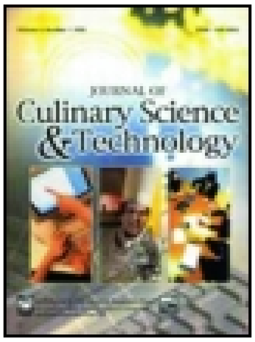

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Food Perception and Aesthetics - Linking Sensory Science to Culinary Practice

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ABSTRACT

This systematic overview tries to link scientific knowledge on human perception and appreciation mechanisms to culinary practices. We discuss the roles of the human senses during eating, starting out with basic mechanisms of taste and smell perception, up to principles of aesthetics. These insights are related to how foods are experienced, how ingredients are combined, the use of flavor bases in cuisines, the creation of a full course meal, the choice of a beverage with a dish, and how people learn to appreciate new foods.

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Introduction

Food service outlets, restaurants, bars and hotels provide a substantial part of people's food provision, and their role has continued to increase over time (e.g., Binkley, 2006; Saksena, Okrent, & Hamrick, 2018), however, there is currently only a weak connection between food science research and the culinary arts and hospitality education of chefs. A large part of a chef's training focuses on the acquisition of technical preparation skills (Eren, 2018; Müller, VanLeeuwen, Mandabach, & Harrington, 2009; Pratten, 2003), and during these practical experiences the chefs obtain insights in the effects of culinary determinants, such as ingredient quality, ingredient mixing ratios and preparation methods by tasting the end results of their endeavors. Although countries may differ in the education they offer for chefs, varying from a dual training system combining school with working in a restaurant (e.g., in Germany) to culinary institutes with bachelor, master and associate degrees (e.g., in the US), gaining practical experience in the kitchen seems key. Later on, in their professional life chefs tend to know their clientele by experience. They choose recipes and ingredients, determine the production process and the composition to be created using their personal vision of the menu to be offered (Giboreau, 2017). By presenting chefs with more systematic knowledge on human perception and appreciation mechanism, we hope to contribute to

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the chefs' conceptual knowledge and, thereby, improve their insights in the effects of their culinary handlings and facilitate their creative processes. In this way, scientific insights could contribute to a more efficient and successful hospitality sector. Conversely, we hope that the current paper will also increase the interest of sensory investigators in gastronomic and culinary processes.

Some recent developments have already improved the connections between various scientific disciplines and the hospitality sector. For instance, the interest of chefs in principles of food science has sparked a creative culinary renaissance, resulting in the naissance of molecular gastronomy (Barham et al., 2010; This, 2006) and several world-renowned chefs like Ferran Adrià (Adrià, Soler, & Adrià, 2008; García-Segovia et al., 2014; Perrone & Fuster, 2017), Heston Blumenthal (Blumenthal, 2008; Edwards-Stuart, 2012), and René Redzepi (Redzepi, 2010, 2015) have created their own culinary laboratories in which they experiment to develop and optimize their recipes and eating experiences. In addition, we see an increased interest in scientific disciplines to study gastronomic experiences and processes. For example, Mouritsen (2012) has used the term *gastrophysics* to refer to advances in the physical sciences that stimulate the scientific study of food. Spence (2017) proposes the same term for a different subject matter, *viz.* scientific studies on the effects of the design of the eating context on the perception and evaluation of food (Piqueras-Fiszman, Varela, & Fiszman, 2013). Besides these two fields, we see interests from researchers in neuropsychology (Shepherd, 2011), artificial intelligence (Amorim, Góes, da Silva, & França, 2017; Varshney et al., 2019), digital manufacturing (Zoran & Coelho, 2011) and engineering (Aguilera, 2017).

In this paper, we try to contribute to strengthening the link between scientific research and culinary practice by focusing on the sensory perception and the aesthetic appreciation of food when used in the kitchen, while being served and presented, and during eating. We complement the other scientific approaches by describing the mechanisms of sensory perception and their effect on aesthetic appreciation that are relevant for understanding food experiences as they have been studied in experimental psychology, sensory science, and experimental aesthetics. We try to link these mechanisms to phenomena that can be observed when tasting and eating foods, and we indicate how some of these insights might be used to develop new food products and to improve people's interactions with foods.

The role of the senses in food perception

Food products are a unique subset of consumer products in that sensory experiences during interaction with them can involve all of the senses: vision, touch, audition, smell, and taste (Schifferstein, 2006). People smell aromas just before food enters their mouths; when the food is in the oral cavity, they perceive taste and food flavors that reach the olfactory epithelium in the nasal cavity via the retronasal pathway at the back of the mouth. People also feel the rough, smooth, sticky, or slippery surface of the product on their tongues and they feel the thickness, hardness, elasticity, and stiffness of the product mass in their mouths when they masticate. In addition, they hear the crunching, crackling, crispy sounds while they bite, and possibly the soft smacking and slurping sounds while they chew and swallow. In some cases, you might even perceive the movement of food in your mouth. For instance, in Japan you may be presented with Katsu ika odori-don, the so called dancing squid bowl (Richayanami, 2010), which consists of a freshly killed cuttlefish atop either rice or noodles. Upon pouring soy sauce on the squid, it seems to wriggle as its muscles contract in response to the sodium in the sauce (Gates, 2017; Schrader, 2019). Another example concerns sherbet powder, which is used in Kaktus ice-cream (Schoeller, 2020) and works similarly to Alka-Seltzer. This powder contains a mixture of a powdered acid and a powdered base that react when mixed with moisture, and produce a fizzy effect in water or a tingling effect when mixed with saliva on the tongue (Helmenstine, 2019). The perception of sensory information is the starting point for how a food product is experienced: whether it is pleasing or not, the cognitive associations and meanings it evokes, the actions it triggers, and the emotional responses that it may elicit (Brakus, Schmitt, & Zarantonello, 2009; Hekkert & Schifferstein, 2008; Vyas & van der Veer, 2006).

In this paper we describe the relationships between how food products are perceived and how this can contribute to pleasant experiences. We first focus on how food products are perceived through the various sensory modalities by describing some of the mechanisms that explain how the physical characteristics of food products can evoke sensations like sweetness, stickiness or pungency. Although we discuss mechanisms in all sensory modalities separately, we also describe some of the ways in which the senses interact. In addition, we describe the ways in which perception in multiple modalities can contribute to the pleasantness that people experience when eating foods. Hence, we use the term "aesthetics" here in terms of "gratification of the senses" or "sensuous delight", in line with the eighteenth-century philosopher Baumgarten (Goldman, 2001; Hekkert, 2006) and not to imply simply the visual appearance of the food.

A questionnaire study in which participants reported the importance of the sensory modalities during the usage of 45 different everyday products (Schifferstein, 2006) demonstrated that on average the relative importance sequence of sensory modalities is vision, followed by touch, smell, audition and taste. However, the importance ratings for the sensory modalities differed greatly between the different products. For food products taste was judged to be most important, generally followed in descending order of importance by smell, visual appearance, tactual properties, and lastly, sound. In this paper, we ordered the discussion of perception mechanisms following this importance hierarchy, beginning with the sense of taste and ending with the sense of audition. Additionally, earlier sections are more elaborate than later sections, as they are more relevant and studied in the context of food products.

Taste perception

Receptors

Taste perception occurs when people insert food products in the mouth. Taste receptor cells are mostly found in taste buds that are distributed over the tongue, where many can be found in structures called papillae. The taste receptor cells can only distinguish between a handful of taste qualities. The detection of each of these qualities can be linked to a number of substances that are directly relevant for human functioning. The sweet quality allows for the detection of sugars and sweeteners – many of which are carbohydrates and contribute to the energy provision of the body. The salty quality is related to the detection of ions, such as Na^+ and K^+, which are important for ionic homeostasis in the body and play a role, for instance, in the conduction of nerve pulses. Umami is a savory taste quality that is relevant for the detection of L-amino acids, which signals the presence of proteins that are important for muscle growth and the detection of ribonucleotides that are constituents of DNA and RNA. Although sweet, salty and umami tastes have generally evolved to indicate beneficial foods to consume, sour and bitter tastes likely evolved to indicate foods that may be harmful to consume. The sour quality detects the presence of acids in unripe fruit and spoiled foods, whereas the bitter quality detects plant alkaloids, many of which are toxic and need to be avoided (Kinnamon, 2012).

The sensitivity for the various taste qualities is unevenly distributed over the human tongue. However, the tongue maps that you can find in many textbooks that assign the qualities to very specific tongue areas are overly simplistic. Most areas of the tongue can perceive all taste qualities, but the sensitivity varies considerably. For instance, Boring (1942) shows that that sensitivity at the tip of the tongue is highest for sweet, followed by sour, salty, and bitter. Sensitivity for bitter is low at the tip and sensitivity for sweet is low at the back, but sensitivity for sour and salty seems to be fairly high all over the edges of the tongue. These data concur quite well with the maps of distribution of receptors that can be found in Gray's Anatomy (Standring, 2015). Here we see another striking difference between sweet and bitter receptors: Whereas sweet receptors are mainly found on the edges of the tongue, the bitter receptors are mainly prominent in the middle of the tongue at the base. In addition, bitter receptors can also be found in the throat and on the palate (Collings, 1974). As concerns umami, sensitivity seems to be low at the front of the tongue and higher at the back (Satoh-Kuriwada et al., 2014). Moreover, IMP and MSG seem to taste salty rather than umami at the tip of the tongue (Yamaguchi, 1998). Designers may be able to address the uneven distribution of taste receptors over the tongue when they develop drinking vessels. For instance, wine glass manufacturer Riedel suggests that the slightly flared rim of their Burgundy Grand Cru glass "directs the wine to the tip of the tongue, highlighting the fruit and balancing the naturally high acidity" (Adams, 2018).

