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Gastrophysics: Getting creative with pairing flavours

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ABSTRACT

Traditionally, in the West, the decision about which flavours to pair in a tasting experience has been as much the personal choice of the chef or, more likely, the sommelier, as anything else. However, the last couple of decades have seen a rapid growth of research interest in the pairing of flavours. Nowadays, one can find examples of people pairing everything from beer with food, tea with cheese and chocolate, etc. As interest in the marketing potential of flavour pairing has risen, along with the growing public fascination in the topic, scientists have become increasingly interested in trying to understand the principles (both cognitive/intellectual and perceptual) underlying the successful pairing of flavours. In this narrative review, the relative strengths and weaknesses of the chemical, computational (gastronomy), and perceptual approaches to pairing flavours are highlighted. Thereafter, I show how the various principles of pairing (both perceptual and cognitive/intellectual) can be extended beyond the domain of pairing flavour with flavour to consider the rapidly growing are of sonic seasoning. The latter term refers to those situations in which specific pieces of music or soundscapes are matched, or paired, with particular tastes/flavours based on the crossmodal correspondences. The review ends by considering the future development of pairings flavours, and assessing novel means of establishing connections between flavours and other sensations.

KEYWORDS: FOOD PAIRING; FLAVOUR PAIRING HYPOTHESIS; SONIC SEASONING; COMPUTATIONAL GASTRONOMY; DATA ENGINEERING; GASTROPHYSICS.

1. Introduction: Flavour pairing

There can be little doubting that the popularity of food/flavour pairing[1] has grown rapidly in recent years (though see Pastoreli, 2019, on the long history of food and drink pairing). Indeed, the last few years have seen a rapid growth of interest in the pairing of foods/aroma compounds amongst academics (e.g., Harrington & Hammond, 2005, 2006; Harrington & Seo, 2015; Kustos, Heymann, Jeffery, Goodman, & Bastian, 2020; Lahne, 2018), the popular press, and the general public. Over the last decade or two, researchers have been experimenting with pairing all manner of food and drink products, from wine with cheese (Galmarini, Loiseau, Visalli, & Schlich, 2016; Madrigal-Galan & Heymann, 2006) to tea/coffee with chocolate (Donadini & Fumi, 2014; see also Donaldini, Fumi, & Lambri, 2012), and pairing beer with everything from cheese (Donaldini, Fumi, & Lambri, 2013; Donaldini, Fumi, & Newby-Clark, 2015) to Italian food (Donadini, Spigno, Fumi, & Pastori, 2008b; see also Donadini, Pastori, Spigno, & Fumi, 2008a). Recently, rsearchers have also put forward an explanation for the pairing of oysters with Champagne based on the synergy of umami taste (Schmidt, Olsen, & Mouritsen, 2020). World-famous chefs (Blumenthal, 2008), so-called 'molecular sommeliers' (Chartier, 2012), mixologists (Beaumont, 2006), and food and beverage (F&B) brands (e.g., Bellamy, 2005; Harrington, 2008; Sorilla, 2017) have also become increasingly interested in introducing their customers to flavour pairings that move beyond the traditional matching of wine with food (see Spence, 2020a, for a review).

While the majority of the examples of aroma pairing that have been reported in the literature to date have been based on perceived similarity (Galmarini, 2020; Tonkin, 2021), or molecular overlap, which can perhaps be thought of as pairing based on chemical similarity (Chartier, 2012; Coucquyt, Lahousse, & Langenbick, 2020), it is important to note that a wide range of different approaches to pairing have been articulated by those working in the hospitality industry (see Eschevins, Giboreau, Julien, & Dacremont, 2019; Spence, 2020a, for reviews). In fact, similarity-based pairing turns out to be but one of a large number of approaches (c. 15, including perceptual, cognitive, and affective strategies) to pairing as articulated by the 10 sommeliers and 10 beer experts studied by Eschevins et al. And, going beyond the pairing of

[1] To be clear, the terms food pairing and flavour pairing are used synonymously in this review. However, they should be, and are, distinguished from the specific example of the food pairing hypothesis.

food and drink, there has recently been an explosion of interest in the pairing of music (and, on occasion, soundscapes) with food and drink items too. The latter, which has developed out of a fascination with the emerging field of 'sonic seasoning' (e.g., Spence, 2016, 2017b), can also be seen as fitting within a broader interest in 'Sensploration' (Leow, 2015). The latter term has been introduced to describe the growing number of customers who appear to be interested in searching out multisensory (tasting) experiences that help them to explore the surprising (and, in some cases, almost synaesthetic) connections between their senses (see Sachse-Weinert, 2014). Intriguingly, it has been suggested that many, and quite possibly all, of the cognitive/intellectual and perceptual approaches to pairing flavours outlined in **Table 1** might equally well apply when thinking about the pairing of music with food and drink (see Spence, 2020b, for a review). The latter suggestion is one that will be discussed later.

Here, and in the rest of this narrative review article, it should be noted that the term 'flavour', when talking about flavour pairing, is typically used to refer to the pairing of the aromatic contribution to flavour. While a few examples of taste pairing are mentioned (Schmidt et al., 2020), the normal use of the term 'flavour' by scientists incorporates the contribution of taste (or gustation), olfaction, and mouthfeel (see Spence, Smith, & Auvray, 2015). When it comes to texture/mouthfeel, it is worth noting, in passing, how many creative chefs choose to prioritize texture contrast, rather than pairing based on combining similar textures (see Spence, 2017a).

INSERT TABLE 1 ABOUT HERE

1.1. Outline

In this narrative review, the aim is to highlight the growing interest in pairing flavours, be it with other flavours or with sonic stimuli. At the same time, however, I would also like to consider the role that data engineering, what is sometimes euphemistically referred to as 'cooking with data' (cf. Varshney, Varshney, Wang, & Myers, 2013a), or 'food computing' (see Min, Jiang, Liu, Rui, & Jain, 2018, for a thorough review of the latter) may play in helping to advance the field in the years ahead. This will be contrasted with the more traditional methods of behavioural assessment based on laboratory research by sensory scientists. While there would seem to be little hope that computational gastronomy will provide an effective means of predicting novel combinations of flavours that work well together anytime soon, a number of the areas where data engineering is already, or may in the future, contribute to our understanding of the principles understanding successful multisensory flavour perception are nevertheless highlighted. Furthermore, the growing evidence for sonic seasoning, with music increasingly being paired with specific tasting experiences will also be reviewed. The way in which ubiquitous digital technologies (such as mobile and smart phones) may help to spread the opportunity to experience such currently unusual cross-sensory pairings (e.g., via sensory apps) is also highlighted.

