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Neurogastronomy: Factors Affecting the Taste Perception of Food

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Abstract

Neurogastronomy is a new formation that includes many researches to provide a connection between gastronomy and neurology. The existence of biological, emotional and cultural factors as flavor in the brain can be explained as neurogastronomy. The data received with the five senses are collected in the brain and perceived in its relevant parts. Research on what kind of perception is created with the formation of missing sensory data in the brain has been increasing day by day. In addition, by considering the different reflections of sensory data from reality, it is examined how they lead to perceptions in the brain. Plate design is very important in terms of visual presentation. What kind of an effect the presentation types of plate design have on customers and what kind of plate design they prefer is a matter of curiosity for researchers. Every stage of life continues in the light of technological developments. One of these technological developments is virtual reality. With the use of virtual reality in the field of neurogastronomy, it is possible to simulate the senses differently. This situation creates the possibility of causing different perceptions in the brain. In this study, neurogastronomy, the concepts of taste and flavor and the parameters affecting the perception of taste were addressed, the studies on the effect of plate presentation and atmosphere were examined, and information was conveyed by making a comprehensive literature review.

Keywords: Flavor, Neurogastronomy, Sensory perception, Taste.

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1. Introduction

Neurogastronomy, a field, which is shaped around gastronomy and neurology, can be explained as that the brain triggers our perception with the creation of flavor using biological, emotional and cultural factors. It can be also defined as the examination of complex brain processes during eating (Robinson, 2015).

When dining in a restaurant, all external factors affect thoughts about food during eating experience. Playing of a music loved, the softness of yoghurt, the temperature and density of the food, the color of the meat and the smell of the food are among all these factors. So much so that, especially with the effect of smell, eating becomes an experience process during which all the senses are felt together with the revival and recall of past memories (Yilmaz & Tugcu, 2021).

Scientific research regarding the perception and experiencing of foods is mainly based on “neuroculinary” which includes the concepts of “neurochemsitry” and “neurogastronomy” (Shepherd, 2012). Although neurogastronomy mainly deals with the aspects of taste experience, it takes place in the field of molecular gastronomy. Molecular gastronomy is a much wider field of food preparation and presentation, which is also interested in the neurological connections of food perception and experience (Kuran, 2014). In recent years, in addition to ever increasing number of academic researchers, many marketing and design practitioners have revealed various factors that appear to increase the visual appeal or flavor of food images for the typical consumer (Spence et al., 2022).

Governing flavor is not an easy task. There are more than 400 smell receptors in the human nose. Each receptor may give response multiple different smell molecules, and each smell generator type may activate more than one receptor. Taste receptors are also quite complicated. First, researchers have found taste receptors in the lungs, intestines, and pancreas, which they suspect they encode information about metabolism. Second, researchers have recently asserted that humans have receptors for tastes

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different from the five basic tastes, with fat and calcium being leading candidates in this regard (Breslin, 2013).

At least some of the perceptual processes are biologically determined. Both taste and smell are based on the direct perception of chemicals in the environment by means of receptors on the tongue and nose. This process, which goes from the moment the knowledge of a chemical compound is possessed to the moment the representation emerges at the subjective level of the individual, takes place on a continuum between stimuli, senses, receptors, nerves and action (Tomc, 2011).

In the present study, neurogastronomy, the concept of taste and flavor, the parameters affecting the perception of taste, the perception of smell, visual factors, auditory elements, the factors affecting the flavor of the food on the plate as well as studies conducted on this topic were examined.