Taste intensity perception

When we increase the concentration of a tastant, the perceived sensation of that tastant usually increases. The shape of the psychophysical function displaying perceived intensity as a function of concentration of tastant dissolves in water is usually concave and monotonically increasing. This implies that adding a certain amount of substance has a larger effect in water or at low concentrations than when a solution already has a large concentration. Analogously, adding a pinch of salt to a dish that does not have any salt, like a chocolate chip cookie, will have a greater taste impact than adding that same pinch of salt to something already salty, such as bacon.

Looking specifically at one of the taste qualities, sweetness, Figure 1 shows psychophysical functions of 16 different sweeteners displaying sweetness intensity as a function of the logarithm of concentration. When displayed in this way, the functions have a sigmoid shape (Wee, Tan, & Forde, 2018). When we compare the shapes of psychophysical functions for various sweeteners, we can see that naturally occurring sugars and sugar alcohols (panels A and B) generally require a relatively high concentration to be perceived as sweet compared to the non-nutritive so-called intensive sweeteners (panel C). Aspartame, acesulfame-K and sucralose are artificially created substances that were developed to replace high-calorie carbohydrates. Stevia and luo han guo are natural sweeteners that are obtained from plants: stevia from the leaves of the stevia plant, and luo han guo from monk fruit. In each panel, the function of sucrose is added for comparison.

Figure 1 shows that psychophysical functions for sugars and sugar alcohols are steeper than for some of the artificial sweeteners. This can be due to the occurrence of side tastes that tend to become more intense with increasing concentration levels, e.g. for Acesulfame-K. As a consequence – and although their name suggests otherwise – it is not possible to achieve very intense sweetness levels using such artificial "intensive" sweeteners. For instance, the reference curve for sucrose depicted in panel C is steeper and does not seem to level off, where all the "intensive" sweeteners show tendencies to approach a maximum intensity level.

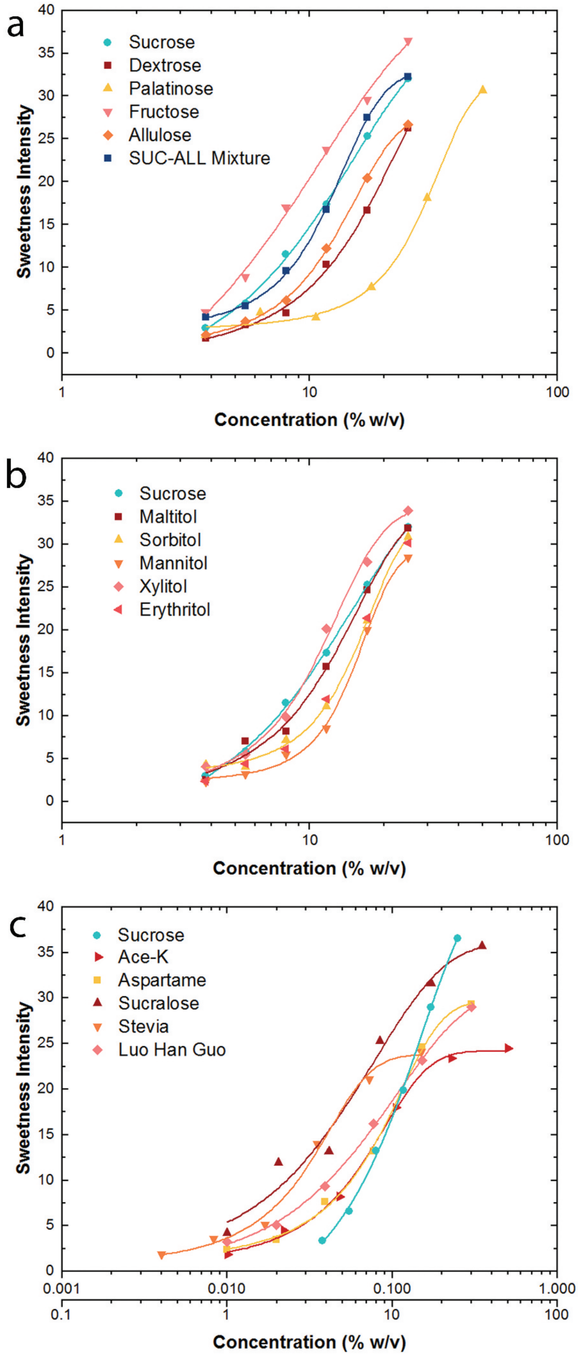

Figure 1. Psychophysical functions for 16 sweeteners including (A) sugars, (B) sugar alcohols and (C) non-nutritive sweeteners (with sucrose plotted using the secondary x-axis (0.1–100% w/v) (Reprinted by permission from Wee et al., 2018).

Prolonged stimulation

Just like the other sensory modalities, the sense of taste shows adaptation. Adaptation implies that with prolonged stimulation the perceived intensity of that stimulus decreases over time. Hence, after keeping a sugary drink in the mouth for some time, the perceived sweetness intensity of that drink will decrease and any subsequent sips of that drink will taste less sweet. Moreover, adaptation to one sweetener may also decrease the intensity of any subsequent other sweeteners (McBurney, 1972). Adaptation can occur for all the taste qualities. This implies that any taste, pleasant or unpleasant, may decrease in intensity and eventually fade into the background when someone keeps the food for a longer time in the mouth or takes multiple bites of the same food in a row.

Adaptation occurs most rapidly and completely if a stimulus continuously occupies a specific receptor. However, in the mouth the production of saliva, tongue movements and mastication movements that mix the contents of the mouth interfere with and decrease the degree of sensory adaptation. Nonetheless, the sequence in which different meal ingredients are eaten can significantly affect the perception of the meal components. For this reason, restaurants may serve a neutralizing palate cleanser, such as a sorbet, between courses. Guests may also want to take a sip of a more neutral beverage between bites.

Even the taste of something seemingly neutral, such as water, can change after adaptation to specific tastants. For instance, McBurney and Shick (1971) have found that water tastes sweet after adaptation to bitter tasting substances, such as caffeine and salts like $MgSO_4$, Na_2SO_4, and KNO_3. The perception of the sweet taste in response to water may be due to a rinsing effect: The removal of a substance that was blocking the sweet taste receptor may generate a receptor-based, positive off-response in receptor cells upon rinsing (Galindo-Cuspinera, Winnig, Bufe, Meyerhof, & Breslin, 2006). This same phenomenon can also be observed in a culinary context: After eating artichokes, water tastes sweet (Bartoshuk, Lee, & Scarpellino, 1972) due to the presence of the salts of cynarin and chlorogenic acid in these vegetables (Kinghorn & Soejarto, 1989).

Some substances are known to modify taste perception quite drastically. For instance, many people have experienced the noticeably different taste of orange juice after brushing their teeth, as the sweetness of the orange juice has decreased and the sourness and bitterness has increased (Allison & Chambers, 2005). In this case, adaptation to sodium lauryl sulfate, a detergent and foaming agent used in tooth paste, along with flavors with a cooling effect, such as menthol, may be responsible for this effect. Another example is the protein miraculin, which can be found in the berries of miracle fruit, and has the unusual property of blocking sour receptors and, thereby, modifying sour taste into sweet taste (Kurihara & Beidler, 1968). By transferring the genes coding for miraculin to other species, researchers have been able to produce transgenic lettuce (Sun, Cui, Ma, & Ezura, 2006), tomatoes (Yano et al., 2010), and strawberries (Sugaya, Yano, Sun, Hirai, & Ezura, 2008) with significant amounts of miraculin. It would be interesting to investigate how these taste-modifying fruits and vegetables can find their way in culinary practice.

Mixing tastants

Although psychophysical functions of purified substances in water solutions give some insight into basic taste perception mechanisms, during the consumption of food products the human gustatory system is typically stimulated by a large number of different chemicals. During the perceptual process many of these substances, or the signals they elicit, affect one another. Hence, the sensation elicited by an unmixed component usually differs from the sensation elicited by that same component as part of a complex stimulus.

When studying taste mixtures, we need to distinguish between mixtures of similar versus dissimilar tasting substances. In the first mixture type, all components elicit similar taste qualities, which leads to the formation of a unified percept, consisting of only a single taste sensation. For example, if someone tastes a mixture of sucrose and fructose, only a sweet sensation is perceived. In the second mixture type, dissimilar tasting substances are mixed, leading to the formation of a complex percept, in which several taste qualities can be discerned. For example, a sucrose/citric acid mixture elicits a sweet and a sour taste (De Graaf & Frijters, 1989).

Studies of mixtures of similar tasting substances in water have often shown that they behave hyper-additively, which means that on a molar basis using a mixture to produce a certain taste intensity requires lower concentrations than when that same intensity is produced with unmixed components (e.g., De Graaf & Frijters, 1986). In mixtures of sweeteners this degree of hyper-additivity is usually relatively small (De Graaf & Frijters, 1987), although the effect may be larger with some of the artificial "intensive" sweeteners that may elicit unwanted side tastes that are suppressed by the other component in the mixture (Frank, Ducheny, & Mize, 1989; Schifferstein, 1996). As a consequence, the sweetener Acesulfame-K is mostly mixed with aspartame when used commercially (Fry & Hoek, 2001). However, extreme cases of hyper-additivity are found for the umami taste quality when L-amino acids and nucleotides are mixed. Figure 2 shows how taste intensity varies with the proportion of nucleotide in a mixture of monosodium glutamate (MSG) with disodium 5′-inosinate (IMP) (Yamaguchi, 1967). Two substances that are almost tasteless when unmixed (the left and right extremes of the curve)

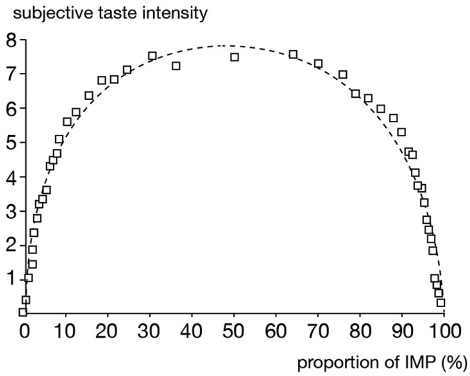

Figure 2. The extreme cases of hyper-additivity observed for the umami taste quality when mixing an amino acid (mono sodium glutamate) with a nucleotide (inosine mono phosphate) (Adapted from Yamaguchi, 1967; copyright John Wiley & Sons).

together create a mixture with a clearly perceptible umami taste (see also Rifkin & Bartoshuk, 1980).