2. Computational gastronomy

One of the most popular approaches to pairing flavours emerged out of the field of computational gastronomy and builds on the 'food pairing hypothesis', according to which: "If two ingredients share important flavour compounds, then they will go well together." (Ahn &

Ahnert, 2013, p. 272). A slightly more nuanced definition of flavour pairing has been offered by de Klepper (2011, p. 55) who suggests that: "The more aromatic compounds two foods have in common, the better they taste together. Intriguingly, this effect is particularly strong when two foods share aromas that make up their characteristic flavour." It is interesting to note that some commentators have even gone so far as to suggest that the: "Molecular composition of food dictates the sensation of flavour." (Jain, Rakhi, & Baglerb, 2015a, p. 3).[2] While the latter claim is undoubtedly appealing, it should be stressed that the evidence mostly suggests that predicting the consumers' sensory-discriminative, or hedonic, response to the flavour of real food and beverage products is a surprisingly difficult thing to do, and certainly beyond the current capabilities of computational gastronomy, machine-learning, and artificial intelligence (AI). At best, one can perhaps say that the molecular composition of a food or beverage product narrowly constrains the space of possible flavour experiences, but it certainly doesn't always dictate them (see Spence, 2021d, on this theme). So, while some modest success has been achieved in the case of predicting the perceived qualities of novel odorant molecules (Khan, Luk, Flinker, Aggarwal, Lapid, Haddad, & Sobel, 2007; Zarzo, 2011; cf. Lapid, Harel, & Sobel, 2008),[3] the problem when it comes to real food and beverage products (which are typically composed of several hundred, if not more than 1,000, volatile organic compounds; see Spence, 2021d)[4] relates both to the existence of numerous genetic differences in gustatory and olfactory abilities (e.g., see Reed & Knaapila, 2010; Trimmer, Keller, Murphy, Snyder, Willer, Nagai, Katsanis, Vosshall, Matsunami, & Mainland, 2019), as well as the fact that the consumer's response to many flavourful stimuli is often influenced by their prior exposure, as a result of learning (e.g., Rozin & Zellner, 1985; Stevenson & Boakes, 2004; Zellner, Rozin, Aron, & Kulish, 1983). Hence, without knowing anything about an individual's prior tasting history, it can, for example, be hard to take account of the consequences of any differences in the pairing of ingredients/flavours within a given culture on what is perceived as a good, or perceptually similar, match (e.g., Blank & Mattes, 1990; Rozin, 1983).

2.1. Molecular sommellerie and food pairing

In his book, *Taste buds and molecules*, Francois Chartier describes molecular sommellerie as: "the practice of developing food pairings & food & wine pairings based on dominant aromatic compounds" (Chartier, 2012, p. 211). While Chartier's book is packed with apparently successful food-wine pairings, and the approach has been enthusiastically endorsed by the likes of Ferran Adrià/Juli Soller of elBulli fame, the text itself is short on detail about how exactly such molecular matches are established. For instance, Chartier (2012, p. 92) suggests that: "thymol—the volatile compound responsible for the most important aromatic characteristic of

[2] Though note that this particular claim, which appeared in the preprint, did not make it into the final published article (see Jain et al., 2015b).

[3] That said, olfactory researchers have recently started to make some impressive progress in terms of predicting what novel molecules will smell like (see Keller, Gerkin, Guan, Dhurandhar, Turu, Szalai, et al., 2017), though, at least according to Sell (2006), there are simply far too many uncertainties to make this anything like an exact science. And again, remember that most food and beverage products actually contain several hundred or more volatile organic compounds.

[4] It is, though, worth noting that according to Dunkel, Steinhaus, Kotthoff, Nowak, Krautwurst, Schieberle, and Hofmann (2014) there may be no more than 226 key flavour odorants that substantively contribute to the flavour of food and drink.

thyme—is also the principal sapid (flavor) molecule contained in lamb. This explains the age-old use of thyme in lamb recipes." However, after reading statements such as this, one is left wondering how many of the suggestions in Chartier's book actually reflect intuition and the results of trial-and-error, backed up by molecular explanation, when appropriate, rather than necessarily being led by the molecular composition of foods in the first place. It is perhaps also worth noting here how there are, in fact, many different types of thyme, expressing a distinctive array of olfactory profiles (see Thompson, Charpentier, Bouguet, Charmasson, Roset, Buatois, Vernet, & Gouyon, 2013). It is unclear exactly which kind of thyme Chartier has in mind here.

Chartier (2012, p. 113) also mentions complexity, writing at one point that: "In Europe, cloves are used mainly to enhance the taste of desserts, while in most other parts of the world they serve to render meat's flavour more complex." Here, though, it is important to note that there is simply no one-to-one mapping between chemical structure and perceived complexity (see Spence & Wang, 2018, for a review). And, at least according to research by Wang and Spence (2019), it would seem that both perceptual and cognitive explanations can underpin a taster's decision that a particular flavour experience is, or is not, 'complex' (see also Parr, 2015). While multi-element tasting experiences are undoubtedly often described as such, even unitary taste/flavour sensations may sometimes be described as 'complex' (as was, for example, the case for the participants in Wang and Spence's, 2019, study of wine complexity). That said, confusion between molecular (or chemical) complexity and perceived complexity is one that often occurs in the literature (e.g., see Dunn & Sanchez, 2021).

The global popularity of the food pairing hypothesis[5] was built out of a small number of famous unexpected combinations of ingredients/flavours that appeared to work surprisingly well together, such as, for example, white chocolate and caviar, blue cheese and pear (or whisky), fried onions and chocolate, and balsamic vinegar with strawberries. World-famous chef Heston Blumenthal was certainly a vocal proponent of molecular flavour pairing. As Ahnert (2011, p. 2) notes: "The chef Heston Blumenthal, together with flavour scientists has suggested that two foods that share chemical flavour compounds are more likely to taste good in combination." However, despite Blumenthal's initial enthusiasm, the chef soon came to recognize the shortcomings of the flavour pairing approach. As he stated in *The Times* newspaper: "Looking back at my younger self I'm almost embarrassed at my bumptious enthusiasm, not least because I now know that a molecule database is neither a shortcut to successful flavor combining nor a failsafe way of doing it. Any foodstuff is made up of thousands of different molecules, that two ingredients have a compound in common is a slender justification for compatibility. If I'd known then what I know now, I would probably never have tried this method of flavor pairing: there are simply too many reasons for it not to work. As it was, in my naivety I just got stuck in." (Blumenthal, 2010, p. 45). As the chef put it in his The Big Fat Duck Cookbook: "I soon realised that the molecular profile of a single ingredient is so complex that even if it has several compounds in common with another, there are still as many reasons why they won't work together as reasons why they will… Molecular profiling is a great tool for creativity, but it

[5] Indeed, there was a time, a decade or two ago now, when every research kitchen seemed to have a copy of the eye-catching food pairing poster pinned to its walls. According to one website concerning the Food Pairing book (see https://www.barnesandnoble.com/w/the-art-and-science-of-foodpairing-peter-coucquyt/1137406631?ean=9780228100843, visited on June 1st, 2021), where it is claimed that: "Now over 200,000 chefs and restaurants in 140 countries regularly access the database when designing their menus."

supports intuition, imagination and emotion rather than replacing them." (Blumenthal, 2008, pp. 171-172).