2. Conceptual Framework

Humans have a complex relationship with food. For some, food is sustenance, for some it is a source of subsistence, for some it is an emotional reward and it can be even a medicine. As the obesity epidemic shows, it can also be the exact opposite. Neurogastronomy encompasses a series of disciplines that address this relationship, including basic science, nutrition, psychology, agriculture, food science and health, and is a relatively new science, considering its history. The term was first designed and suggested in 2006 by Gordon M. Shepherd, a professor of neurobiology at Yale School of Medicine. Gordon Shepard used the term, neurogastronomy, in 2006, when he first realized how important smells are in producing certain tastes. That year, he published a paper about molecular biology of smell in Nature, in which the olfactory receptors and the biochemistry of food preparation and how all these are processed by the brain are included (Shepherd, 2006). The fundamental hypothesis of neurogastronomy is that food flavors are created in the brain as a product of information we receive from all of our senses. This explains that the thing that gives a steak its distinctive flavor and makes it different from the grilled chicken in taste is the smell. When a juicy steak is bitten, some of its molecules bind to taste receptors on the tongue and give basic sensations such as sweet, salty, sour, bitter or umami. On the other hand, more volatile smell molecules reach from the back of the mouth towards the nose. This retronasal olfactory signal combines with taste signals in the orbitofrontal cortex of the brain to give a more complex taste sensation (Fried, 2017).

Neurogastronomy is a new multidisciplinary field dedicated to understanding gastronomy in the context of the brain and behavior. It brings the science and cuisine together by exploring behaviors that affect how the human brain experience eating and drinking. This field has transformed into its own learning space by examining the molecular biology of olfactory receptors, the biochemistry of food preparation, olfactory imagery and the brain favor system (Pérez-Rodrigo & Aranceta-Bartrina, 2021). The field of neurogastronomy, in which the brain perceives taste, the relationship between the brain and behavioral models is important, and the senses are kept in the foreground, brings a new perspective to the perception of taste. This science focuses on how the brain can be reinvented to perceive food differently rather than exploring how food can be redesigned to change its taste. For example, it is a concept about making the brain think carrots are delicious, instead of genetically modifying carrots to improve their taste (Yilmaz & Tugcu, 2021).

Although quality controls of foods are mostly performed with objective evaluation methods, sensory analyses are also frequently used today. Sensory analysis is a method of evaluating foods in terms of appearance, taste, smell, touch and sound. The response of a person or persons given to a stimulus is measured in the sensory analyses. Consequently, stimulus-response reaction is essential in the evaluation in which intensity, quantity, quality, dimension and hedonic response (personal taste) are addressed. Perceived sensory properties, despite being associated with demographic structure of persons, show variation according to the geography lived, the family structure being raised and their personal education and development. The gastronomy concept is associated with the subject exactly at this point (Yilmaz et al., 2021).

3. Five Senses

Human beings need and use their five senses at the moment of decision making in every period of their life. Sometimes, contradictions may arise between senses. For example, from a distance, the drink in a glass may seem hot, but when approached, and touched by hand, it may be realized to be cold. Our most commonly used sense organ is sight and while using the sense of sight, other senses are used in the following steps either to confirm or contradict what is seen. When we go to a restaurant for dining and the moment we enter through

the door, the first thing that attracts the attention of most of us is the style of the place. The first used sense is the sense of sight, which the next stages are decided according to the perception at this first moment. In other words, the decision regarding the taste of the food that will come out of the kitchen and how that food will be presented are made based on the appearance and comfort of the restaurant. The presentation of the plate, the amount of the portion, the color and shape of the presentation, the layout and quality of the table are other elements that the buyer attaches importance about (Yilmaz et al., 2021).

Olfaction is expressed as a "dual sense" consisting of orthonasal and retronasal smells. Orthonasal smell perception, which is received from external smells through the nostrils, is often associated with aroma by humans. By means of the perception of retronasal smell coming from inside of the mouth, small breaths are sent with exhalation from the back of the mouth and nasal passages, passing through the space connecting the nasal passage to the back of the throat. When it comes to the chewing and swallowing functions of the brain, it is possible to perceive and identify a wide diversity of foods with retronasal smell perception. In a study, apples and onions were cut into small cubes, participants' eyes were closed, their noses were gagged, and a food cube was placed in their mouth. Participants were then asked to suck on the cube. At this time, it was not understood what the product was, but when the nose was opened, it was immediately understood whether it was an apple or an onion in the mouth. In fact, sweet, salty, bitter, sour and umami tastes are perceived in the mouth, when the nose becomes involved, the smell of hundreds of millions of different olfactory stimuli are perceived. In other words, the perception is completed when nose and mouth function together (Herz, 2015).