In mixtures of dissimilar tasting substances, ideally each component does not contribute to the intensity of the sensation elicited by the other component. In these mixtures we mostly see that the intensity of the components in the mixture is lower than the intensity outside the mixture, a phenomenon called mixture suppression (Frijters, 1987). Figure 3 shows the results of a study on taste interaction in sucrose/citric acid mixtures (Schifferstein & Frijters, 1990). In panel A, the sweetness of the mixtures is given as a function of the sweetness of unmixed sucrose. The sweetness intensity of all mixtures lies below the diagonal, implying mixture suppression. Panel B shows the sourness of the mixtures as a function of the sourness of unmixed citric acid.

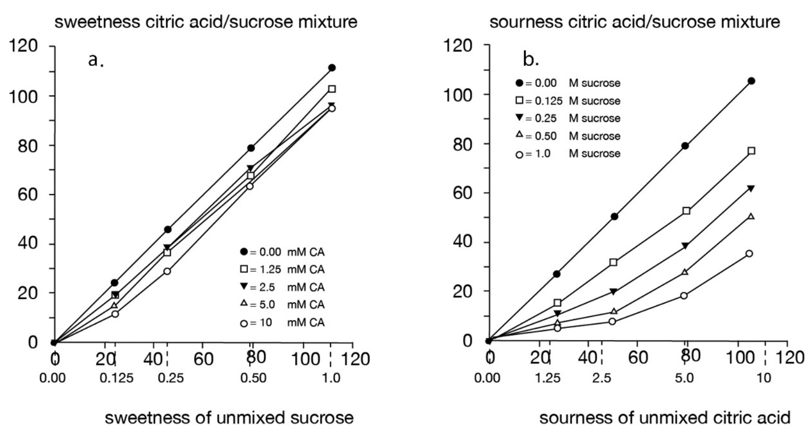

Figure 3. The perceived sweetness and sourness of citric acid/sucrose mixtures, plotted as a function of the sweetness of unmixed sucrose (left) and the sourness of unmixed citric acid (right) (Adapted from Schifferstein & Frijters, 1990; copyright Oxford University Press).

Similar to panel A, all mixtures lie below the diagonal, implying sourness suppression by sucrose. In addition, panel B clearly shows that the degree of suppression increases with increasing sucrose concentration. Furthermore, comparing panels A and B indicates asymmetry: The effect of sucrose on the sourness of citric acid is much larger than the effect of citric acid on the sweetness of sucrose. In a simple culinary example, one can imagine how the unpalatable sourness of pure lemon juice can quickly be suppressed with the addition of sugar in the process of making lemonade. In this example, the sweetness cuts the sourness and – to a lesser degree – the sourness cuts the sweetness.

Similar asymmetric results are found when quinine (bitter) and NaCl (salty) are mixed: Whereas adding NaCl leads to a dramatic decrease in the bitterness of quinine, adding quinine only has a minimal effect on the perceived saltiness of NaCl (Schifferstein & Frijters, 1992). A similar study for the interactions among sucrose and NaCl (De Graaf & Frijters, 1989) shows that the sweetness of sucrose is actually enhanced by adding NaCl at low concentrations of sucrose (Figure 4). This is potentially a result of the sweet side taste of NaCl at low concentrations. In contrast, at high concentration levels the sweetness of sucrose is generally suppressed by adding NaCl (left panel). The saltiness of NaCl is generally suppressed by the presence of sucrose, with higher sucrose concentrations producing more suppression (right panel).

The mixture studies discussed above were all performed in water solutions, which implies that all components were completely mixed into a uniform, homogeneous sample. However, chefs can play with the degree to which they mix components, which may result in very different culinary experiences. For instance, a guacamole or avocado cream can be prepared in very different ways when all ingredients are pureed and mixed to create one homogenous taste

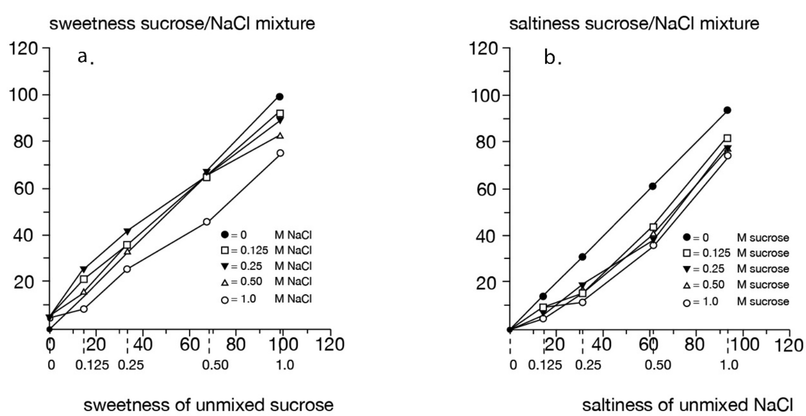

Figure 4. The perceived sweetness and saltiness of sucrose/NaCl mixtures, plotted as a function of the sweetness of unmixed sucrose (left) and the saltiness of unmixed NaCl (right) (Adapted from De Graaf & Frijters, 1989; copyright Oxford University Press).

and texture, compared to when all ingredients are cut into small cubes, which allows for a unique flavor in each bite. Depending on how large or small the dice are cut, the flavors will blend to different degrees in the mouth.

In culinary practice chefs tend to add a bit of salt to many dishes – including desserts – as a basic flavor enhancer. Besides adding its own salty taste, the addition of salt seems to enhance desirable flavors. When investigating this phenomenon, Kemp and Beauchamp (1994) found that NaCl in a mixture generally showed no flavor potentiation effect, but suppressed pure tastes and flavors. Nonetheless, in more complex mixtures the suppression of some unpleasant tastes (such as bitterness) may release other, desirable components from suppression, thereby increasing their relative intensity or their salience (Breslin & Beauchamp, 1997). Sodium's functionality in terms of flavor and associated palatability enhancer makes reducing sodium levels for health reasons in processed foods challenging (Liem, Miremadi, & Keast, 2011). Similar to using salt in sweet dishes, some chefs may use sugar as a flavor enhancer in savory dishes, which is probably done for comparable reasons.

Pleasantness of taste sensations

People appear to have an innate preference for sweet tasting substances and an innate aversion for bitter tasting substances, as these responses can already be observed in neonates (Steiner, 1973). Theory suggests that there is an optimum stimulation level for each tastant, which is sometimes referred to as the bliss point. For tastants that generally taste unpleasant (bitter, sour) this concentration can be quite low, whereas for other tastants (sweet) it can be relatively high. The straight lines in Figure 5 show that the pleasantness of citric acid (left) and NaCl (right) stimuli in water generally decreases with increasing

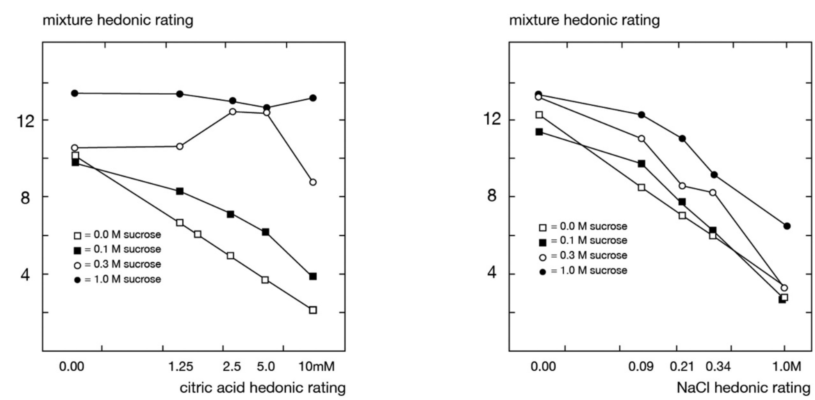

Figure 5. Mean hedonic ratings for sucrose/citric acid mixtures and sucrose/NaCl mixtures plotted as a function of the mean hedonic ratings for unmixed citric acid (left) and unmixed NaCl (right) (Adapted from Frank & Archambo, 1986; copyright Oxford University Press).

concentration level. As expected, adding a sweet substance like sucrose can increase the pleasantness of the stimuli, as the mixture curves show. However, the most interesting observations occur when 0.3 M sucrose is added to 2.5 or 5.0 mM citric acid, as this mixture is more pleasant than either of its unmixed components (Frank & Archambo, 1986). Finding such highly preferred mixture combinations may be a central challenge for culinary professionals.

Similar to Figure 5, Yamaguchi and Takahashi (1984) observed that pleasantness ratings of NaCl, tartaric acid, caffeine, and MSG generally decreased monotonically with concentration levels when tasted in water. However, when these substances were presented in foods, the typical optimum curve was found for most tastants, and the maximum pleasantness levels seemed to be quite similar for different food products. Hence, overdosage of tastants is unlikely to occur in food practice. The most evident example may be the use of salt: Even though perception and preference may vary over people, at a certain level most people will agree that a dish tastes too salty. Elaborate testing may help to find the optimum combinations of constituents for a dish. For instance, in developing a new soup recipe, researchers or chefs may try to find the optimum levels of L-amino acid and nucleotides to produce the best umami taste (Baryłko-Pikielna & Kostyra, 2007).