Anecdotal and first person experience with the results of computational gastronomy inspired approaches to novel flavour combinations have often been disappointing. For instance, when Bernard Lahousse of Food Pairing presented at the Brainy Tongue Workshop that was held at the Basque Culinary Centre in San Sebastian, Spain on October 24-26th in 2016 (Redacción, 2016), he created a number of novel cocktails, based on the principles of Food Pairing. However, the drinks mostly remained untouched by the delegates (a combination of chefs and scientists working on the chemical senses/food).[6] Similarly, reports concerning the novel flavour combinations that have been suggested by IBM's Chef Watson have, on occasion at least, also been pretty negative (e.g., see Trout, 2015).[7] Taken together, such observations, should they be representative, again hint at the possibility that predicting successful new combinations of flavours is simply beyond the best of what AI/data engineering currently has to offer. Intriguingly, an online search while research:hing this article (i.e., 6 years after the initial hype concerning Chef Watson raises the question of creativity, and whether it is even possible in the context of AI: "Computational Creativity. The next big question we face in artificial intelligence and cognitive computing is, "Can a computer be creative?"" (https://researcher.watson.ibm.com/researcher/view_group.php?id=5077).

In terms of formal evaluation, there is surprisingly not much evidence, but what there is certainly does not tend to support the food pairing hypothesis. For instance, in "Food Pairing from the perspective of the 'Volatile Compounds in Food' Database," Kort et al. (n.d.) put the Food Pairing Theory to the test in an experiment with untrained participants. However, no support for the theory was found. The authors write that: "food pairings with more aroma overlap did not taste better than food pairings with less overlap. For example, chocolate and tomato (43% overlap) did not taste better than cauliflower and pear (no overlap).…food pairing based on aromatic overlap is not a guaranteed recipe for success. Balancing flavors is what does the trick." (see Bredie, Petersen, Hartvig, Frøst, Risbo, & Møller, 2015, for a similarly pessimistic view).

[6] The first author was understandably rather surprised, therefore, to receive an email recently offering tickets for the latest The Fat Duck offering: "Volume 2 of the Anthology series explores one of Heston's great gastronomic discoveries, flavour pairing. What do caviar and white chocolate taste like together? Curious?...this flavour pairing really is a must try." (Email dated, May 26th, 2021.) That said, there is presumably still a joy/surprise to be had in offering one's guests the pick of the surprising flavour combinations that really do work, regardless of one's belief or otherwise in the underlying food pairing hypothesis.

[7] What should we say about IBM's Chef Watson (https://www.ibmchefwatson.com/community; Bilow, 2014; Kleeman, 2016; Taft, 2014)? On the one hand, one hears those working on the system suggesting that: "…we have developed a computational creativity system that can automatically or semi-automatically design and discover culinary recipes that are flavourful, novel, and perhaps healthy." (Varshey et al., 2013b, p. 14). While the latter claim is undoubtedly true, the more relevant question is how many of the recommendations that Chef Watson comes up with are, in fact, both flavourful or delicious, and original. Writing in *The Chicago Tribune*, Rex Huppke (2015) described IBM's Chef Watson foodie app as nothing more than an overcooked pot of pomposity. While Kleeman notes that "Watson makes suggestions that no human would ever make, like adding milk chocolate to a clam linguine or mayonnaise to a Bloody Mary." before she eventually gives up on the app, while preparing the food for a dinner party.

2.2. Problems with the food pairing hypothesis

A number of potential problems soon reveal themselves when thinking about the underpinning logic of the food pairing hypothesis. For example, early accounts failed to take account of the concentration of particular volatile organic compounds. Potentially relevant here, there are also some compounds whose perceived identity change as a function of their concentration (e.g., Kruger, Feldzamen, & Miles, 1955).[8] Furthermore, cooking can change the nature of ingredients: consider here only how beta-ionone, a violet smell, can emerge on cooking carrots (see Buttery & Takeoka, 2013; Chartier, 2012, p. 203). Again, the approach based on the food pairing hypothesis, at least initially, failed to take account of how the ingredients were processed/cooked. At the same time, however, it is also important to recognize just how frequently ingredients are added to a recipe for non-flavour purposes, such as, for example, to add a dash of colour (Spence, 2018; 2021b; Woolgar, 2018), or to add texture/mouthfeel (Spence & Piqueras-Fiszman, 2016). Think here only of saffron that, at various points in history, has been the world's most expensive spice (Crossley, 2014). It can be argued that this spice's phenomenal cost has had at least as much to do with the golden orangey-yellow appearance that it gives to a dish as to the rather subtle flavour that it imparts (Spence, 2021c). Furthermore, in the contemporary era, the explosion of natural blue food dyes, such as Blue Majik, really only makes any sense in the context of food colouring – given that they often taste foul (Spence, 2018, 2021b).

Acquired taste properties are also an important issue to consider when thinking about creative flavour pairing. This is because a large body of research demonstrates that exposure can change the perceived sensory qualities of food aromas, and thus influence what they are perceived as similar to. Think here only of how in the West, we typically describe vanilla, strawberry, and caramel as smelling sweet (e.g., Blank & Mattes, 1998; Dravnieks, 1985; Jones, Roberts, & Holman, 1978; Stevenson & Boakes, 2004). Interestingly, however, spices such as nutmeg are used differently in different cuisines, and hence are rated as sweeter amongst some consumers than others (e.g., non-white vs. white North Americans, respectively, in the study reported by Blank & Mattes, 1990). At the same time, however, consumers often come to like many flavours that they did not initially like the taste of (e.g., beer, coffee), as a result of their being paired with a rewarding stimulus such as sugar, caffeine, alcohol, or fat (Rozin & Zellner, 1985; Zellner et al., 1983). The 'mere exposure' effect also influences people's liking of flavours, ingredients, or foods (Nacef, Lelièvre-Desmas, Symoneaux, & Jombart, 2019; Nicklaus, Boggio, Chabanet, & Issanchou, 2004; cf. Fondberg, Lundström, & Seubert, 2021).

The food pairing hypothesis also fails to take account of the sometimes marked genetic individual differences such as have been evidenced for cilantro/coriander (e.g., Eriksson, Wu, Do, Kiefer, Tung, Mountain, Hinds, & Francke, 2012; Mauer & El-Sohemy, 2012), and androstenone, in uncastrated boar meat (e.g., Lunde, Egelandsdal, Skuterud, Mainland, Lea, Hersleth, & Matsunami, 2012). In fact, significant differences in pleasantness and sensory threshold have now been reported for a surprisingly large number of food-relevant olfactory stimuli (Reed & Knaapila, 2010; Trimmer et al., 2019). One might also consider the relevance of individual differences in taster status (e.g., Bartoshuk, 1980; Derval, 2010; Kim, Jorgenson,

[8] Though, proponents of the food pairing hypothesis might rightly want to suggest that such volatile organic compounds are few in number, and that the difference in concentration needed to change perceived identity may be unlikely to occur in a naturalistic food context.

Coon, Leppert, Risch, et al., 2003), and/or any individual differences in sweet-liking (e.g., Iatridi, Hayes, & Yeomans, 2019; see also Venditti, Musa-Veloso, Youl Lee, Poon, Mak, Darch, et al., 2020). That said, it could perhaps be argued that any pairing recommendations that are based on molecular overlap should not be affected too much by such genetic differences in taster status, or sweet-liking, as they are likely to affect all foods of a given taste similarly. At the same time, however, it might be stressed here that individual differences in multisensory flavour perception, no matter whether of genetic origin or the result of nurture, are likely to play havoc with any attempt to pair sensations, regardless of whether the approach in based on chemical similarity or perceptual similarity.

