

Advances in Brain-Computer Interfaces for Taste Perception: Current Insights and Future Directions

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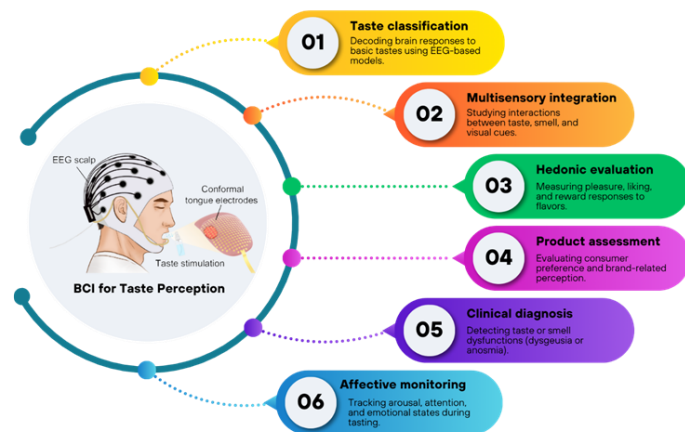
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ABSTRACT



Human taste perception is a complex multisensory process that integrates chemical, emotional, and cognitive responses within the brain. Traditional methods for evaluating taste rely on subjective reporting, which limits reproducibility and accuracy. Brain-Computer Interface (BCI) technology provides an objective solution by decoding neural activity associated with taste perception using non-invasive techniques such as EEG and fNIRS. The research contribution aims to deliver an extensive overview of the latest advancements in BCI-oriented taste research, emphasizing various applications, methodological frameworks, and potential future pathways that connect the domains of neuroscience and sensory technology. This review examines the use of EEG and fNIRS modalities for signal acquisition, preprocessing, feature extraction, and classification across 36 studies conducted between 2020 and 2025. These works employ both traditional algorithms and deep learning models, including SVM, CNNs, and Transformer-based frameworks, to decode neural signatures of basic tastes and multisensory interactions. Results show that BCIs have successfully identified distinct brain responses for sweet, sour, salty, bitter, and umami stimuli. They have also been applied in multisensory integration, hedonic evaluation, consumer behavior analysis, clinical diagnosis of taste disorders, and affective monitoring. However, challenges remain in signal noise, dataset standardization, and model interpretability. In conclusion, BCIs represent a promising and interdisciplinary approach for objectively studying and enhancing human taste perception through the integration of neuroscience, engineering, and artificial intelligence.

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1. INTRODUCTION

Taste perception is one of the most complex and least understood sensory modalities in humans, integrating chemical detection, multisensory processing, and emotional evaluation within the brain [1]. Traditional methods for studying taste perception, such as sensory questionnaires, hedonic scales, or behavioral tests, heavily rely on subjective reporting [2]. These approaches, while valuable, are limited by personal bias, linguistic variability, and contextual influence [3]. Consequently, there is still a significant gap in developing objective and reproducible tools that can quantify human taste experiences directly from neural activity [4]. Understanding how the brain encodes various gustatory stimuli encompassing the five basic tastes (sweetness, saltiness, sourness, bitterness, and umami perception) remains an open scientific and engineering challenge [5].

Recent advances in neuroscience and biomedical engineering have introduced Brain-Computer Interfaces (BCIs) as a promising solution to this problem. BCIs allow direct measurement and interpretation of brain activity through non-invasive techniques such as EEG and fNIRS [6]. These technologies can capture event-related potentials, spectral features, and hemodynamic responses associated with sensory experiences, offering a quantitative window into how the human brain perceives and evaluates taste [7]. In contrast to subjective assessment methods, BCI systems can objectively record neural correlates of taste perception, enabling researchers to decode flavor-specific brain signatures and emotional responses with increasing precision [8].

The state of the art in this field shows a growing interest in using BCIs for sensory and consumer research. Several studies have demonstrated that EEG signals can discriminate between basic flavors with classification accuracies exceeding 80% [9], and that fNIRS can detect cortical activations linked to pleasantness and taste intensity [10]. Machine learning and deep learning methods, including SVM, CNNs, and LSTM models, have been increasingly adopted to enhance the interpretability and performance of these neural decoding tasks [11]-[13]. Despite these advances, current research remains fragmented, most studies use small datasets, lack standardized protocols, and seldom integrate multimodal BCI approaches [14]. There is therefore a pressing need to consolidate existing findings and identify future directions that could strengthen methodological rigor and interdisciplinary application.