No matter how important the olfaction is, it is not the only sense to create the perception of taste by combining with taste. In a workshop held to measure how much visual perception affects flavor, participants were given two glasses, one with white juice and the other with red juice, to measure how much visual perception affects flavor. Participants described the red juice to be more concentrated and selected attributives connected to forest fruits. They described the white juice as more delicate and resembling green apple or light-colored fruits. In reality, both juices were the same, but one contained red food colorant (Mitzman, 2014). It is seen that visual perception regularly affect the flavor perception of our brain. Thus, this prospect will also change the way we perceive food after we put it into our mouth. Although most people do not realize that the sense of hearing affects the flavor perception, potato chip manufacturers are aware of this and use it especially in their advertisements. It is stated that the sound of a food breaking crisply in the mouth evokes the feeling of freshness (Mitzman, 2014).

The smell of food is another important element and it shows us the finer details about everything. Such as whether it is good or bad, fresh or spoiled. Appealing to the buyer's sense of olfaction is more about ingredients' quality and being delicious than how the food looks on the plate. As smell and taste are interconnected, pleasant smells may increase appetite. Due to the fact that smells make the person think that the food is good, they enable a decision to be made about the food without tasting it (Holmes, 2017).

The sense of feel and touch is also very important in this regard. For example, it is revealed how important the sense of feel and touch is in situations such as touching a dirty chair caused by oil residue or being served cold soup or hot lemonade (Krishna, 2016).

Tasting is one of the most important factors in the presentation of the food. The taste of the food should undoubtedly be delicious. In fact, when the tasks are put in order, the stages are observing the food, smelling it and having an idea about its taste, checking whether it is cold or hot and finally tasting it. While trying to prove that the food is perfect from the beginning to the end of these stages, the actual taste of the food is felt in the final stage. At the end of the collective action of the five senses, the presentation of the food takes place (Wan et al., 2020).

Living organisms exhibit a substantial selectivity by utilizing their chemical and physical senses, instead of eating and reproducing with whatever is available (Le Bon et al., 2017). Taste is very important for the survival of people living in social groups. In a way, it is considered to be the most significant sense helping to distinguish between nutritious and poisonous food sources (Spence, 2017). Taste memory includes the recognition of a taste, and its characteristics related to hedonic value, degree of familiarity and nutritional or toxic properties associated with that taste and plays an important role in identifying nutritious foods and preventing toxins. Taste recognition is an often instinctive response that is part of an innate behavioral repertoire, however often involves brain processes that recall past experiences when it is mostly associated with the consequences of ingesting the food. In accordance with this, it can be expressed that a taste perception concludes with learning that allows the storage of information about the taste and its

relationship with the environment and that can be used as a guide for future food consumption (Nunez-Jaramillo et al., 2009).

4. Taste, Flavor and the Presentation of Foods

Flavor and taste are often perceived as the same, but are actually two very different concepts. The perception of taste starts at the moment when we take the food into our mouth, then is directed to the brain where the final decision about the taste of the food is made. Thanks to receptors on our tongue, bitter, sweet, sour, salty and umami tastes are explored. There is a group of researchers stating that humans have five basic tastes, whereas another group indicates that it is possible to add oily, acidic and metallic tastes to these five basic tastes (Spence, 2017). Kokumi, which is called the sixth taste, functions as a flavor enhancer rather than a taste, increasing the perception of other basic tastes, especially sweet, umami and salty (Yilmaz & Altuntas, 2022).

While taste is two senses perceived in the mouth and nose, flavor is much more multidimensional. Flavor identification is an ability specific to the human being among species. In this dimension, perceptual senses such as appearance, smell, sound, temperature, taste and touch interact with each other. Flavor is the sum of all senses we perceive while eating the food (Breslin, 2013; Holmes 2017).

All senses, especially the sense of smell, are effective in the sense of taste, which is an important component of the sensory mechanism. The senses influence the person's food preferences as well as wishes, working together in a multisensory framework. A person's perception of food is about the mood in the brain, the effect of memory, and the inferences obtained from the one's learning and experiences (Shepard, 2006).