2.3. Interim summary: Computational approaches to flavour pairing based on similarity

Regardless of the benefits of the food pairing hypothesis (which, as we have seen, may primarily be in terms of an aid to culinary creativity), it is important to remember that the approach is based on the overlap of volatile organic compounds, so is at best merely a guide to similarity-based pairing. However, as was mentioned earlier, this turns out to be just one of many different reasons for wanting to pair foods/flavours. In an intriguing study reported by Eschevins et al. (2019), the existence of a number of different approaches to pairing were documented as being used by wine and beer professionals in the hospitality industry. Spence (2020a, b) streamlined the 15 categories of pairing principle outlined by Eschevins et al., and organized the 11 remaining categories under the headers of either a cognitive/intellectual or perceptual approach to flavour pairing (see **Table 1**). Note here how complexity and similarity (e.g., at least when based on the food pairing hypothesis) may be most appropriately considered as cognitive rather than perceptual approaches to matching, given the idea is often more appealing than the perceptual matches that actually result.

Recently, Sony AI started to promote a project aimed at providing AI-inspired recipe support (https://ai.sony/articles/sonyai003/). Intriguingly, the first presentation of the new concept was with Chartier at a chef's conference (see Chartier & Kitano, 2019). According to the website, "Sony AI launches the "Gastronomy Flagship Project″ consisting of Research and Development of AI Powered Recipe Creation App". The website continues*:* *"*As an example, when a user selects chocolate and junmai sake, AI suggests ingredients that pairs well (in this case cauliflower, nori and sea urchin and others)." The website also contains the following:

> "Recipe creation is a very challenging research area for AI, as there are infinite possibilities for combinations of ingredients, as well as constraints such as location, climate, season, and a person's health and food preferences, that must be taken into account.
>
> Sony AI will utilize a variety of data sources – including recipes and ingredient data, such as taste, aroma, flavor, molecular structure, nutrients, etc. – to develop a Recipe Creation App that will be powered by proprietary AI algorithms to assist the world's top level chefs in their creative process of ingredient pairing, recipe design and menu creation.

> Through this App, Sony AI aims not only to assist in making delicious food, but also to contribute to people's health and the sustainability of the environment."

However, I am unaware of any formal evaluation of the success of this particular gastronomic AI creativity project as far as predicting flavourful (or should that be delicious) new recipes is concerned. The danger is that it may be no more successful than Chef Watson. That said, that there may be a value in suggesting recipes given a certain set of ingredients that a consumer currently has in their fridge (Segnit, 2019; see also Teng, Lin, & Adamic, 2012). However, bear in mind that this is more an example of getting creative with existing recipes than coming up with a genuinely novel recipe.

As to the ultimate aim of creative flavour pairing, it is presumably to deliver deliciousness (see Spence & Youssef, 2018; see also Dunn & Sanchez, 2021). That said, some innovative chefs have also argued for those combinations of flavours (or dishes) that are 'interesting'. For instance top Michelin-starred Spanish chef Michelin-starred chef Andoni Luis Aduriz's, comment that: *"You know, I went to cooking school decades ago, and there they taught me how to make delicious food. It's not my goal to make delicious food anymore. I want to make interesting food."* (quoted in Ulla, 2012). It has been argued that the molecular gastronomy movement was primarily directed at trying to understand 'deliciousness' (e.g., Barham, Skibsted, Bredie, Bom Frøst, Møller, Risbo, Snitkjær, & Mortensen, 2010; McGee, 1984), though, at least according to some commentators, the attempt has been a failure (see Spence & Youssef, 2018, for a review).

In summary, therefore, is unclear whether there is really any meaningful role for big data, AI, machine learning, or computational gastronomy more broadly when it comes to creating the next generation tasty (i.e., delicious), and possibly also interesting, dishes and/or drinks. That said, there are undoubtedly various areas where the data-engineering approach to cuisine has proved very fruitful, it is just that these cases have little to do with predicting successful new combinations of ingredients; that is, they do not materially inform creative flavour pairing.

3. What has data engineering delivered to gastronomy?

According to the 'antimicrobial hypothesis', the question of what exactly herbs and spices are doing in our cuisine is explained in terms of their helping to avoid microbial infections in foods (Sherman & Billing, 1999; Sherman & Flaxman, 2001; Sherman & Hash, 2001). Support for the hypothesis has emerged from a number of sources, including from computational gastronomy research that has relied on the careful analysis of thousands of online recipes, and occasionally cookbooks. For instance, Sherman and his colleagues have demonstrated a correlation between the mean average temperature of a country and the number of herbs and spices typically used in the recipes of the country (or at least those that have been recorded for posterity; see Dunn & Sanchez, 2021, on the latter point). The suggestion here being that the likelihood of microbial infection increases along with the ambient temperature (especially in the days before the advent of widespread refrigeration). What is more, analysis of recipes by Sherman and Hash (2001) has also highlighted how there are typically more herbs and spices in meat-based recipes than in vegetable recipes, consistent with the greater risk of infection in the former case. That said, it should also be noted that other researchers have failed to find any correlation between temperature and the use of spices when they analysed the cuisines/recipes of the more than twenty distinct cultural regions in China (see Zhu, Huang, Zhang, Zhang, Zhou, & Ahn, 2013). Nevertheless, taken together, the field of computational gastronomy research would appear to have made a substantive contribution to supporting the antimicrobial account of spice use.

Another intriguing strand of computational gastronomy research has given rise to the concept of flavour networks (Ahnert, 2013). The atheoretical search for patterns present in online recipes has revealed some intriguing differences between the cuisines of different cultures. So, for example, Ahn et al. (2011) reported that North American and Western European recipes tend to incorporate ingredients that share flavour compounds, whereas East Asian cuisines tend to incorporate less shared flavour molecules in their recipes than would be expected by chance. Ahn and Ahnert (2013) reported that an analysis of South Korean recipes shared fewer compounds that expected if ingredients were combined by chance. A similar trend toward combining ingredients with different flavour profiles has now been shown to be shared by the cuisine of a number of other Asian countries (Ahn, Ahnert, Bagrow, & Barabási, 2011). According to Ahnert (2013, p. 2): "By comparing the network of ingredients to a body of 56,498 online recipes, downloaded from epicurious.com, allrecipes.com, and menupan.com, we were able to show this hypothesis is confirmed in most Western cuisines, but not in Eastern ones. This result indicates that shared compounds may offer one of several possible mechanisms that can make two ingredients compatible." That is, the computational gastronomy research on flavour networks has highlighted a cultural element to the way in which different aroma compounds are combined.

Subsequently, an analysis of more than 2,500 online Indian cuisine recipes by researchers working at the Indian Institute for Technology in Delhi revealed that ingredients tend to be combined in recipes (the average Indian dish contains seven ingredients) because they are dissimilar (Jain et al., 2015b; see also Bhattacharya, 2020; Ferdman, 2015; Zolfaghifard, 2015). This, then, would appear to be another much more productive direction for research in computational gastronomy than the food pairing hypothesis route discussed earlier. Indeed, several other research groups have since gone on to analyse the statistics of the flavour networks in other cuisines (see, for example, Issa, Alghanim, and Obeid (2018) on the food pairing hypothesis in Eastern Mediterranean cuisine and Tallab and Alrazgan (2016) for an assessment of the food pairing hypothesis in the Arabic cuisine of Syria, Lebanon, Palestine, and Jordan.

