), *The development of intersensory perception: Comparative perspectives* (pp. 39–56). Hillsdale, NJ: Erlbaum.

Walsh, L. M., Toma, R. B., Tuveson, R. V., & Sondhi, L. (1990). Color preference and food choice among children. *Journal of Psychology, 124*, 645–653.

Wan, X., Woods, A. T., van den Bosch, J., McKenzie, K. J., Velasco, C., & Spence, C. (2014). Cross-cultural differences in crossmodal correspondences between tastes and visual features. *Frontiers in Psychology: Cognition, 5*, 1365.

Wan, X., Zhou, X., Mu, B., Du, D., Velasco, C., Michel, C., & Spence, C. (2014). Crossmodal expectations of tea color based on its flavor. *Journal of Sensory Studies, 29*, 285–293.

Wang, Q. (J.), & Spence, C. (2017). Assessing the role of emotional associations in mediating crossmodal correspondences between classical music and wine. *Beverages, 3*, 1.

Wang, Q. (J.), Wang, S., & Spence, C. (2016). "Turn up the taste": Assessing the role of taste intensity and emotion in mediating crossmodal correspondences between basic tastes and pitch. *Chemical Senses, 41*, 345–356.

Wardle, S. G., Mitchell, C. J., & Lovibond, P. F. (2007). Flavor evaluative conditioning and contingency awareness. *Learning & Behavior, 35*, 233–241.

Woods, A. T., Marmolejo-Ramos, F., Velasco, C., & Spence, C. (2016). Using single colors and color pairs to communicate basic tastes II; foreground-background color combinations. *i-Perception, 7*, 5.

Woods, A. T., & Spence, C. (2016). Using single colors and color pairs to communicate basic tastes. *i-Perception, 7*, 4.

Zampini, M., Sanabria, D., Phillips, N., & Spence, C. (2007). The multisensory perception of flavor: Assessing the influence of color cues on flavor discrimination responses. *Food Quality & Preference, 18*, 975–984.
Zampini, M., Wantling, E., Phillips, N., & 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*, 335–343.
Zellner, D. A., Bartoli, A. M., & Eckard, R. (1991). Influence of color on odor identification and liking ratings. *American Journal of Psychology, 104*, 547–561.

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