These studies show that mixing tastants with different taste qualities reduces their individual intensities, increases stimulus complexity and can lead to increased pleasantness (Yamaguchi & Takahashi, 1984). Analogously, also food combinations can be experienced as more pleasant than each of their components separately. Table 1 provides common examples of culinary taste combinations in which dissimilar taste combinations produce a well appreciated taste.

Although some tastes may be experienced as unpleasant at first, with repeated presentations people may learn to appreciate them over time. Examples include the bitter components in grapefruit, coffee, bitter melon and beer, or the sourness in citrus fruit, fermented foods, and vinegar. The same holds for some tactile sensations, such as the “spiciness” pungency we will discuss later (Byrnes & Hayes, 2013).

Individual differences in taste sensitivity

People may differ in the degree to which they are sensitive in perceiving different taste substances. Although there is controversy on this topic, Lim, Urban, and Green (2008) make plausible that there are at least two different ways in which people’s perceptions of taste sensations may differ. Because people’s intensity ratings for basic taste stimuli (sweet, sour, bitter and salty) are correlated, there seems to be a general factor determining their sensitivity to perceiving multiple taste stimuli, which may be related to the density of fungiform papillae on the tongue. In addition, for bitterness perception people

Table 1. Commonly consumed examples of food products in which two or more dissimilar tastes are combined. The rows show the taste qualities of the main ingredient or predominant quality, while the columns show the taste qualities of the added ingredient or supporting quality. Please note that many foods and ingredients elicit multiple tastes and, therefore, divisions between categories are not always clear-cut.

		Added or supporting taste				
		Sweet	Sour	Salty	Umami	Bitter
Predominant taste	Sweet	x	Sweet soft drink with slice of lemon; sour-coated candy	Salted caramel;salted peanuts in candy bars; grilled peaches with sea salt	Melon with ham; watermelon with feta; fruit salad with roasted vegetables	Herbs infused in milk/cream; chocolate shavings on desserts
	Sour	Sugar added to lemonade; sugar added to tomato sauce	x	Salt on margarita rim; tequila, salt and lemon;	Sauerkraut; anchovies in tomato sauce	Grapefruit
	Salty[a]	Chinese tomato soup; ketchup on fries	Potato chips and vinegar	x	Bread with marmite; parmesan cheese on popcorn	Chili con carne with a pinch of chocolate
	Umami	Old cheese with honey; sweet glaze on meat	Lemon on fish; cooked ham with balsamic vinegar	Cured meat; Steak with salt; tomato with salt	x	Celery added to tomato juice; coffee used to marinate meat
	Bitter	Adding sugar to chocolate or coffee	Tea with lemon; vinaigrette on bitter greens	bacon and endive; salting bitter melon/gourd	Tea flavored with tomato; roasting coffee	x

[a]Salty foods are often created by adding salt to agricultural products during processing. Naturally occurring savory foods are more likely to classify as umami.

may differ in their sensitivity to a substance called PROP. This type of sensitivity is genetically determined and is related to the expression of a particular bitter taste receptor (TAS2R38), which also affects the perception of other bitter substances, such as quinine, but not the perception of the other taste sensations. However, these genetic differences in bitter taste perception do not seem to result in consistent differences in the consumption of vegetables with bitter tastes, such as brassica species (Gorovic et al., 2011; Shen, Kennedy, & Methven, 2016).

Smell perception

The sense of smell has the largest number of different receptor types among the senses. Olfactory receptors likely form the largest gene superfamily in the vertebrate genome. The total number of olfactory genes in the human genome is estimated to approximate 1000 (Axel, 1995). Only about one third of these are functional and, therefore, humans likely possess about 350 different olfactory receptor types (Glusman, Yanai, Rubin, & Lancet, 2001). Each olfactory sensory neuron likely expresses only one type of receptor (Axel, 1995), implying that there are about 350 different types of olfactory receptor cells, with which people should be able to smell a large variety of different qualities.

Identifying and naming smells is experienced as quite difficult. Product smells are, on average, accurately identified by 39% [range 0–85%, SD 24%] of the participants. In addition, reaction times are generally slow, where averages lie above 10 s (Desor & Beauchamp, 1974). There is also simply no one-to-one mapping between molecular structure and the associated flavor experience (e.g., Spence, Wang, & Youssef, 2017). Furthermore, smell identification can easily be hampered by information that suggests an incorrect source. For instance, DuBose, Cardello, and Maller (1980) showed that providing aqueous flavor solutions with inappropriate colors can easily prompt incorrect flavor identification responses.

In contrast to the sense of taste, where preferences for specific taste qualities seem to be innate, the majority of evidence suggests that preferences for smells seem to be acquired. However, knowing the source of a smell can have a large effect on its hedonic evaluation (Herz & von Clef, 2001). An interesting case here is the durian, a Southeast Asian fruit that has a very strong odor that many people find offensive (e.g., Wertit, 1962). Its smell has been described from the most pleasantly sweet to rotten onions, turpentine, and raw sewage and evokes different reactions from extreme fondness to disgust. Knowing that the smell comes from a durian fruit, may make the scent much more agreeable to those who are familiar with the fruit or willing to try it.

Similar to the sense of taste, the sense of olfaction also shows adaptation and mixture interactions. In several everyday situations, people adapt quite quickly to smells. For instance, people are mostly unaware of their own body odor and when they enter a room, they may perceive its smell, but this easily fades into the background. Therefore, we have to be aware that also during the tasting of food and beverages, people can easily become adapted to smells, particularly if they are not intense, and this may affect their perception of subsequent items they try. Just as people try to mask undesirable body odors with the scents of toiletries, a particular smell within a dish may be masked by the presence of another ingredient. Chef Heston Blumenthal experimented with flavor adaptation in his restaurant by providing two squeeze bottles together with a cinnamon/vanilla ice cream. One squeeze bottle contained sticks of cinnamon and the other a vanilla pod. Sniffing one bottle before tasting the ice-cream would produce adaptation to one of the flavors and, thereby, boost perception of the other flavor (Blumenthal, 2008; Spence et al., 2017).

Role of smell in food perception

Food flavors are usually chemically very complex. For instance, in strawberry flavors more than 300 substances have been identified (e.g., Nijssen, 1996) and this composition varies considerably with strawberry variety, ripening stage, geographic and seasonal influences, and storage conditions (e.g., Forney, Kalt, & Jordan, 2000; Schwieterman et al., 2014). The flavor components make up less than 0.01% of the fruit fresh weight, but they have a major impact on its perceived quality (Buttery, 1981). Flavor companies often have strawberry flavors for many different applications, such as soft drinks, yogurts, ice cream, and detergents. Each application may require different specifications, both in terms of functionality and in terms of ideal perceptual properties. In addition, the geographical market for which a flavor is developed may implicate preferences for specific flavor profiles (Barnekow et al., 2007). Hence, the properties of commercially available strawberry flavors can vary widely. Companies make use of the availability of multiple flavors to target specific consumer markets. Therefore, processed foods and drinks such as McDonald's burgers (Sameer, 2012) or Fanta beverages (Heley, Welsh, & Saville, 2020) may vary in taste between geographic regions.

People often underestimate the importance of smell for food perception, because they ascribe many smell sensations to the sense of taste. As described in the previous section, taste perception is limited to a handful of sensations that are perceived solely by the sensory receptors in the oral cavity. Many other sensations that are attributed to the sense of taste are actually perceived by the sense of smell (Rozin, 1982) and the sense of touch (Mouritsen & Styrbæk, 2018) as discussed in later sections. The well-known taste-smell confusion may be due to the fact that people actively insert food into the mouth, whereas they are unaware that volatile compounds are released from the food during mastication and reach the olfactory receptors retronasally (Burdach, Kroeze,

& Köster, 1984). As a consequence, the importance that people attribute to the sense of taste during food consumption may be overrated compared to the importance they attribute to the sense of smell.

Some odorants seem to evoke a perception of sweetness or sourness, even though such sensations are usually attributed to the sense of taste. For instance, a strawberry flavor can enhance the sweetness of sucrose (Frank et al., 1989; Schifferstein & Verlegh, 1996), citrus flavor can enhance the sourness of citric acid, soy sauce flavor can enhance the saltiness of NaCl, almond flavor can enhance the bitterness of quinine (Frank, van der Klaauw, & Schifferstein, 1993), and so on. These combinations suggest that the odor needs to be similar in quality to enhance the sensation of the tastant. However, a lemon odor has also been found to enhance the sweetness of sucrose in some cases (Schifferstein & Verlegh, 1996), suggesting that qualitative similarity is not always necessary to produce a taste enhancement effect. Because the smell receptors in the olfactory epithelium of the nose are spatially separated from the taste receptors in the oral cavity, any interactions between the chemical senses must take place in the central nervous system. However, if smells and tastes are congruent, which means that they often have been experienced simultaneously, participants are likely to infer that they both come from the same source and thus localize the smell in the oral cavity, together with the source of taste (Lim, Fujimaru, & Linscott, 2014; Lim & Johnson, 2012).

These outcomes suggest that taste sensations may be simulated by adding flavors to a food product. This opens up opportunities to replace taste substances in the food that are judged to be undesirable from a nutritional point of view (e.g., sugar, salt, MSG) by smells. In this way, the concentrations of tastants can be reduced to some extent without reducing the perceived intensity of that component. Bartenders make use of this effect when they prepare cocktails: They may add some citrus peel or herbs on the top of a cocktail or on the rim of the glass in order to enhance the sensory experience by adding a certain smell. This phenomenon is also used in the "Air up" water bottle (https://www.air-up.com), which consists of a special bottle and straw that lead air through an aroma pod and into the mouth with the drinking water. Through retronasal smell, the water appears to taste like whatever aroma is in the pod, such as orange, passion fruit or grapefruit.