What is more, according to an article that appeared in the MIT Technology Review, the research on the flavour network has further brought into question the value of the food pairing hypothesis (see Emerging Technology from the arXiv, 2011). This is both because in countries such as India, Korea, and other parts of Asia, dissimilar (rather than overlapping) ingredients are combined in recipes. However, even in those western cuisines, where ingredients that share molecules are more common than would be expected by chance, it turns out that there are normally just a few key ingredients that are responsible for such effects. When these are taken out of the mix, then there is no longer any evidence for the food pairing hypothesis. Instead, the evidence seems to support the more traditional notion of food cultures being defined by a small number of prototypical ingredients. Here, just consider how, lard, paprika and onion help to distinguish Hungarian cuisine; Note that the idea that different cuisines are identified by small numbers of ingredients was a point first made by the work of Elizabeth Rozin (1983).

Meanwhile, Simas, Ficek, Diaz-Guilera, Obrador, and Rodriguez (2017) argued from their computational gastronomy analysis for food-bridging, a new kind of network construction that apparently 'unveils the principles of cooking.' Though, one might say, that it has more to do with how ingredients are combined in recipes than with cooking *per se*. Another intriguing example of computational gastronomy comes from the work of Veselkov, Gonzalez, Aljifri, Galea, Mirnezami, Youssef, Bronstein, and Laponogov (2019). These researchers used a machine-learning algorithm of random walks on graphs (operating within the supercomputing DreamLab platform) in order to highlight a selection of foods with cancer-beating molecules (typically from amongst the flavonoids, terpenoids, and polyphenols) that they refer to as 'hyperfoods'. Veselkov and colleagues then went on to construct a 'food map' with anti-cancer potential of each ingredient defined by the number of cancer-beating molecules found could be expected to be found therein. Jurafsky (2014) who demonstrated from an analysis of online menus that the average cost of a North American meal increase by an average of six cents for every additional letter in the description of the dish.

Computational gastronomy, machine learning, and AI – have not really provided the insights into creative flavour pairing that were promised (by some). Note that in none of the examples that have been mentioned in this section is the computational gastronomy attempting to say anything about (nor trying to predict) what will taste good. All of the above examples, can rather be positioned as analysis strategies to reveal patterns in existing data sets, and from there possibly extend to identify food stimuli with particular properties (see Veselkov et al., 2019).

4. Flavour-music pairing

There has been explosion of interest in the pairing of music with specific flavours in food and drink. In part, this is linked to the rise of sensory marketing in recent decades (Hilton, 2015 Yeoh & Allan, 2020) and, more particularly, the emerging fascination amongst many younger consumers with Sensploration (Leow, 2015). This interest has also been supported by a growing number of interventions from food delivery companies, chefs (Spence, Levitan, & Youssef, 2021), baristas (Spence, 2020b, 2021a) and food and beverage brands (Spence, 2019a, 2021a). there would, for example, seem to be great potential for home food delivery services, where the take-away, or meal kit, is delivered together with a curated music selection (e.g., a Spotify playlist) designed to enhance, or modify, the consumer's tasting experience through creative flavour pairing (see also Fiegel, Childress, Beekman, & Seo, 2019): Along just such lines, a few years ago, Munchery and Google Play Music teamed up to transform a simple meal into a dining experience by means of creative pairing (e.g., Roncero-Menendez, 2015; Samuely, n.d.). Twice a week from August 17th through September 11th, 2015, as part of the daily menu offering, custom playlists were paired with specific dishes on the website (e.g., 'Coffee Shop Indie Radio' paired with chocolate cake, while 'Sunny Patio Vibes' paired with a lightly grilled chicken dish).

In 2018, Spotify teamed up with the alcohol delivery service Jimmy Brings to create the 'Songmelier Edition', pairing a range of wines with the perfect music (Khale, 2018). Meanwhile, as part of the "Krug Echoes" project, artist and composer Henry Ozark created a number of bespoke musical compositions to match different Krug champagnes, such as Krug Clos du Mesnil 2004, Krug, 2004, and Krug 2006 (see https://www.krug.com/playlist/krug-echoes; https://www.krug.com/krug-lovers/ozark-henry; see also Pilley, 2021). What such examples highlight, I would argue, is the growing commercial interest in flavour-music pairing. That said, in such cases, it is often unclear what the principles of pairing might be.

Moving from the chemical approach to pairing (as stressed by the food pairing hypothesis) to an approach that is based on perceptual/cognitive reasons for pairing undoubtedly makes it much easier to go beyond intramodal pairing into the realm of the crossmodal pairing of music with flavour. At the same time, however, it is also worth remembering that not everyone believes that similarity judgments between the senses make much sense (see Helmholtz, 1868/1971; though see Von Hornbostel, 1927/1950, for a different position). There is probably little benefit in delving further into the nuances of this historic debate here, given the growing body of evidence showing that people are happy to rate certain sounds (but also shapes, colours, and textures) as being more or less similar to (or, at the very least, as corresponding to) a given, taste, aroma, or flavour than others, either when physically present, or else when merely imagined (e.g., in the case of familiar flavours; Spence, 2011a, 2019b; Spence & Levitan, 2021). Nevertheless, it is important to note that establishing a crossmodal correspondence between sensations in different sensory modalities might not necessarily be taken to demonstrate that the stimuli are perceived as being similar to each other. One alternative here might be to consider the connection between the senses as more metaphorical than perceptual in nature (e.g., Marks, 1996; Marks & Bornstein, 1987; Peterson, Fleischhauer, Beseoglu, & Bücker, 2008; Piesse, 1891; Wagner, Winner, Cicchetti, & Gardner, 1981; Walker, 1987; cf. McNeil, 1993 – 1994).

Pairs of stimuli might also be linked because their occurrence happens to be correlated. As an example of the latter, consider only how specific pieces of music may be linked to flavours because they commonly co-occur in food adverts, without the music necessarily being judged as similar to the taste/flavour of the product. The most famous example of the latter perhaps being Hilltop's "I'd like to buy the world a Coke" from 1971 being associated with Coca-Cola (the latter an example of an arbitrary crossmodal semantic pairing (Walker-Andrews, 1994). Furthermore, the occurrence of any kind of crossmodal harmony, or crossmodal perceptual emergence, between particular combinations of chemosensory and auditory stimuli would presumably require the establishment of a 'multisensory gestalt'. However, the latter have been remarkably difficult to demonstrate empirically by those researchers who have investigated the topic in the laboratory over the last century or so (see Spence, 2015, for a review). Hence, while crossmodal flavour pairing is undoubtedly an intriguing area, there are also some challenges that do not occur in the case of intramodal flavour-flavour pairing. Parallels between the flavours and sonic stimuli might exist without there necessarily being any direct crosstalk between the senses (see Spence, 2021e). It is, after all, still uncertain whether the many successful examples of sonic seasoning are best explained in terms of crossmodal priming based on crossmodal correspondences (Wang, Spence, & Knoferle, 2020), or whether this even necessitates the possibility of crossmodal similarity (cf. Helmholtz, 1878/1971; von Hornbostel, 1927/1950). The distinction between perceptual similarity and crossmodal metaphor (where metaphor refers to symbolic, representative, or structural similarity; Montoro, Contreras, Elosúa, & Marmolejo-Ramos, 2015) also deserves further research

