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The Integration of Taste and Smell in the Human Brain-------How We Perceive Flavor

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Abstract:

Whenever we like food, we say that it "tastes good". However, most of what we refer to as taste is actually smell. This paper examines how the human brain integrates signals from taste buds and the nose to form the perception of flavor. A common misconception among the general public is that these two signals are completely separate. However, they do have interactions, particularly in regions of the brain, such as the orbitofrontal cortex, where finally the tongue meets the olfactory system. One of the concepts that will be discussed is retronasal olfaction: the process by which odors from food in the mouth travel upward into the nose during chewing and swallowing. This paper discusses the conclusions based on reading the paper from Small et al. (2004), who, through imaging research, found that different brain regions react differently to the same smell, depending on how it enters the head through the nose or the mouth. Through a review of neuroscience and behavioral research, this paper aims to demonstrate that flavor is not merely a sensation of the tongue. It is, in fact, a multi-sensory process that is influenced by biology, memory, and culture.

Keywords: Flavor, smell, taste, orbitofrontal cortex, olfactory system

1. Introduction

Our experience of flavor does not stem from a single sensory modality alone but from the integration of multiple senses—including taste and smell. While we often think flavor comes only from the tongue which is taste. Recent scientific research has shown that smell actually plays a much larger role. This interplay between taste and smell has emerged as a prominent area of research in neuroscience and psychology—particularly as researchers seek to understand how the brain constructs the perception of flavor. In recent years, the process of how signals from the taste buds and the nose are processed in the brain has been studied. It has been found that these two senses converge in a brain region called the orbitofrontal cortex.[1]. This area helps combine different sensory inputs into one perception — flavor. One important aspect of this field of study is that there is retronasal olfaction. This is when smells from the food on the tongue travel up the nose when we eat. Smells from the food in the mouth travel up to the nose through the nasal cavity when we chew and especially when we swallow. This process is essential for the identification and appreciation of distinct food flavors. This paper will discuss some of the studies — including the imaging studies by Small et al. (2004) — on how flavor is formed in the brain. This article will discuss both neuroscience studies and behavioural experiments to answer the question: how taste and smell integrate to form flavor? Understanding how these two sensory modalities interact holds practical value: it can help enhance food experiences, inform the treatment of olfactory and gustatory disorders, and even guide the development of improved artificial flavor systems. From this research, we can see that flavor is not merely about food, instead, it is a product of how our brain brings our senses together to give us meaning.

2. The Science of Taste and Smell

2.1 Taste: Structure and Function of Taste Buds

Taste buds—the primary structures of the gustatory system—are onion-shaped and function as the key sites for taste perception. One taste bud includes up to 100 taste receptor cells which is the cells with neuronal properties, such as the capacity to transduce signals from their environment (in this case, the stimulus). The taste buds are innervated by branches of the facial nerve and the glossopharyngeal nerve in the tongue. [2]. Additionally, taste buds are primarily located on the tongue. They sit inside small structures called papillae, of which there are different types, such as fungiform ones which can be found on the front of the tongue, foliate ones which on the sides, and circumvallate ones. A smaller number of taste buds are also present in the soft palate and pharynx. In fact, the taste receptor cells are never permanent: they undergo turnover every approximately 1–2 years, ensuring the gustatory system functions effectively throughout an individual's lifespan.

These taste buds receive innervation from branches of the facial nerve and the glossopharyngeal nerve. These nerves transmit gustatory information from the tongue to the brainstem, and subsequently to higher-order brain regions—most notably the gustatory cortex

There are five clear basic taste qualities: sweet, bitter, umami, salty, and sour. Each of these tastes is mediated by distinct receptor complexes—composed of specialized proteins—that are expressed in taste buds. For instance, sweet and umami tastes are usually mediated by G protein-coupled receptors, whereas salty and sour tastes are primarily mediated by ion channels. When these receptor cells are activated, they trigger the generation of electrical signals, which are transmitted via the gustatory nerves. Collectively, these signals form the neural basis of taste, which the brain then integrates with other sensory inputs—such as olfaction and food texture—to construct the perception of flavor[3]

2.2 Smell: Structure and Function of The Olfactory System

The olfactory system, which is responsible for our sense of smell, uses a network structure to detect, process, and transmit different odor signals to the brain. Unlike taste buds, the primary detectors of olfaction are olfactory receptor neurons (ORNs), which are located within a small region of the nasal cavity called the olfactory epithelium Each of the olfactory epithelium contains a large number of olfactory receptors and each of them has their unique type of olfactory receptor protein. Humans possess approximately 400 functional genes that encode these olfactory receptors, but each olfactory receptor protein is specific to a single type of odorant. This huge number of functional genes allows us to distinguish 1 trillion different odors that are greater than five basic tastes[4]
Inbred Strains</keyword><keyword>Sensory Receptor Cells/*physiology</keyword><keyword>Smell/*genetics</keyword></keywords><dates><year>1991</year><pub-dates><date>Apr 5</date></pub-dates></dates><isbn>0092-8674 (Print .