Adding flavor during cooking

During cooking, people add herbs and spices primarily for extra flavor. Herbs are leafy green parts of herbaceous plants that typically originate from temperate climates. Spices are obtained from roots, flowers, fruits, seeds or bark from woody or herbaceous plants that are typically native to warm tropical climates. Any part of the plant that is not a leaf and can be used for seasoning would fall into the spice category. They often evoke stronger flavor impressions than herbs and, as a result, they typically are used in smaller amounts. Some spices can also be used as a preservative. Some plants form the basis for both herbs and spices. For instance, the leaves of Coriandrum Sativum are the source of cilantro (herb), while coriander (spice) comes from the plant's seeds. Dill, fennel, and fenugreek are other examples in which the seeds are a spice, while the leaves and stems are an herb (Christensen, 2014; Spicer, 2003).

Similar to a perfumer, chefs compose the overall flavor of a dish by combining ingredients that provide complexity in the form of top, middle, and base notes in flavor. The top or high notes are those which are smaller molecules that dissipate rapidly and are the first scents to be perceived, like citrus or fresh herbs. This can also refer to notes that are called "bright", like acidic flavors. It is for this reason why top notes are added just before serving and are not cooked into a dish. The base or low notes are those which add depth to the dish. These are typically umami or earthy flavors such as mushrooms, bacon, aged cheese, miso, smoke or roasted flavors. The middles notes are typically the substance of the dish. These are the vegetables, some meats (poultry, fish), and grains that do not specifically provide the bright/sour/sharp/herbal flavors nor the deep roasted/meaty/umami flavors. When a dish seems "flat" or "one-note" it is potentially missing the high or low notes to add complexity (Christensen, 2008; Sare, 2011).

The culinary world uses the term "flavor base" to describe a specific combination of aromatic vegetables, herbs, and spices. Although it is called a "base" they are often composed of flavors that could be a combination of top, middle and base notes. Different cuisines have different specific flavor bases composed of ingredients often grown in that cultural region (Table 2). These flavor combinations form the base of many traditional dishes within that cuisine, such as stocks, soups, stews and sauces. They provide a foundation of flavor that will often distinguish a dish from a similar one in another cuisine (Colon-Singh, 2014; Hevrdejs, 2014; Peterson, 2020).

Individual differences in smell perception

People may differ widely in their sensitivities for smells. Because people have many different smell receptors, there are also many different types of smells for which they may be more or less sensitive. In a classic paper, Amoore (1977) identified six categories of volatile components for which people differed considerably in their sensitivity, based on a list of 80 individual components. Hence, there may be many components for which people differ considerably in their smell sensitivity (Reed & Knaapila, 2010). One example from cooking practice refers to the differences in preference for cilantro or coriander. While many people love it, others claim that it smells foul, like soap or dirt (Mauer & El-Sohemy, 2012). These coriander haters appear to be overly sensitive to

Table 2. Examples of flavor bases in several culinary traditions (Górska-Warsewicz, Rejman, Laskowski, & Czeczotko, 2019; Peterson, 2020; Wikipedia, 2020).

Cuisine	Flavor base name	Aromatic vegetables	Herbs, spices and other flavorings	Cooking fat
French	mirepoix	onions, carrots, and celery	thyme, bay leaf	butter, rendered goose and duck fat
French	duxelles	mushrooms, onion or shallot, herbs	thyme, parsley	butter
Italian	soffritto	onions, carrots, celery	parsley, sage, bay leaf	olive oil, butter
Spanish	sofrito	garlic, onion, peppers, and tomatoes	parsley, saffron, bay leaf	olive oil, lard
German/ Dutch	Suppengrün	leeks, carrots and celeriac	parsley, thyme	butter, lard, schmaltz
Polish	włoszczyzna	leeks, carrots, parsnips, celery root, savoy or white cabbage	parsley, celery leaves	butter, lard, schmaltz
Russian/ Ukrainian	smazhennya or zazharka	onion, carrot and possibly celery, beets or pepper		butter, lard, schmaltz
Cajun/ Creole	holy trinity	onions, celery and bell peppers		coconut oil
Indian	curry paste	onions, garlic, chilis, tomato	ginger, cardamom, cumin, cloves, cinnamon, fenugreek, coriander, nutmeg, mustard seed, pepper, fenugreek, turmeric	ghee, vegetable oil, mustard oil, coconut oil
Indonesian	bumbu	onions, garlic, chilis	shrimp paste, ginger, galangal, kemiri, salaam leaves	coconut oil
Thai	curry paste	shallots, garlic, chilis	lemongrass, kaffir lime leaves, ginger, galangal	vegetable oil, coconut oil

several aldehydes that produce this soapy or pungent aroma (Eriksson et al., 2012).

Visual perception

The sense of vision plays an important part in the food experience. Through vision, people can see properties like color, size, shape, quantity, and surface texture. The natural colors of fruit and vegetables inform chefs and consumers whether a product is unripe, ripe, overripe or rotten (e.g., Schifferstein, Wehrle, & Carbon, 2019). In addition, the sense of vision plays a major role in determining what consumers find attractive. Here we discuss the impact of food presentation on its appreciation.

In the culinary world, chefs refer to visual aesthetics as the art of plating, in which the components of the dish are artfully arranged on the plate for the consumers' first interactions with the food. Looking at pictures and illustrations from cookbooks of different times and cuisines suggests that plating, as well as art and fashion, is subject to trends. Recent examples of food trends include the stacking of food to create a more impactful presentation, molecular spherification of ingredients such as sauces, the conceptual division of a dish into carefully thought through pieces, tapas style dishes that can be shared, and dishes that look well on social media (Koh, 2015).

However, surprisingly little empirical research has been published on the optimal ways in which foods could be presented on the plate to make them more attractive, even though such knowledge would be valuable to restaurant owners and foodservice providers. Several studies have compared the responses of groups of diners, who received the same ingredients on their plate, but these were presented in different ways. Dishes for which the plating was inspired by art works tend to be preferred to dishes arranged in a more conventional way and diners are also willing to pay more for such dishes (Deroy, Michel, Piqueras-Fiszman, & Spence, 2014; Michel, Velasco, Fraemohs, & Spence, 2015; Michel, Velasco, Gatti, & Spence, 2014). Other studies have shown that diners like dishes presented in a neat rather than a messy manner (Zellner et al., 2011), they prefer to have dishes which are centered compared to arranged off to one side (Michel et al., 2015), and they favor linear over circular arrangements of ingredients (Youssef, Juravle, Youssef, Woods, & Spence, 2015). In addition, with asymmetrical dishes the way in which a dish is placed in front of the eater may be important, as diners may prefer specific plate orientations (Spence, Youssef, Michel, & Woods, 2019; Youssef et al., 2015). When the food is presented in a more attractive way, people also tend to like the food on the plate more (Zellner, Loss, Zearfoss, & Remolina, 2014).

Schifferstein, Howell, and Pont (2017) investigated the effects of background colors on the perception and attractiveness of different vegetables.

They found that the optimal background colors differed substantially for various vegetables. The attractiveness of cucumber was highest on a light orange background, for carrot on dark orange, for tomato and yellow bell pepper on dark blue, and for eggplant on a light blue background. In a subsequent study using only neutral background colors (Howell & Schifferstein, 2019) the differences in attractiveness ratings were much smaller on the various backgrounds, with highest ratings generally found for the darkest background except for the eggplant, which was found most attractive on the lightest background. Hence, backgrounds with neutral colors (white, gray, black) are more likely to present multiple vegetables in an attractive way than hued backgrounds. This finding could explain why most restaurants primarily serve their dishes on tableware that is white, off-white, or black.

Touch perception

The sense of touch is involved in many different ways during food perception. People can perceive the weight and size of the food that is in their mouths, they can perceive its texture, especially when they bite and masticate, they sense the temperature, and the food may tickle their tongue or leave a burning sensation. These touch sensations all transmit to the brain via the trigeminal nerves which route through the jaw, tongue, teeth and oral cavity. All these diverse sensations contribute to how the food is perceived.

With food, we often talk about its mouthfeel: How the food feels in your mouth when you explore its surface, bite in it, masticate and swallow it. Mouthfeel attributes include whether the food is hard or soft, rough or smooth, crunchy or crispy, chewy, gummy, creamy, sticky, or slimy. Just as it is difficult to describe a scent, there are also some specific complex food textures that are difficult to describe. Preference for certain textures may be partly determined by culture. People with Western origin tend to like meat balls with loosely formed, chunky textures, whereas people with an Asian background like smooth, pureed mixtures of proteins and starches that are shaped into tight balls that are springy and somewhat bouncy. This so-called Q texture can be described as chewy, gummy or rubbery. In some cases, tasteless elements are even added to Asian dishes to introduce this texture, like the tapioca balls in bubble tea (Erway, 2015).

Serving temperature is extremely important for most dishes. The temperature has an important influence on the texture of dishes (e.g., ice cream that melts, sauces that solidify if they cool down), but also on the taste properties (e.g., desserts become sweeter if they heat up). As ice cream is cold, it requires more sweetener than a yogurt or custard for your tongue to be able to register the sweetness (Cruz & Green, 2000). Colder water also tastes better than warm water, as your taste buds are less able to taste the impurities. Inversely, many other foods, such as cheese or fruits taste best when eaten at room temperature.