4.1. Sonic seasoning

The term 'sonic seasoning' (Spence, 2016, 2017) refers to the use of music to systematically change taste and/or flavour of food and drink experiences by means of matching music. Sonic seasoning has become much more popular in the years since Crisinel, Cosser, King, Jones, Petrie, and Spence (2012) first published their bittersweet symphony paper. The latter publication demonstrated that it was possible to bring out the sweet or bitter notes in a sample of cinder toffee simply by changing the sonic properties of an accompanying soundtrack. In this case, the soundtracks were then incorporated on a restaurant menu at The House of Wolf restaurant (now closed) in North London (see Spence & Piqueras-Fiszman, 2014). At the same, time, however, it is worth stressing that the concept of sonic seasoning is premised on the notion that people can choose music to season food as they see fit. That is, neither the putatively sweet nor the putatively bitter tracks were perfectly matched with the bittersweet taste of the dark chocolate dessert in the restaurant example (or to the cinder toffee in Crisinel et al.'s laboratory study).[9] As such, one might want to consider those examples of perceptual pairing that are designed to modulate (by perceptually suppressing or enhancing) either the bitter or sweet taste, depending on a guest's personal preferences, as sonic seasoning that has a perceptual consequence. Along similar lines, in a marketing-led intervention, the Xin café in Beijing played sweet music with people's drinks, and so enable them to reduce the amount of sugar in their drinks without altering the taste (see Blecken, 2017). Notice, though, how in these latter cases, the music/soundscapes that are paired with the flavour of the food and beverage products are not necessarily the most perceptually similar sonic stimuli to the flavour gestalt. Rather, they are just meant to represent, and hence emphasize, one element of it (e.g., the sweetness in the above examples).

The world of flavour-music pairing has been most extensively discussed in relation to wine (De Luca, Campo, & Lee, 2019; see Spence & Wang, 2015a, b, c, for reviews). That said, there has also been an explosion of interest in sonic seasoning in the world of coffee, from both championship baristas through to Korean coffee-shop where customers sitting at the counter are offered a pair of wireless headphone to listen to music specially chosen to match their choice of coffee (see Spence, 2020b, 2021a). This approach to the sonic accompaniment to the experience of drinking coffee is one that has also been trialled by the mainstream purveyors of coffee such as Starbucks in the UK (Spence, 2011b), and, more recently, Keurig in the US (Spence, 2021). Spence worked with a German composer to create a music track that matched the taste/flavour of Starbucks Via coffee. The track was made available online for consumers to listen to while drinking the company's new coffee product offering at home. Meanwhile, early in 2021, Keurig came out with a series of five Spotify playlists to augment five of the coffee blends that they sell, this time supported by research by Spence and Felipe Reinoso-Carvalho (see Spence, 2021a). The underpinning idea in both of these cases was to offer sonic seasoning to consumers in the home environment. In both cases, the music was composed/selected to match elements of the tasting experience. Semantic/ethnic matching was incorporated as one element in the Keurig playlists: Think Colombian coffee with Colombian musicians (e.g., Shakira). Note here how semantic/ethnic matching presumably counts as a cognitive approach to crossmodal matching (cf. Peng-Li, Chan, Byrne, & Wang, 2020) (see

[9] Sweetness is associated with the following auditory attributes: high pitch, low dissonance, low roughness, legato articulation, consonance and the sound of the piano; Bitterness is associated with low pitch, high roughness, low sharpness, low speed, and the sound of brass instruments (see Knöferle & Spence, 2012; Knoferle et al., 2015).

Table 1). Meanwhile, in 2015, Spence and colleagues worked with Just Eat to optimize the type of music (from 19 musical selections) for five different styles of take-away food in the UK (Sanderson, 2015; Spence et al., 2021).

To date, the majority of such examples of sonic seasoning in the home have been brought to the customer by means of branded multisensory food or beverage experiences (as in the above examples; see also Spence, 2019a), typically as short-term marketing interventions. In the future, however, it would seem likely that more sensory apps will be developed such as the Wine Listening app (http://winelistening.com/), that allow customers to scan any wine label (i.e., regardless of brand) and offer a putatively matching Spotify playlist.

It is also interesting to note how during the recent Covid-19 pandemic, many chefs/restaurants have started to deliver meal kits given that so many restaurants have been closed during the pandemic (Spence et al., 2021). At the upper end of such offerings, those chefs wanting to deliver a truly multisensory dining experience in the home environment have started to offer curated playlists (often available on online platforms such as Spotify) to help augment their guests' meal experience. Thus far, the majority seems to be based on idiosyncratic choices of the chef (see Spence et al., 2021). However, as this review has hopefully made clear, the intersection of creative and scientific approach to pairing flavours, be it with other flavours, or with musical stimuli/soundscapes, would appear to be one that holds great promise for the future. In the latter case, it is likely to become ubiquitous by means of sensory apps and other forms of digital technology.

Researchers have now established musical recommendations for a growing range of taste, mouthfeel/textural, and flavour qualities: In addition to the bitter and sweet soundscapes noted above, these include salty (Wang, Keller, & Spence, 2021), spicy (Wang, Keller, & Spence, 2017), sour (Huisman, Bruijnes, & Heylen, 2016; Mesz, Sigman, & Trevisan, 2012), creamy (Reinoso Carvalho, Wang, Van Ee, Persoone, & Spence, 2017), and body in the case of red wine (Burzynska, Wang, Spence, & Bastian, 2019) etc. (see also Knöferle & Spence, 2012). Meanwhile, musical matches for specific food aromas/flavours, such as vanilla and citrus (Bronner, Bruhn, Hirt, & Piper, 2012), candied orange, crème brûlée, and ginger biscuits (Crisinel, Jacquier, Deroy, & Spence, 2013), or the flavour of particular products has also been reported.

Look closely, though, and it turns out that many food and beverage stimuli actually have a flavour that evolves over time. Such temporal variation is often assessed by means of specialized analysis techniques from the field of sensory analysis such as the Temporal Dominance of Sensations (e.g., Galmarini et al., 2016; Wang, Mesz, & Spence, 2017; see also Charles, Romano, Yener, Barnabà, Navarini, Märk, Biasoli, & Gasperi, 2015; Wang, Mesz, Riera, Trevisan, Sigman, Guha, & Spence, 2019). As such, one might imagine that the optimal musical match for a given food or beverage product should also evolve over time. This has been the approach that Spence has adopted in various creative commercial flavour pairing projects, including with Guinness in 2017 (McGregor, 2017) and with Godiva in 2018 (together with former student Janice Wang). In the latter case, for example, we worked with creative partners in order to develop soundscapes whose musical elements are synchronized with the evolution of the flavour on the palate as a piece of chocolate slowly melted on the tongue. The *Godiva: A symphony of taste* project thus provides a nice example of how musical compositions can be created specifically to match the temporally evolving taste/flavour profile of a complex food such as chocolate.[10]

A carefully-orchestrated piece of music can sometimes also help a consumer to structure their temporally-evolving taste experience (Crisinel et al., 2013).[11] This was demonstrated in one innovative project were a separate instrumental track was associated with each of the dominant olfactory notes in a glass of Courvoisier cognac (e.g., violet flower, candied orange, crème brûlée, coffee, etc). Initially, the idea was that people would sniff each distinct aroma while listening to the matching instrument (a set of six customized scents was sent out to a select group of premier customers). Thereafter, they were supposed to taste the drink while listening to a musical composition that incorporated elements from each of the individual tracks. The idea was that the temporal structure of the music (with different instruments tied to different aroma notes) would enable the consumer to better pick out the various distinctive elements in their tasting experience. A similar approach has been adopted more recently by chef Jozef Youssef (of Kitchen Theory fame) and sound designer Steve Keller in a project for Chivas whisky ('The Sound of Chivas Ultis', 2017).