The duration that allows us to know whether the food is bitter, sweet or sour is at the macro level, but the process of perceiving flavor is a variable at the micro level (Baral, 2015). Flavor arises when we engage all our sense organs. Taste is a weaker perception than flavor. The perception of flavor is about concepts such as “memory, experience and neurobiology” (Konnikova, 2016). The orbitofrontal cortex is the part of the brain that processes flavor. Apart from the sense of taste; the senses of sight, sound, smell as well as temperature stimuli are elements that support and contribute the perception of taste (Kurgun, 2017).

Over the past 17 years, the laboratories of Dr. Nicholas Ryba of the US National Institute for Dental Craniofacial Research and Charles Zuker of the Hovart Hughes Medical Institute have identified receptor cells for sweet, sour, bitter, salty and umami tastes. The information from these cells is transmitted to the taste cortex of the brain. Recent studies have revealed that sweet and bitter tastes are represented in different regions of the taste cortex (Chen et al., 2011). While chewing a food, enzymes in the saliva break down the food. As the food breaks down, the tongue papillae touch the food particles. Each papilla contains taste buds possessing 50 to 100 chemical receptor cells that describe the five basic tastes: bitter, sweet, salty, sour and umami. An adult is assumed to have 2,000 to 4,000 taste buds. Taste buds are repaired and regenerated every week. The papilla also has many sensory cells that recognize and analyze the morsel in the mouth and transmit the information to the brain by activating nerve cells. According to studies, the perception of taste takes place in the brain, not in the tongue (Baral, 2015). At this point, understanding complex brain processes that help us comprehend what, how and why we eat falls in the field of neurogastronomy.

All foods have a taste, however, the likes and dislikes of two individuals eating the same food regarding its taste are actually created in the brain. How does this difference arise between two people who eat exactly the same food? The brain is affected many factors while creating this taste. Factors such as how the person feels at that moment, whether she/he is sick, whether she/he likes that food, whether the food is too hot or too cold, and the color of the plate affect the pleasure the person receives. All these are interesting domains of neurogastronomy. Neurogastronomy brings scientists and cuisine experts together to understand how we feel before or while eating. Thanks to this concept, the idea of developing alternatives for people who have taste disorders or dietary restrictions for various reasons becomes the source of scientific studies (Michel et al., 2014).

While eating and drinking, the person experiences numerous sensations including taste, smell, touch, temperature, sight, sound, and sometimes pain/irritation. This multifaceted sensory experience forms the basis of perceived taste. However, some sensations contributes more to taste perception than others (Kurgun, 2017).

Customer expectations are formed at the moment when the food is ordered in a gastronomic facility. This is the first stage. The second stage takes place at the

moment the food is served, during which the person decides the internal evaluation of the food or the restaurant in general with all her/his senses (Piqueras-Fiszman, 2012). The appearance and arrangement of the food on the plate are therefore decisive factors. Sight and followed by olfaction are the first senses enabling this decision to be made (Reisfelt, 2009). A good food presentation primarily appeals to the sense of sight (Zellner, 2011). Not only the visual presentation of the food, but also variables such as the color and shape of the plate can be effective in stimulating the desire to eat. For instance, changing the color of the plate to increase the visual contrast of the plate increases food and drink intake in a considerable extent (Kokaji & Nakatani, 2021). Carelessly prepared meals can lead to the development of the prejudice that the food is of poor quality, tasteless and non-hygienic, even before perceiving the taste of the food (Lee & Lim, 2020). Eating delicious food evokes positive emotions such as warmth, satisfaction, and relaxation (Petit et al., 2016). People are impressed by the beauty, and the same also goes for the arrangement of foods. Accordingly, guests who receive foods on the plate in an elegant style tend to claim that their food is more delicious compared to those who receive the same foods on the plate in an unattractive way (Zellner et al., 2014). The eyes are connected to the mouth via the brain, which is endorsed by the assumption that the food is more delicious and better for us, in case we like what we see (Michel et al., 2014).