Sauces are a means of adding additional layers of flavors to a dish. However, when chefs plate a dish to increase its visual aesthetic, it is difficult to control the placement of liquids on a plate. Therefore, chefs have found different ways to add volume, texture, and stability to sauces and liquids to be able to control placement on a plate. Chefs sometimes use food additives to create foams, gels, and emulsions. Some of these additives are found in the toolbox of a food scientist (e.g., sodium alginate, xanthan gum, tapioca, maltodextrin) but others can be found at most grocery stores (e.g., flour, gelatin, eggs) (Mouritsen & Styrbæk, 2018). By giving sauces more texture, the mouthfeel of the dish will change. In some cases, using textural agents makes it possible to reduce the amount of unwanted fat for nutritional purposes, as is done for instance in ice cream (Baer, Wolkow, & Kasperson, 1997).

Chemesthesis occurs when chemical compounds activate nociceptive receptors in the skin. Chemesthesis takes on many forms. Menthol creates a cooling sensation; carbonation creates a tingling sensation or effervescence; Sichuan peppercorn creates a numbing sensation. The most common form of chemesthesis is "pungency", being the spicy, hot, burning sensation that is associated with chili peppers. Different chemicals can elicit pungent sensations, although some are more pungent than others. Eugenol is found in cinnamon, cloves, allspice and bay; piperine is found in black pepper; allyl isothiocyanate is found in mustard, radish, horseradish, wasabi, arugula, watercress, and nasturtium; gingerol is found in ginger; allicin is found in garlic and onion. All of these chemical compounds create some level of burning sensation in the mouth. At mild levels of pungency, foods are sometimes described as "piquant" (e.g., Mouritsen & Styrbæk, 2018).

Perhaps the most prevalent form of chemesthesis pungency is created by the capsaicinoids found in chili peppers. The intensity of the burning sensation is usually expressed in Scoville Heat Units (SHU), which is the dilution of a given pepper extract in water that can be detected by a panel of tasters. Peppers differ considerably in the amount and type of capsaicinoids they contain and each component produces a different kind of heat sensation effect in the mouth (Guzmán & Bosland, 2017). After tasting a food with pungency, the sensation generally increases for a while, before it starts decreasing in intensity. The higher the concentration of capsaicin, the longer it takes before the maximum burn intensity is reached, and the longer it takes for the burn sensation to wear off. In addition, the intensity of the burning sensation depends on whether one is used to eating chili or not: frequent users rate burning sensation generally as less intense than infrequent users (Prescott & Stevenson, 1995). Drinking cold milk and sugar-containing beverages is considerably more effective than drinking water to extinguish the fire in the mouth (Nasrawi & Pangborn, 1990; Nolden, Lenart, & Hayes, 2019). When using chili peppers during cooking, mixing chili with foods containing fat, starch or protein is likely to decrease the perceived burn of the pepper (e.g., Schneider, 2014).

Auditory perception

Although the contribution of sound to food perception may not be that obvious, it plays a role in many experiences with a tactual component. For instance, in the crispness of potato chips, the crunchiness of cookies, but also in the fizziness of soft drinks. In several studies that manipulated sound perception during eating, the role of auditory input was clearly demonstrated. For instance, potato chips were perceived as being both crisper and fresher when either the overall sound level was increased of the biting and mastication sounds, or when just the high frequency sounds (in the range of 2 – 20 kHz) were selectively amplified (Zampini & Spence, 2004). Similarly, carbonated water samples were judged to be more carbonated when the overall sound level was increased or the high frequency components of the water sound were amplified (Zampini & Spence, 2005). One can immediately recognize the level of carbonation of a beverage by the sound it makes when opening a can, or the crispness of an apple when hearing someone bite into it. Sounds can also be used in different ways to improve the eating experience. For instance, Heston Blumenthal accentuated a seafood dish in his gastronomic restaurant with the sound of crushing waves from an mp3-player inside a shell.

Combining foods in an attractive way

In the previous sections, we discussed the contributions of the various sensory modalities to how foods are experienced in the kitchen and on a plate. We know that all sensory modalities can contribute to the appreciation of food products. But how can we use this knowledge and which additional insights do we need to create attractive food combinations? People do not consume food products in isolation. When cooking food, ingredients are typically combined into a dish, and multiple dishes may be consumed simultaneously during a course. People may add condiments to enrich the flavor of their meal. Which rules do chefs use to make sure that these combinations are pleasant?

Structure of the meal

In 19th century French haute cuisine, dishes such as eggs, vegetables, salads and meats were often served separately, one after another, creating very elaborate menus such as the famous 17-course menu composed by Auguste Escoffier (Sporting Road, 2018). Even though this fashion has long changed, part of this order is still noticeable in the arrangement of more modern menus. Prominent courses are served in the following order: amuse-bouche, soup, appetizer, salad, fish main course, meat main course, cheese and dessert. Depending on the elaborateness of the menu, some courses are left out or added. Within a course, the arrangement of different colors, textures and tastes is carefully chosen to create an internal balance in flavor as well as aesthetics. When eating a course, the diner typically combines the different elements in a single bite to have the ultimate tasting experience. Each course may be paired with a different, suitable drink (Harrington, 2005). Throughout the course of a meal, chefs usually aim for an increase in taste intensity and complexity, as the taste of a light dish with subtle tastes would likely be overruled after a dish with an intense taste, such as a strong cheese. In this traditional style, the different courses of a meal usually follow a single cuisine, even though different cuisines may be mixed in more modern meals. When the meal is not created around a particular ingredient (e.g., truffle), chefs will usually avoid to use the same prominent ingredients in more than one course. The same goes for cooking techniques. Portion sizes are usually adjusted to the number of courses, so that the total amount of food does not exceed a comfortably edible amount.

In restaurants, chefs are responsible for combining ingredients that go together well, and a wine or beer expert may provide suggestions on which beverage to take with each course. However, many of the rules that these professionals use seem to be acquired through practice, may be rather implicit, are not well documented and thus have remained largely unclear. The question whether two or more things together produce a good combination is not confined to the food realm. This question is also evident when choosing the garments for an outfit, decorating a house, composing a piece of music, and so on. All these areas are still largely the terrain of artists and craftsmen, because science is unable to provide consistent, clear-cut rules that determine what are good, universally appreciated combinations. Nonetheless, below we will give an overview of some of the findings that can support chefs and other hospitality professionals when offering dining experiences.

Pairing principles from culinary practice

Eschevins, Giboreau, Julien, and Dacremont (2019) interviewed sommeliers and beer experts to find out why they thought that some beverage-food pairs would match or not. On the basis of these interviews, the authors identified fifteen pairing principles. In some cases, these principles referred to considerations of perceived properties that were likely to match well. In other cases, the principles referred to general knowledge or the expert's individual insights (Table 3).

Indeed, many flavor combinations have grown historically. Some of these combinations were formed for physiological reasons, such as roasted goose with mugwort, which helps to digest the fatty sauce and meat. Other combinations grew from seasonal and regional ingredient availability, such as bell pepper,

Table 3. Classification of pairing principles identified in interviews with sommeliers and beer experts (Adapted and expanded table, based on the analyses from Eschevins et al. (2019)).

Category	Principle	Explanation
Perceptual	Balance of intensity	Neither food nor beverage should dominate the pair
	Balance of quality	Contrasting flavors should have equivalent intensity levels
	Harmony	The degree to which sensations go together
	Similarity	Two products that share one or more properties
	Avoid off-flavor	Avoid emergence of off-flavor
	Rinsing effect	The beverage allows the taster to take full advantage of the next bit of food
	Decrease of sensory property	The companion product masks a disliked characteristic in the primary product
	Enhancement of sensory property	The companion product increases the intensity of one or more positive characteristics of the other product
General knowledge	Norms	Usual, classical associations encountered in culinary culture, such as white wine with fish
	Culinary practices	Two different flavors that are often encountered together create a familiar combination
	Geographical identity	Two products that come from the same region or country
	Quality level	Products with similar quality levels
	Moment of the meal	Products fit with the same moment of the meal (starter, main dish, or dessert)
	Specific situation	Products fit with the same context of consumption (e.g., aperitif with a friend on a terrace, dinner in gastronomic restaurant)
	Season	Preferences may change according to season
Personal considerations	Individual preferences	Personal liking of the products or preference for some combinations
	Experience	Matches based on the chef's autobiographic memories
	Surprise	Thinking outside the box

eggplant, zucchini and tomato combined in a French ratatouille. This also accounts for the use of herbs and spices, such as those who contribute to the flavor bases (Table 2). Many of these combinations have stayed unchanged over time or have only been slightly adapted by chefs. A common way of innovating, thereby, is substituting a single ingredient of a dish, such as the type of cheese used on a pizza, or making the patty of a burger vegetarian.

To give some examples of concrete rules that tend to be used when choosing the best wine with a dish, Table 4 presents an overview of the most common principles mentioned in the culinary literature (Paulsen, Rognså, & Hersleth, 2015). One food-wine combination that is typically avoided is the combination of red wine with seafood. When combined, diners often report a ferrous taste, an unpleasant fishy or metallic odor, and sometimes also bitterness in the mouth. Indeed, Tamura et al. (2009) demonstrated that reports of a fishy aftertaste correlated with the concentrations of total iron and of ferrous ion, but not with the concentrations of the phenolic tannins in red wine. The fishy aftertaste seems to be due to the formation of volatile compounds such as hexanal and heptanal, while the ferrous taste in the mouth could be explained by the metallic character of 1-octen-3-on (Tamura et al., 2009).