However, while music can undoubtedly be created to match the specific temporal evolution of the flavour of a specific food or beverage product, this is clearly a niche undertaking. As such, the cost of engaging in such a creative challenge will likely represent a barrier to the widespread optimization of music with specific flavour experiences in the future. As such, more basic sonic seasoning examples, such as those mentioned above with the accentuation of sweetness, may be expected to be the most commonly encountered examples of flavour-music pairing in the years ahead (Blecken, 2017; Crisinel et al., 2012).

Returning to one of the themes that was mentioned earlier, one might wonder about individual differences in chemosensory perception and what impact they may have on the crossmodal matching of music with flavour. While there is little research directly on this topic, what research there is from Crisinel and Spence (2012) demonstrated that a group of dark chocolate likers and a group of dark chocolate dislikers picked essentially the same auditory stimulus as matching the taste of dark chocolate (despite differing significantly in terms of their liking for the food stimulus). One other individual difference, namely the difference in taster status may also play a role here, given the suggestion that when supertasters match the intensity of the their (bitter) taste sensations to a sound intensity, they tend to choose a louder sond than do non-tasters or medium tasters (Marks, Stevens, Bartoshuk, Gent, Rifkin, & Stone, 1988). Elsewhere, Knöferle, Woods, Käppler, and Spence (2015) were able to demonstrate that four variants of a short musical composition composed to correspond to each of the four basic tastes, established by research on Western participants, could be mapped on to the intended taste at a level that was almost as consensual by a group of participants from India. Specifically, a group of North American participants concurred with intended taste on 77% of trials, while that figure was 72% in an online sample of Indian participants.

At the same time, however, given that emotion has been shown to influence the mapping in many crossmodal correspondences (Spence, 2011a; Wang & Spence, 2017), one might

[10] See https://www.youtube.com/watch?v=wvH_fYCoPzs; https://www.youtube.com/watch?v=rph6oyIEJ9o.

[11] Zooming out, one might also consider the similarities not just in the structure of the tasting experience with a musical excerpt, but the structure of meals and music more generally, as highlighted by Rozin and Rozin (2018).

reasonably expect to pick-up somewhat different mappings, at least for those crossmodal correspondences based primarily on emotional mediation. Note here also that while some aspects of music appear to be fairly universal, salient culture-specific differences have also, on occasion, been reported (at least amongst more remote populations). So, for example, various aspects of music, such as harmonic organization appear to convey both universal and culture-specific meaning (Athanasopoulos, Eerola, Lahdelma & Kaliakatsos-Papakostas, 2021; McDermott, Schultz, Undurraga, & Godoy, 2016; Walker, 1987). Nevertheless, the key point to stress is that thus far, the research has suggested that sonic seasoning, and creative flavour-music pairing have been shown to be robust to individual differences, be they the result of nature or nurture (at least when tested amongst westernized populations with access to the internet).

5. Why bother pairing (flavour) sensations

One might question the benefits of pairing wine with food, or, for that matter, music with food and drink. With regard to the first point, Mike Steinberger (2006), wrote 15 years ago now that: "If one were to compile a list of the least-significant issues confronting mankind in the first decade of the 21st century, the question of wine's compatibility with cheese would surely rank high." Similarly Ferran Centelles (2014), former head sommelier at the El Bulli restaurant, stated on Jancis Robinson's website that: "I keep recalling the realistic statement Jancis made during the International Culinary Forum in Barcelona in September 2012: 'we would be sending out a very negative message if we gave people the impression that finding the perfect pairing is terribly important and that something would go wrong if you just drink what you wanted and ate what you wanted'. I could not agree more with that. I strongly believe that matching is overvalued on many occasions and sometimes it receives exaggerated attention from consumers and professionals."

Over the course of human history, the majority of food and drink experiences have been of this sort – that is, more or less arbitrary combinations (though see also Pastoreli, 2019). The question is whether anything magical, or extraordinary, can emerge when the combination of flavours works especially well together (Spence, 2020b). The general public's interest in pairing suggests that consumers do see value in this kind of activity, though my sense is that the results of especially good pairings rarely tend to be exceptional in the case of food and beverage (i.e., flavour-flavour) pairing. Oftentimes, in fact, the recommendations are as much about what not to pair, to avoid unpleasant combinations, e.g., as was traditionally the case for the metallic taste that would sometime result from pairing red wines with white fish (Tamura, Taniguchi, Suzuki, Okubo, Takata, & Konno, 2009; and see Spence, Wang, & Youssef, 2017, for a review).

As in so many things, there has been more research on wine pairing with music than for pretty much any other food or beverage product (see Spence, 2019a, 2020d; Spence & Wang, 2015a, b, c, , for reviews; see also Campo, Reinoso-Carvalho, & Rosato, 2021). However, not all wine experts appear convinced of the benefit, one comes across wine experts, such as Alex Hunt, MW (2015), asking: "Why then, I have been wondering, do I get creeped out by things like 'wine and music matching'? After all, although I favour an informal approach to wine and food pairing, I think this particular matching exercise can be fun, and have no fundamental objection to it. Substitute tracks for snacks, however, and I instinctively cringe. Part of it is probably pretension, as exemplified by a gem of an album discussed by Richard in a recent Noble Rot article: Jazz For Wine Tasting (or the Vineyard Jazz: Wine-Tasting Music Series). The pieces carry names like 'Burgundy', 'Zinfandel' and 'Riesling'. Texturally they are near-indistinguishable." Of course, the fact that some wine-music matches might be nothing more than superficial and pretentious certainly doesn't mean that they all are! Hunt also queries whether wine-music events are anything more than merely "a bit of harmless fun". "Why mess with the skilled winemaker's art?" Hunt seems to be asking when he posed the following question on Jancis Robinson's website: "Why spend time trying to unearth the music that will improve a particular wine when you could instead just try to find a wine you like in the first place?" Such a point of view misses, the possibility that it is the very experiencing of some kind of unexpected connection between such seemingly different sensory inputs (e.g., music and wine) that many find rewarding/enjoyable in its own right (cf. Leow, 2015, on the notion of Sensploration). Note that this joy in the matching can presumably be experienced no matter what the inherent merits of the wine may be (see also Joe, 2014).