In food presentation, different colors, ingredients, textures, shapes and arrangements of foods should be taken into consideration to create a pleasant combination on the plate (Styler, 2006). The perception of how food is prepared and to what extent quality ingredients are used, and good food presentation can create an indicator for food quality and appetite (Namkung & Jang, 2008). Food presentation is a way of reflecting the chef's skills to the food and also an indication of respect shown for the diners (Lee & Lim, 2020).

5. Effects of Food Presentation and Atmosphere on Consumption

The atmosphere of a restaurant can encourage people to eat faster, as well as lead them to overeating (Lawton, 2004). In a similar vein, an atmosphere can encourage a person to stay longer in the restaurant and order additional food (Wansink, 2004). For example, in a study, 1,400 diners have been examined in a restaurant in which instrumental music is played. It has been reported that, customers dined 11 minutes longer and spent more money on foods in the environment with music and that the money spent was much greater when slow music is played than when fast music is played (Milliman, 1986).

Fast-food restaurants are characterized by bright lights, reflective surfaces and stimulating yellow-red colors and are designed for customers to eat and leave quickly (Sobal & Wansink, 2007). In these restaurants, there usually exists reverberated music or loud sounds from customers. Some studies have shown that people dining in a fast-food restaurant eat faster and more per minute than those in a quieter restaurant (Van Ittersum & Wansink, 2012).

Lighting and noise psychologically affect food consumption and dining time directly or indirectly (Garg et al., 2007). People are less stimulated when the lights are low (Areni & Kim 1994; Lavin & Kanunsuz, 1998). Soft or warm lighting increases dining time (Scheibehenne et al., 2010). It has been found that severe or bright lighting reduces the length of stay in the restaurant, whereas soft or warm light usually causes people to stay longer (Summers & Hebert 2001).

The more disturbing the noise, the less time people stay in a restaurant (Hargreaves, 1996). This condition sometimes leads customers to eat faster. In contrast, slow music is associated with slow eating, but also with higher consumption of both foods and drinks (Caldwell & Hibbert, 2002).

The more customers like the music, the longer they stay in the dining environment (Wansink, 2004). When longer time is spent, more food such as dessert or another drink can be ordered. In general, loud music or noise has been stated to accelerate food intake in a restaurant (Stroebele & de Castro, 2004). On the other hand, soft music prolongs dining times, encourages additional consumption and leads more food to be ordered (Wansink & Ittersum, 2012). In a study examining the effect of vertical or horizontal serving of the plate on consumption perception, it has been found that even though the quantities served are the same, when the food is served vertically, that is, stacked on the plate, consumers perceive the portions as smaller compared to when the food is served horizontally, that is, evenly distributed. In addition, it has been noted that customers are more satisfied with the portion size when the food is served horizontally by spreading on the plate.

Traditionally, decisions about food plating in high-end restaurants are based on chefs' intuition and fundamental rules. The arrangement of the plate

Figure 1. Examples of asymmetric plating [Source: Zellner et al., 2014]

mostly depends on the ingredients constituting the flavor of the food and the style of the chef or restaurant. Trends regarding asymmetrical plating (Figure 1), which is one of the vertical food arrangements taking inspiration from architecture in Carême's time, preserve their place in modern food plating (Zellner et al., 2014).

In a study carried out in the London Science Museum, with the participation of 7,495 people, 65% of whom were female and 35% of whom were male, investigating the effect of plating on customers; the order of the food on the plate was demonstrated to participants in a way that there will be six different alignments, with different appearances. The results of the comparisons revealed that the plate with balanced presentation was highly preferred (Zellner et al., 2014).

It is well known that the appearance of the food, especially its color, may affect flavor perception and identification. Changing the appearance of foods can be achieved by using virtual reality (VR) technology, which has become increasingly accessible, sophisticated and widespread in recent years. VR offers researchers a new way to conduct sensory and psychological studies to explore the impact of visual information on consumer perception. In a study investigating whether making a coffee that appears milkier in a VR environment can change the perceived flavor and liking, 30 British consumers were given four samples of cold brewed black coffee at 4% and 8% sucrose concentration, served with a straw in a white mug. Participants put on VR headsets during the course of the study (Figure 2) and watched the same mug and straw on a virtual environment. The color of the beverage was manipulated in VR such that participants could see a dark brown or light brown liquid in the mug while sipping the coffee. Participants were asked to indicate sweetness, creaminess and liking for each sample. The results obtained indicated that the color of the beverage viewed on the VR display affected the perceived creaminess of the coffee; when participants were shown a lighter brown coffee by only changing the VR view of the beverage, they expressed to perceive the coffee to be more creamy. However, the color of beverage had no impact on perceived sweetness or liking (Wan et al., 2020).