As regards the choice of beverages that will complement a dish, Bode (1992, p. 20) summarized the conventional considerations used in Western society when choosing wine with the different courses of a meal as follows: "The actual choice is often a very personal thing, based on experience, the opportunity to try various wines, and individual taste and preference. [...] The most basic rules to follow are: start with a light and younger wine for the hors d'oeuvre; fish is normally served with a dry white wine; the entrée with a light and young red wine; the relevé with its dark meats, rich sauce and accompaniments, is usually served with an older, full-bodied red wine; and our sweet course with a white wine again, this time sweet and older, or even champagne if the pocket allows. If cheese is served, a good red wine or, to be very British, a glass of port, should accompany this last course."

In conclusion, some of the pairing principles that culinary experts use have a link to universal principles of perception, whereas others are rooted in culinary practices that are specific for a particular culture or region, while another set are dependent on the idiosyncratic experiences and preferences of the culinary professional. An extensive overview of the literature on food pairing was recently created by Spence (2020). Below we will consider how some of these principles can be related to the literature on human perception and aesthetics.

Principles of perceptual organization

In a world (over)loaded with information, people appreciate structure and organization. This enables them to detect order in chaos and to make sense of

Table 4. Pairing principles mentioned most often in the culinary literature (from Paulsen et al., 2015; reprinted with permission from Elsevier)

Pairing principle	# Quotes
Food sweetness level should be less than or equal to wine sweetness level	9
Wine overall body should be equal to food overall body	8
Wine and food flavor intensity should be equal	8
Food and wine flavor types can be matched using similarity or contrast	7
Fatty food requires a wine that cuts through the fat (either acidic, fruity or tannic)	7
Food acidity level should be less than or equal to wine acidity level	6
Wine tannin levels should be equal to animal-based food fattiness levels	5
Flavor persistency of wine and food should be equal	5

the world. The principles of perceptual organization have been summarized in the Gestalt laws, which define a number of grouping principles (e.g. similarity, balance, harmony, unity in variety) that affect the aesthetic appreciation of objects positively (e.g., Hekkert & Leder, 2008; Ramachandran & Hirstein, 1999). Other aesthetics principles depend on the knowledge and experience that people have, which affects the meaning that consumers attribute to products. This determines the familiarity and novelty of products and the possible challenges that their usage involves (e.g., Schifferstein & Hekkert, 2011). These principles can be applied to individual food products, but also to food combinations, food-beverage combinations, or the different courses that together form a full course meal.

Contrast

In order to organize a number of stimuli, people need to be able to detect the different elements and determine whether they are similar or not. Detection will improve when elements stand out from their background and, therefore, the perception of both contrast and similarity are important prerequisites for perceptual organization.

According to Hyde and Witherly (1993), highly palatable foods produce a large number of instances at which sensory contrast can be perceived. For instance, while foods are processed orally, the properties of the food change (e.g. due to mastication, mixing with saliva, and temperature changes) and the conditions in the oral cavity change (e.g. cooling or warming). The sense of touch plays a dominant role in perceiving many of these contrasts. For instance, the melting of ice cream in the mouth includes a transition from a hard and ice-cold texture to a soft and creamy texture. In addition, cooling the tongue makes it less sensitive to the taste of sucrose, producing local sweetness sensitivity differences over the tongue. Furthermore, the melting releases tastants and odorants from their matrix. Combining ice-cream with a crunchy waffle, nuts, caramel, or pieces of chocolate is likely to increase its palatability, because it produces additional opportunities for perceiving contrasts.

Analogously, contrasts in appearance, flavor, and texture are critical in enjoying the different elements of a dish or a meal (e.g., Lawless, 2000). Think, for instance, about the differences between the juicy, elastic, fibrous texture of meat, the thickness and lumpiness of mashed potatoes, and the firmness and crispiness of freshly cooked vegetables. The contrasts between these foods make the meal delicious: they lose most of their appeal if you mix them and miniaturize them in a blender, which turns them into a single, homogeneous mass. Likewise, an Indian Thali meal can consist of more than 20 different sweet or salty elements, traditionally served on a banana leaf or on small stainless-steel containers. These are all served simultaneously or directly after one another without a break. Sweet dishes are thus eaten in between the salty ones, not at the end as is common in western culture.

According to the aesthetic 'unity-in-variety' principle (e.g., Berlyne, 1971; Hekkert & Leder, 2008), people perceive the greatest amount of pleasure or beauty when they experience as much variety as possible, while simultaneously experiencing a maximum of unity. To increase variety, elements are needed that are different, that can be distinguished, that contrast. On the other hand, to create unity elements are needed that are similar, that are in harmony with each other and together form a bigger whole. Hence, both contrasting and unifying elements can contribute to producing a pleasant combination. If we take the example of composing an outfit: when you decide to wear dark blue jeans, you can combine this with a contrasting white top, but if the top has a pattern with blue figures this may make the combination more sophisticated. In the food domain, an example would be a dish in which different vegetables are cut to be the same size and shape. In this case, the vegetables have unity in their form, but provide variety in taste and color. To find the right balance in combining similar and contrasting elements requires aesthetic sensitivity.

Similarity

The search for similarity is dominant, for instance, in the Nespresso Coffee Codex, which provides harmonization charts that compare the main dimensions of the sensory profile of coffee to the sensory profile of several other beverages in order to assess whether the coffee fits well with this particular beverage or not. For coffee the six dimensions defined are aromatic complexity, gustatory-olfactory persistency, body-texture, smoothness, acidity and bitterness. For each of the other beverages a different, beverage-specific set of dimensions is derived that is somehow comparable with the coffee dimensions. The idea is that if both beverages have a similar sensory profile, they will provide a good combination when presented together.

Analogously, some chefs and food scientists have suggested that food ingredients that share flavor components are more likely to taste better together than ingredients that do not share such components. To test this flavor-pairing hypothesis, they performed chemical analysis of the flavor components of the various foods or ingredients to be combined. Searching databases with flavor components can help to find ingredients with similar profiles (e.g., Garg et al., 2018). However, critical evaluations of the flavor pairing hypothesis have not always supported this hypothesis (Kort, Nijssen, van Ingen-visscher, & Donders, 2010; Varshney, Varshney, Wang, & Myers, 2013).

On the basis of the analysis of over 56,000 recipes Ahn, Ahnert, Bagrow, and Barabási (2011) concluded that North American and Western European cuisines exhibit a tendency toward recipes that share flavor compounds. In contrast, in East Asian cuisine the more flavor compounds two ingredients share, the *less* likely they are used together. These food pairing effects were mainly due to a few ingredients that play a disproportionate role in the recipes in the different cuisines (milk, butter, cocoa, vanilla, cream and egg in North America; beef, ginger, pork, cayenne, chicken and onion in East Asia). Regional cuisines typically depend on just a few authentic ingredients combinations (Rozin, 1973; Rozin & Rozin, 1981) and thus the success of the flavor-pairing hypothesis highly depends on whether these key ingredients share flavor components. In subsequent studies analyzing 2,543 Indian recipes Jain, Rakhi, and Bagler (2015a, 2015b)) found that regional cuisines in India followed negative food pairing patterns: the more two ingredients shared flavor components, the less likely they were to co-occur in the Indian cuisines. The negative food pairings were mainly due to individual, characteristic spices used in the different cuisines. Overall, these studies analyzing recipes suggest that whereas shared flavor compounds may play an important role in some cuisines (North America, Western Europe), alternative combination principles may play a more dominant role in other cuisines (East Asian, Indian). Another problem with food pairing on the basis of similarities in chemical flavor composition is that it builds on the assumption that flavor concentrations can be translated one-to-one in specific perceived qualities, which is unwarranted. In addition, the volatile compounds that are present in a food may change during cooking (see Spence et al., 2017 for a discussion).

Complexity

Studies investigating the role of perceived complexity mostly start out from Berlyne's theory describing the connection between complexity and hedonic measurement (e.g., Lévy, MacRae, & Köster, 2006). This theory asserts that, for each individual, hedonic response to a stimulus increases with its complexity until an optimal level is reached, then it declines (Berlyne, 1970, 1971). This response function may thus be represented with an inverted-U curve, but people may differ in the level of arousal that they prefer. In addition, this optimum arousal level is not fixed: When a person becomes more experienced in an area, their preferred level of complexity typically increases with time (Walker, 1980). A typical product for which this applies is chocolate: While milk chocolate contains a lot of sugar and is usually liked from the start, the flavors of dark chocolate are a lot more complex and take some time to get used to. When one becomes acquainted with the taste of dark chocolate, it can become preferred over milk chocolate, even though it is less sweet. The same holds for becoming acquainted with the bitter taste of coffee.

In a recent review of complexity studies in the food and beverage domain, Palczak, Blumenthal, Rogeaux, and Delarue (2019) found that researchers have played with the number of food components (ingredients, size of pieces, flavor notes) in order to generate different levels of complexity, but complexity has typically been varied within a single sensory modality only. However, out of the fourteen papers that investigated the relationship between complexity and hedonic responses, only one paper found an inverted U-curve relationship as suggested by Berlyne's theory. This paper investigated only the complexity of visual images (Mielby, Jensen, Edelenbos, & Thybo, 2013), which depends on factors like the size and number of different products, the number of different colors, and the type of color contrasts (Mielby, Kildegaard, Gabrielsen, Edelenbos, & Thybo, 2012). The other studies observed either positive, negative, or no relationships.

As regards in-mouth complexity, Palczak, Giboreau, Rogeaux, and Delarue (2020) found that chefs used various strategies to increase complexity, specifically in gourmet desserts: They combined different flavors and tastes, they contrasted textures, they worked on the temporal evolution of sensations, and they tried to surprise their customers. Temporality was manipulated within a single spoonful (by combining fast sensations from chocolate sprinkles or lemon zest, with medium lasting sensations from pieces in different sizes, and the lasting sensations of spices or sticky textures) and over the course of a dish (by playing with the stacking of layers within a dish) (Palczak et al., 2020). Sensory tests confirmed that the products indeed exhibited the expected complexity levels intended by chefs. These authors indicate that the ways in which chefs use new configurations of ingredients to combine different, tastes, smells and textures to create complexity can lead to gourmet product innovations with multiple textures, flavors or layers. However, the chefs themselves normally do not use the term complexity; they rather talk about roundness, balance, richness, diversity or variation. Oppositely, they may call a dish "flat" or "one-note", which may also refer to flavor and color in addition to texture. They may refer to complexity as the time needed to understand the culinary experience (Palczak et al., 2020).