When we are smelling or chewing the food the odors travel backward to the nasal cavity (retronasal olfaction). These odorant molecules dissolve in nasal mucus and bind to their corresponding olfactory receptors on ORNs. The binding will create the signals which are transmitted to the olfactory bulb which is a structure of the base of the brain. [5]

The processed signals within the olfactory bulb are transmitted to two key brain regions. First is the piriform cortex (often referred to as the primary olfactory cortex) where identify the basic odors. Secondary, the limbic system which links odor to emotions and memories.

Notably, unlike the taste signal, olfactory signals bypass the brainstem and thalamus and directly reach the cerebral cortex and the limbic system, this is why individuals exhibit immediate emotional and mnemonic responses to odors (faster than responses to other sensory stimuli)

2.3 The Basic Different and the Interaction between Taste and Smell

Taste and smell, as these two core senses for flavor perception differ significantly in structure, neural pathways and functional "levels".

Taste relies on the onion-shaped taste buds with more than 100 receptor cells on the tongue papillae innervated

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by facial nerves and glossopharyngeal nerve[2] . It only encompasses five basic tastes: sweet, umami, bitter, sour, and salty. The G protein-coupled receptors for sweet and umami and the ion channels for salty and sour. These signals are transmitted through the brainstem and thalamus before reaching the cerebral cortex, and their primary function is to act as a "safety and nutrient checker" [2]

By contrast, olfaction depends on olfactory receptor neurons in the nasal olfactory epithelium. Humans possess approximately 400 genes that encode unique olfactory receptors. Enabling to detect over 1 trillion odors. Unlike taste signals, olfactory signals bypass the brainstem and thalamus and first connect to the olfactory bulb.. After that is the piriform cortex and limbic system which are for odor identification and limbic system. That is why humans react rapidly to unusual odors, such as that of spoiled milk[6]

The interaction between taste and smell is critical for flavor perception. Retronasal olfaction refers to the process by which odors released during food chewing rise back into the nasal cavity For instance, when people eat chocolate, the aroma of chocolate is transported upward while taste buds detect its sweet taste.[1] At this point, the sensory inputs from olfaction and taste combine. Centrally, the orbitofrontal cortex integrates those signals.[7]

fMRI studies by Small et al. (2004) showed that the combination of retronasal odors and taste activates the orbitofrontal cortex to a much greater extent than orthonasal olfaction alone The insular cortex also processes flavor's pleasantness, like people prefer ripe tomato rather than over rotten ones. These integrated taste and olfactory inputs form experiences and memories (e.g., "chocolate flavor") rather than being merely described as "sweet food"[8]

3. Integration of Taste and Smell in the Brain

3.1 Role of the Orbitofrontal Cortex

The orbitofrontal cortex (OFC) is a brain region that plays a key role in integrating signals and information from taste and olfaction to generate flavor perception, and it is often regarded as the brain's "flavor center" When we eat and smell food, the orbitofrontal cortex receives signals from the taste buds on the tongue and the olfactory receptors in the nose. Moreover, orbitofrontal cortex is also capable of receiving information about food temperature, texture and even the shape, all of which contribute to a comprehensive food experience.[9]

Neurons in the orbitofrontal cortex respond to both taste stimuli and retronasal odors – the odors that travel from the mouth to the nose during chewing, swallowing and smelling. This indicates that taste and olfaction converge and combine in this brain region to form flavor. Research has demonstrated that the orbitofrontal cortex is more active when people taste or smell food and feel pleasure, whereas after people are full it's activity decreases. This indicates that the OFC not only integrates sensory information but also encodes the pleasantness of food—a phenomenon referred to as sensory-specific satiety. [10, 11]

Furthermore, the orbitofrontal cortex is also influenced by memory, prior experience and expectations. For example, previous experience with how tastes combine with smells changes how our orbitofrontal cortex responds when individuals encounter similar flavor blends again. In [1]'s research people who were familiar with a taste - odor pairing showed stronger activity of orbitofrontal cortex when they taste totally the same flavor like vanilla and sweet than when tasting unfamiliar flavors. Memory also plays a role: if individuals remember a food as pleasant, they are more likely to expect it to taste good, and this expectation modifies how their brains process the food. Expectations people have can alter the flavor experience even before tasting. For instance, seeing and smelling something that they suggest it sweet can make the taste appear sweeter, due to the orbitofrontal cortex.