Figure 2. Participant wearing a virtual reality headset [Source: Wan et al., 2020]

A study conducted to compare liking scores of chocolates with different shapes as round and squared has shown that participants rated the round chocolate as creamier/sweeter than the squared one. Shape-based food research indicates that when foods are round, preferences for these foods tend to increase, on the other hand, healthy foods are preferred when they are presented in a squared shape (Baptista et al., 2021).

In a study investigating the effect of visual presentation of food on consumer preferences, waffles prepared with the same ingredients were served in three different plates, luxuriously designed black stone plate, paper plate representing street food style and white classic plate (Figure 3). Various fruits, whipped cream, candies, white chocolate and tuile were used as waffle toppings. Biometric methods such as eye tracking and face reading were also employed in the study (Berčík, 2021). Based on the results, it can be said participants rated the visual presentation of a waffle placed in a luxurious black plate as the best. When the waffles were compared in terms of smell, the waffle served on a black plate smelled best to participants, followed by the one on a white plate. The waffle on the street plate, on the other hand, received the lowest smell score (Berčík, 2021).

The same study also noted that participants considered normal to pay a difference of about 1 Euro, when the same product is served in different plates. It was stated by participants that they would be willing to pay for a waffle an average of EUR 4.4 when served on the stone plate, EUR 3.54 on the classical white plate and EUR 3.04 on the street plate. This indicates a significant effect of the arrangement and presentation of foods on the perception of value (Berčík, 2021).

In a study exploring the effect of plate color on the desire to eat in Chinese restaurants, the consumer behavior of 581 participants has been examined. As a result of the study, gold, white and black colored plates were determined to be the colors of plates that most trigger the desire to eat. It was also reported that gold and white plates create a positive eating experience and that plate color has a significant effect on appetite (Chen et al., 2019). Red plates may cause increased appetite and thus, the presentation on red plates may increase the number of appetizer and dessert orders. Conversely, blue plates are not appetizing, as there are very few foods that are naturally blue.

Figure 3. Visual appearance of different plates on which the waffles were served [Source: Berčík, 2021]

6. Conclusion and Recommendations

Studies indicate that our brain perception has a structure that can be directed by transmitted data. The entrance of smell, sound, sight, taste and touch sensations to the brain in different forms results in the stimulation of different perceptions in humans. Notwithstanding that data coming from the five senses are interconnected with each other, shutting down a sense or reflecting the information coming to the sense different from the facts may cause a change in perceptions formed in the brain. In addition, the fact the brain tries to make decisions with teachings that are culturally from the past suggests that it essentially has habits and shapes the first decision making process regarding flavor with past data.

In terms of plating, people prefer balanced presentations rather than the unbalanced ones of the same components. Plate design is an important component in terms of modeling visual preferences. Also, the color and appearance of the food we eat determine our expectations for the taste of that food. The most important factors in the perception of food served to the consumer are variety, distribution on the plate and portion size, in addition to visual characteristics. Particularly in situations where it may be difficult to set the same scenario in the real world, utilizing virtual reality can be a practical approach. Moreover, the use of virtual and augmented reality will open new opportunities in the future to encourage healthy eating behaviors such as reducing fat intake.

One of the most effective aspects of neurogastronomy is the great influence of social and cultural factors on our flavor perception. By this means, chefs, scientists, artists, designers and musicians, by working together, may enable the doors to open towards developing multi-sensory experiences that engage all senses at various levels.

Declaration of Competing Interest

The authors declare that they have no financial or non-financial competing interests.

Author's Contributions

P. Tokat (0000-0002-4455-2451): *Definition, Data Collection, Investigation Conceptualization, Writing, Methodology, Editing, Supervision, Investigation.*
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