As predicted by Berlyne's theory, the complexity of a dish can become too high to be appreciated well. In Palczak et al. (2020)'s study one of the chefs created one dish deliberately as an "over-complex" product. For this dish it became very difficult to distinguish which element brought which taste or texture, and participants found themselves lost in perceived tastes. This is consistent with the fact that humans are limited in the number of odorants they can discriminate and the ability to identify a particular odorant within a mixture (Laing & Francis, 1989; Livermore & Laing, 1998). When people cannot distinguish between separate components, the flavors may blend into a new quality and thus may actually be perceived as low in complexity. As previously discussed, food flavors are actually a result of a combination of many chemical substances. Chefs may also combine a large number of ingredients to create a new entity, such as when they use over 20 ingredients to create a Mexican mole sauce (Fabricant, 1982) or Indian vangi bath powder (Suvarna, 2020).

Appreciation of familiarity versus novelty

The pairing principles used by culinary experts (Table 3) show that many principles are based on practices that are established within a certain region or culture. However, one of the principles indicates that from time to time the chef would like to surprise their clientele by offering them an unexpected combination. The reconciliation of the tendency to look for the familiar and also look for the novel is coined in the MAYA (Most Advanced, Yet Acceptable) principle (Loewy, 1951), which suggests that people prefer products that are high in both typicality and novelty (Hekkert, Snelders, & van Wieringen, 2003).

Humans thrive on a diverse diet that can contain components that are plant- or animal-based. According to the omnivore's paradox, people are attracted by new foods, but at the same time they have a preference for foods from which they already know that they taste good (Pollan, 2009). It is instrumental that people seek variety in the foods they eat, because a varied diet is more likely to fulfil all dietary needs than a monotonous diet. As a matter of fact, many foods that are initially pleasant lose their sensory appeal during eating, a phenomenon called sensory-specific satiety (e.g., Rolls, 1986), the chemosensory equivalent of momentary boredom. Sensory-specific satiety has been demonstrated not only for taste and smell properties, but also for texture (Guinard & Brun, 1998). In contrast, people's specific nutritional needs may sometimes lead to a specific preference for food containing the missing nutrient (Rozin, 1972, 1976), which helps to resolve one's specific, momentary dietary needs.

From an evolutionary perspective, it makes sense that some people are hesitant to try unfamiliar foods (neophobia) as ingesting them might be hazardous to one's health (Januszewska & Viaene, 2012). There are at least three general means to overcome an aversion to a new food or make a naturally unpalatable food more palatable. The first method is copying behavior from others (Addessi, Galloway, Visalberghi, & Birch, 2005; Hendy & Raudenbush, 2000). If friends or family that you trust are engaging in a specific activity, you are more likely to also engage in that activity (such as trying raw oysters for the first time). A second method is pairing the food with food that is already palatable and preferred (Pliner & Stallberg-White, 2000; Rozin & Rozin, 1981).

As mentioned earlier chocolate or coffee on its own is bitter, but with regular pairing with milk and sugar, one can learn to appreciate the taste on its own without the added sugar/milk. The third method is simply repeated exposure over time (Bornstein, 1989) as mentioned earlier when discussing bitter and spicy foods.

In the food domain, Elisabeth and Paul Rozin (1981) have suggested that the introduction of a new food staple in a culture may be facilitated by adding a familiar combination of seasonings. According to Elisabeth Rozin (1973), many of the world's cuisines involve the use of distinctive and pervasive seasoning combinations, such as the tomato–garlic–olive oil combination for Italian dishes or the soy sauce–rice wine–ginger mixture for Chinese cooking. She refers to these seasoning combinations as flavor principles (cf. the flavor bases in Table 2 and the characteristic elements of different cuisines discussed above). Adding a familiar flavor principle to an unfamiliar food may help to bridge the cultural gap, by increasing people's willingness to try the new food (Stallberg-White & Pliner, 1999). There are varied views on the globalization of cuisine. Americanized Thai food, for example, is different from the food you would find in Thailand. It is a modified approximation of a cuisine altered both by the end user's desires and expectations, as well as the local ingredients. People want something that is novel but not too different. This phenomenon is also addressed in David Chang's *Ugly Delicious* Netflix Series as he traces the history of popular foods and how they evolved and have been modified and adapted into different cultures by their local ingredients and expectations.

Not only the type of food itself is determined by local practices, but also the preparation methods and the tools people use for cooking, serving, and eating food. Bruns, Tomico Plasencia, and Kint (2012) asked multicultural groups of industrial design students to develop a cooking tool for their own culture that would respect the values of another culture. The process started out with a cooking task, where a foreign student prepared a meal and pointed out the markers that were of importance to their culture, whilst the assisting local student identified the concepts that they found most remarkable. In the resulting designs, the most outstanding cultural marker was then applied in the local cooking culture. Through this approach, valuable practices from the foreign culture were used to enrich the cooking or eating experience in the local culture. Designers learned from each other's cultures, which brought mutual respect for the values of the other culture.

For instance, the Dutch students who observed a Japanese student noticed that hospitality is very important for Japanese culture. Food is eaten with attention, all ingredients are cut in bite size and portions are smaller, to facilitate eating with chopsticks. The chef was very calm during cooking, all ingredients were handled with care and measured precisely, and everything was well planned. Dishes were prepared and presented with elegance. For each dish a plate or bowl was chosen, based on color and shape, making sure the plate contrasted with the food, to make it look fresh. These insights were then used to reshape a Dutch potato stew dish. During the design exploration, small scoops of kale stew were served on a piece of smoked sausage, decorated with bacon and pickle. To support the making of this kind of presentation, the students created a spoon that could make small scoops of stew, matching the diameter of the sausages. Furthermore, the students created a plate, consisting of a wooden board with six tapered cylinders on top, which matched the size of the scoops of stew. On the side of the plate there was room for a small cup with gravy. The plate had a light and a dark side to optimize the contrast between dish and plate.

Conclusion

In this paper, we discussed mechanisms of perception that may help chefs in understanding what happens when people consume the dishes the chefs have created. First of all, we considered the input from the different sensory modalities, giving the primary role to taste and smell as main determinants of food acceptance, followed by vision, touch and audition. Here we paid attention to perception mechanisms, such as sensory adaptation and mixture suppression, as explanations for changes in perception when different foods are tasted consecutively, or when they are mixed in different ratios. By playing with the types of ingredients, the sequence of tasting (e.g., by using layers), and the size of the different food particles, chefs manipulate the amount of sensory adaptation and the degrees of mixture interactions (e.g., Spence et al., 2017). Hence, by knowing the ingredients they work with and the ways in which these ingredients influence each other's perception, chefs can determine the tasting experiences of their guests.

Within a meal, people expect to find contrast (in taste, smell, texture, color) between the different courses to avoid sensory-specific satiety, but there should also be a certain degree of coherence. The different courses should vary in the ingredients used and the preparation methods. Within a single course people would expect to find harmonious combinations, which includes also some variation in sensory properties, but this variation should be smaller than between the courses. Concerning food combinations, we can conclude that not a single principle, but rather the interplay of concepts like similarity and contrast, balance, harmony, and complexity together play important roles in defining the attractiveness of foods and food combinations. In addition, the chef's knowledge and experience with different practices will have an important impact on their choices for particular combinations, despite the availability of digital tools that might suggest to try very different, unexpected combinations. The reliability of such tools in proposing enjoyable combinations tends to be quite low for the moment, since they are based on simple rules and make some incorrect assumptions (e.g., that flavor concentration can be translated one-to-one in a specific perceptual quality). Nonetheless, further development and sophistication of these tools may enhance their supportive role in recipe development in the future.

Many studies have reported considerable individual differences in preferred food pairings (e.g., Harrington & Hammond, 2005; King & Cliff, 2005; Paulsen et al., 2015). Hence, even though concepts like similarity and contrast can explain some of the preference patterns, it is still hard to predict which combinations individual people will like. For instance, if people differ in the combinations that they find harmonious or in their optimum complexity level, they are bound to appreciate other combinations. Furthermore, preferred combinations may also be largely determined by the liking for the individual components (e.g., Donadini, Fumi, & Lambri, 2012, 2013; Harrington & Seo, 2015). Hence the pairing operation is only of limited influence on the appreciation for the combination.

In this paper, we have given an overview of the principles identified in scientific research on sensory perception, food pairing, and aesthetics. Knowledge on these basic principles can help chefs innovate and improve their dishes, so they have a greater chance of creating dishes that will appeal to their clientele. Therefore, we think that it is important that this knowledge becomes part of the educational programs for future chefs. However, as we noted in the Introduction, chef training programs are often largely focused on the acquisition of technical preparation skills, with little attention for the scientific knowledge behind their skills. Therefore, we wonder what could be the best way to make these insights available for interested students and chefs?

Maybe we could create a special cookbook that connects each scientific principle to an exemplary recipe? Similar to how McGee (2004) connects the art of cooking to principles of food science, this book could connect the art of cooking, presenting food and menu planning to principles of sensory science and aesthetics by giving examples and discussing these in the light of theory. An alternative could be to create low threshold opportunities to convey the scientific principles, for instance by facilitating an online video platform showing how different principles may turn out in culinary practice. Such a platform would be more accessible on an everyday basis and could instantly cater to the chef's questions.

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