3.2 Mechanism of Retronasal Olfaction

Retronasal olfaction is the process by which individuals perceive food odors from within the mouth. When people chew or swallow the food, tiny odor molecules are released from the food matrix. These molecules travel upward from the throat to the nasal cavity; when they reach the olfactory epithelium, olfactory receptor cells detect them This pathway is known as orthonasal olfaction. [12]

A key point is that retronasal olfaction is typically weaker than orthonasal olfaction. This is because the odor molecules pass through the throat and nasal cavity before reaching the receptors, and a portion of these molecules are absorbed or dissolved by the mucus. Studies have shown that a reduction in the number of these odor molecules directly affects the intensity of retronasal olfaction. [13]

Retronasal olfaction is also vital for its interaction with taste. For instance, when we eat chocolate, the sweet taste is detected by the taste buds on the tongue while the smell of chocolate via retronasal olfaction. These two signals converge in the brain to form the complete chocolate flavor. If people lack the retronasal olfaction, food often seems to be less tasty and enjoyable.

Retronasal olfaction serves as the link between taste and olfaction, and it is a primary reason why flavor is not merely the taste perceived on the tongue.

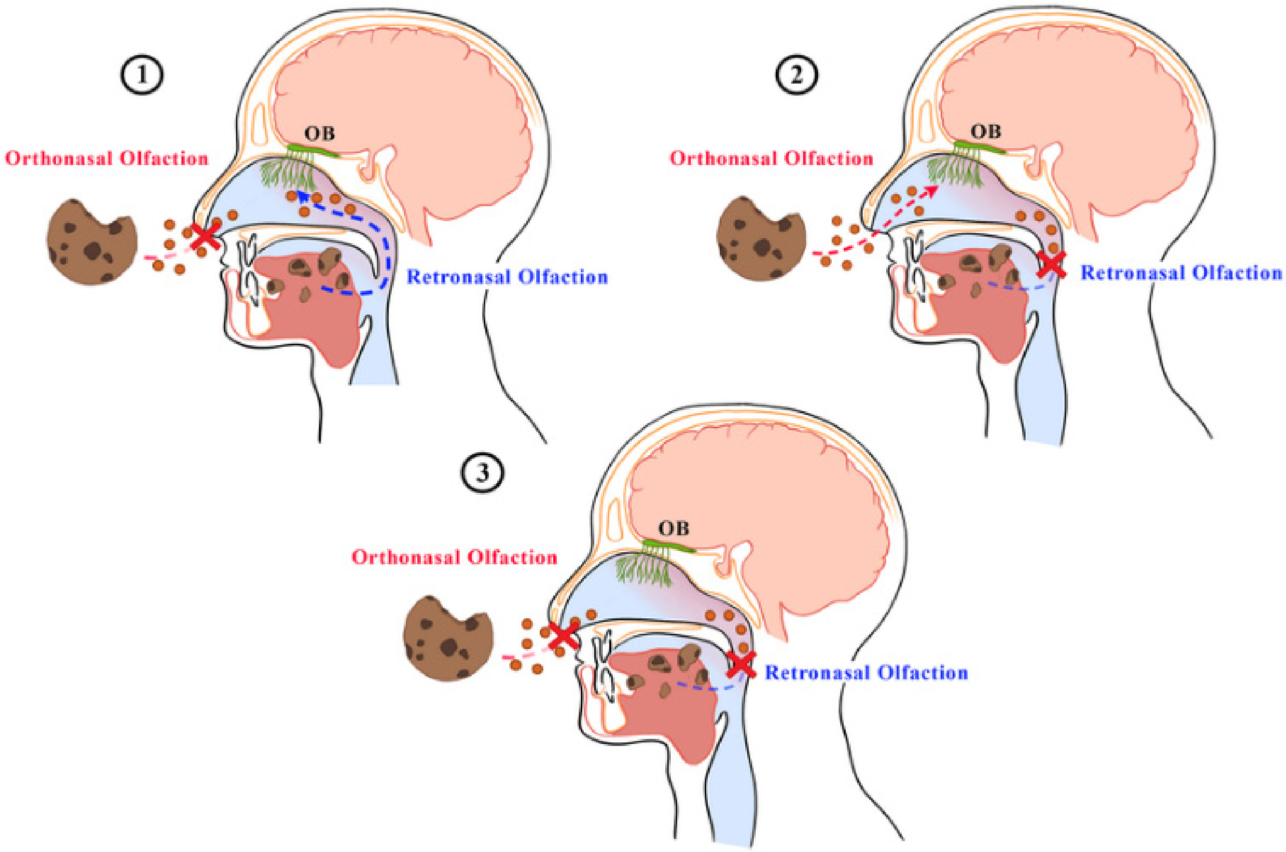

Figure 1. Newman, Lisa, et al. "Multisensory and Nutritional Innovations: A Narrative Review of Opportunities for Food Designers in Supporting Long SARS-CoV-2 Patients." Comprehensive Reviews in Food Science and Food Safety, vol. 22, no. 5, 2023, pp. 1-16. https://doi.org/10.1111/1541-4337.13000