There can also be a positively-valenced 'aesthetic aha' from making sense of a combination of stimuli that, at first, makes little sense (Muth & Carbon, 2013; cf. Spence & Youssef, 2016). Such responses would appear more likely when music paired with flavour than simply by the combination of flavours combined in a dish, or in a food and beverage pairing, say. Indeed, one answer to the question of what may emerge from a particularly well-chosen combination (or pairing) comes from James John, Director of the Bath (now Bristol) Wine School, concerning the combination of Mozart's Laudate Dominum with Chardonnay: '[…] Just as the sonant complexity is doubled, the gustatory effects of ripe fruit on toasted vanilla explode on the palate and the appreciation of both is taken to an entirely new level' (as quoted in Sachse-Weinert, 2012).[12] Such suggestions, note, stand in direct contradiction to the MW Alex Hunt's (2015) claim that there is: "… is no transcendent effect here. I see no claims, and have never experienced, a wine and music pairing that takes the wine to a completely different plane of enjoyment – it just tastes like better (or worse) wine." Ultimately, I would like to argue that in the best cases, multisensory experience design that deliberately combines flavourful and sonic elements in paired flavour experiences can sometimes lead to extraordinary perceptual responses (see Spence, 2020c; see also Brennan, 2020).[13]

At the same time, however, beyond the possible delivery of extraordinary tasting experiences through pairing, it is worth noting that effective pairing, be it of flavour with flavour, or flavour with music may potentially be used to promote healthy eating and enhance nutrition (as suggested by Sony AI; https://ai.sony/articles/sonyai003/) as well as a route to the reduction of unhealthy ingredients (see Blecken, 2017; Wang, Mielby, Junge, Bertelsen, Kidmose, Spence, & Byrne, 2019).

6. Future approaches to pairing (flavour) sensations

[12] The participants in Holt-Hanson's (1968, 1976) early studies of the pitch of hamony between beer and pure tone also reported some pretty extraordinary experiences (though see also Reinoso Carvalho, Wang, De Causmaecker, Steenhaut, Van Ee, & Spence, 2016; Rudmin & Cappelli, 1983).

[13] Here it is perhaps also worth noting how in the early 17th Century in central Europe, there briefly flourished a music, known as *Tafel music* (i.e., table music) that was designed specifically to be listened to at mealtimes (Littler, 1989; Reimer, 1972). That said, no attempt was made to pair specific foods or flavours with particular compositions.

Previously, what started out as an essentially intuitive approach to pairing music with wine (see Spence & Wang, 2015a)[14] has increasingly become a data-driven scientific undertaking. Furthermore, given numerous sonic solutions to match each of the basic tastes, it has been possible to present the many musical selections/compositions and establish, empirically, which are most strongly linked to each of the basic tastes (Wang et al., 2015). Thereafter, one is able to assess empirically in what physical parameters that are most relevant to a specific taste. Such research, for instance helping to cement the association between low pitch and bitter taste.

Looking to the future, it would also seem worthwhile to explore whether it might be possible to generate novel sonic associations / solutions based on the analysis of online language corpora. There is, for example, already evidence that such an approach can pick-up on various implicit gender and racial associations that people hold (i.e., Caliskan Bryson, & Narayanan, 2017). Thus, the suggestion is that novel flavour-music pairing suggestions might also emerge from online analysis rather than, as has recently been the case, from testing large numbers of participants (e.g., see Reinoso-Carvalho et al., 2019, 2020; Wang et al., 2021). So, for example one might expect that the word 'sweet' and its derivatives would appear closer to the word 'piano' than 'brass', and closer to 'high pitch' than to 'low pitch', given the crossmodal correspondences that have been established by the empirical research that has been conducted in the laboratory (Crisinel & Spence, 2010; see also Kennedy, Ashokkumar, Boyd, & Dehghani, 2021). At the same time, however, one would presumably also need to factor in any differences in word frequency that could presumably help to obscure the pattern of results obtained.

There is also growing interest in what analysis of social media feeds may have to offer the researcher (e.g., see Arellano-Covarrubias, Gómez-Corona, Varela, & Escalona-Buendía, 2019; Vidal, Ares, Machín, & Jaeger, 2015). One might want to trawl through such textual sources for evidence of especially good flavour pairings, or music-food matching (cf. Jurafsky, Chahuneau, Routledge, & Smith, 2014). Another intriguing approach to trying to home in on optimized design solutions (i.e., musical selections) to match specific taste/flavour attributes is to consider using genetic algorithms (cf. Yang, 2014), which have been demonstrated to offer efficient solutions to various optimization problems. One could, for example, imagine running large online studies to home in on the optimal musical parameters to convey a specific taste/flavour quality.

One important point to note here, though, is that the latest research that has compared the effects of sonic seasoning (using music to accentuate a specific taste in food) to sensation transference (this, the idea that what we feel about the music will be transferred to what we think about whatever we happen to be tasting; cf. Cheskin, 1957) has revealed that the enhancement of the tasting experience from pairing with a more liked (as compared to a less liked) piece of music tends to be significantly larger than the change in taste/flavour qualities that is associated with sonic seasoning (see Reinoso-Carvalho, Gunn, Molina, Narumi, Spence, Suzuki, ter Horst, & Wagemans, 2020; Reinoso-Carvalho, Gunn, ter Horst, & Spence, 2020). Now, of course, one might wonder whether this reflects anything more than just the specific musical choices, or perhaps the fact that sonic seasoning to modify tastes has yet to be optimized. Such results do, though, raise the possibility that the optimal sensory app to pair music with the taste of

[14] Pete Brown, the British beer writer, has also gone for such an idiosyncratic approach to pairing in his beer and music talks (see Brown, 2012).

everyday food and drink products would be either to select the music from an individual's music library with the most appropriate sonic properties or else to offer a tasty-EQ function to adapt the sonic properties of music to match the flavour profile, or offer the desired type of sonic seasoning – should one want to modify the tasting experience to make the taste sweeter, add a little spice, or perhaps a little salt, then the pitch/tempo etc. of a consumer's favourite musical selections could be adjusted accordingly. Or else, a consumer's music library could be analysed to find the music that most closely approximates the desired musical characteristics for enhancing a given taste quality. However, more generally, our sense is that while we may get better and better at composing music to match, and hence accentuate taste attributes, or perhaps to suppress an undesirable taste attribute, it remains the case that music specially composed to match taste/odour/flavour is simply unlikely to deliver anything like the same emotional punch as professionally composed, popular music. And, given the consumer's familiarity with adding salt, pepper, or sugar to season the food and drink they consume, perhaps these would be the most obvious sonic seasonings for the consumer. However, while a number of sweet and salty musical compositions have now been validated, I am unaware of anyone having proposed a form of sonic seasoning that might deliver equivalent perceptual effects as ground black pepper.

7. Conclusions

Although there is a long history of food being paired with wine and other drinks (see Pastoreli, 2019), the more general pairing of (flavour) sensations, be it with other flavour sensations, or with sound/music has, in recent years, taken on a life of its own. The research reveals that a large number of approaches to pairing, both cognitive/intellectual and perceptual, have been adopted by practitioners/researchers. Intriguingly, the majority of these various approaches to pairing would appear to work equally well regardless of whether one is pairing food with drink, or flavours with sound/music. What is more, the more intelligent pairing of flavour sensations, both intramodally and crossmodally, may ultimately have an important role to play in promoting healthy eating behaviours, as well as perhaps, on relatively rare occasions, leading to extraordinary multisensory tasting experiences. However, as yet, it would appear to be that the successful pairing of sensations is at least as much an art as a science, despite the best efforts of the computational gastronomists.

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