4. Multi-sensory Influences on Flavor Perception

4.1 Cognitive and Emotional Modulation

Flavor perception is not only a sensory experience but also deeply modulated by cognitive and emotional factors. Research has demonstrated that our expectations, memories and emotional states can significantly alter how individuals experience taste and smell. For example, if an individual expects a food to taste sweet, the food will often be perceived as sweeter. This indicates that prior knowledge and expectations can directly modulate sensory processing. Similarly, emotion states such as happiness, stress or distress can also alter taste perception. Individuals experiencing stress may perceive food as less pleasant or detect a different taste, whereas positive moods can enhance the perceived pleasantness of food[14]

These effects are associated with specific brain regions, particularly the orbitofrontal cortex (OFC) mentioned earlier. The OFC not only integrates taste and olfaction signals but also processes information related to emotion and cognition. The amygdala, a brain area that is involved in emotional processing—works in conjunction with the OFC to integrate sensory with cognitive and emotional signals. This is the primary reason why some food looks appetizing or can help people recall a pleasant food memory can be perceived as tastier and more enjoyable. [15]

Memory is also crucial. If people have had an enjoyable memory when they ate some foods previously, they are likely to feel more pleasant when tasting these foods again. [15]

4.2 Cultural and Individual Differences

Taste and flavor vary among individuals for four main reasons, namely biology, culture, emotion and personal experience. Firstly, Genetics can significantly influence how strong that people sense the tastes. The sense of taste

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varies significantly across individuals and cultures, influenced by genetic factors and environmental factors. For genetic variations, such as those people with TAS2R38 gene, which affects their sensitivity to bitterness. Therefore those people fing some vegetables or medicines more bitter than others do. [16]. Secondly, regarding cultural and habitual factors, these factors play an important role and help shape individuals' preferences and their sensitivity to tastes. A study that compares Thai and Japanese taste preferences some evidence. For instance, Thai individuals show a stronger response to sweet, salty, sour, bitter and umami compared to Japanese individuals. Additionally, Thai participants have a stronger preference for spicy foods, a finding that underscores the influence of cultural and dietary habits.[17]

Moreover, emotions, mood, and stress can alter both taste and smell sensitivity levels. When people experience stress or anxiety, they tend to perceive that foods have less flavor or taste less appealing. This thing occurs because emotions can modulate the activity in the orbitofrontal cortex. When people feel pleasant or relaxed, this brain region enhances the sensitivity to smell and taste.[18]

In addition, personal experience and learning shape how individuals perceive flavor. People can "learn" to like or dislike certain tastes or smells depending on their past learning and experiences. For instance, if an individual becomes ill after eating a certain food, that individual may later perceive that this flavor is unpleasant even though the taste and smell remain unchanged. That is known as conditioned taste aversion (CTA). On the other hand, repeated exposure to unfamiliar foods can lead individuals to gradually develop a preference for them as the brain adapts to the new "flavor" [19, 20]

The taste and smell signals bind together in the brain to form "flavor". The orbitofrontal cortex combines the signals with people's emotions or experience or even memories - a process that explains why different people exhibit the different sensitivity to the same food.

5. Conclusion

In conclusion, flavor is not just what people taste, it is derived from the integration of smell and taste.

Taste relies on onion-shaped taste buds that can only detect five basic tastes and send signals to the brain through specific neural pathways. Smell relies on olfactory receptor neurons in the nasal cavity (with nearly 400 functional genes), there are over 1 trillion odors, and its signals reach the brain directly.

The key to flavor lies in their integration. When people chew or swallow food, odors travel to the nose via retronasal olfaction, and the orbitofrontal cortex then acts as a "flavor center," integrating taste, smell, and even a food's shape or texture. Research like Small et al. (2004) demonstrate that this brain region is more active when taste and retronasal smell work together.

Besides biology, cognition like expecting food to be, emotions like stress and happiness, memories like some food linked to memorable previous experiences, genes like some people being more sensitive to bitterness and culture for instance Thais prefer spicy food more than Japanese all influence how people perceive flavor.

To sum up, flavor is a multi-sensory process. Understanding how taste and smell integrate in the brain and how other factors affect the flavor can contribute to optimizing food products—benefiting individuals with taste/smell disorders and aiding in the development of better artificial flavors.

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