The novelty of this review lies in its comprehensive synthesis of recent developments in BCI applications specifically for human taste perception, an area that has received far less attention compared to vision, hearing, or motor control. Unlike previous works that only discuss BCIs in general sensory contexts [15], this paper focuses on the intersection of gustatory neuroscience, signal processing, and computational intelligence. It systematically examines how neural features related to taste are acquired, processed, and classified using advanced algorithms, and how these insights can be leveraged for engineering and industrial applications such as food design, sensory evaluation, and personalized nutrition.

The contribution of this research is threefold. First, it provides a structured overview of current BCI methodologies applied to taste perception, highlighting signal modalities, processing pipelines, and computational techniques. Second, it identifies major challenges (including data variability, interpretability, and scalability) that hinder real-world application. Third, it outlines future research opportunities by proposing a roadmap for integrating BCIs with multimodal sensors and artificial intelligence to create reliable, real-time, and ethically responsible systems for taste-driven sensory engineering. By consolidating these insights, this review aims to bridge the gap between neuroscience and engineering, advancing the objective understanding and technological exploration of how humans experience taste.

2. NEUROPHYSIOLOGICAL FOUNDATIONS OF TASTE PERCEPTION

Human taste perception begins at the peripheral sensory level within the taste buds of the tongue, where specialized gustatory receptor cells detect chemical compounds present in food and beverages [16]. As shown in Figure 1, these receptor cells send neural signals through three main cranial nerves. The facial nerve (cranial nerve VII) transmits sensory input originating from the front portion of the tongue [17]. The glossopharyngeal nerve (cranial nerve IX) is responsible for carrying taste sensations arising from the back section of the tongue [18]. Meanwhile, the vagus nerve (cranial nerve X) delivers sensory information derived from the regions of the pharynx and the epiglottis [19]. All these neural pathways converge in the solitary nucleus of the medulla oblongata, which acts as the first central relay for taste information [20]. From this point, gustatory signals travel through the pons and reach the thalamus, before projecting to higher brain centers such as the insular cortex and the orbitofrontal cortex (OFC) [21]. These cortical areas, often referred to as the gustatory cortex, are responsible for conscious taste recognition, discrimination, and hedonic evaluation [22].

At the cortical level, the five fundamental categories of taste perception (namely sweetness, saltiness, sourness, bitterness, and umami) are represented by complex but overlapping neural activation patterns [23]. Sweet and umami tend to activate anterior regions of the insular and frontal opercular areas, which are linked

with pleasant or rewarding sensations [24]. Bitter and sour flavors often engage posterior parts of the insular cortex that are associated with aversive or protective responses [25]. Salty taste produces intermediate activation because it plays both a sensory and homeostatic role [26]. This distributed neural representation supports the concept of population coding, in which networks of neurons work together to encode different dimensions of taste, including intensity, valence, and quality [27].

Findings from EEG and fNIRS studies have provided important insights into these gustatory processes. In EEG recordings, several event-related potential (ERP) components are observed during taste perception. The P200 component reflects early sensory detection [29]. The P300 component represents attention and stimulus evaluation [30]. The N400 component corresponds to cognitive and affective interpretation [31]. In the frequency domain, taste stimulation typically causes a reduction of alpha-band activity that indicates cortical activation, together with an increase in beta-band activity that reflects higher cognitive integration [32]. fNIRS studies complement these results by identifying hemodynamic changes in the insular and orbitofrontal regions during exposure to different taste qualities [33]. These findings form the physiological basis for non-invasive Brain-Computer Interface (BCI) applications that attempt to decode the brain's electrical and metabolic responses to taste [34].

Taste processing also involves emotional and motivational circuits that modulate the sensory experience [35]. The amygdala and orbitofrontal cortex are central to this integration process. They link gustatory inputs with affective states and reward valuation [36]. Dopaminergic signaling in these regions strengthens learning and memory related to taste experiences, helping to shape food preferences and behavioral responses [37]. For this reason, taste perception cannot be described as a purely sensory event. It represents a unified neural experience that merges cognition, emotion, and motivation into one dynamic system [38]. Understanding the entire neurophysiological pathway illustrated in Figure 1 is essential for the advancement of BCI-based studies in taste perception. By capturing ERP signatures and brain oscillations related to insular and orbitofrontal activation, BCIs can serve as objective tools for analyzing taste-specific neural responses [39]. This foundation supports future developments in sensory engineering, flavor design, and affective computing, where taste is evaluated not only through behavior but also through measurable brain activity [40].

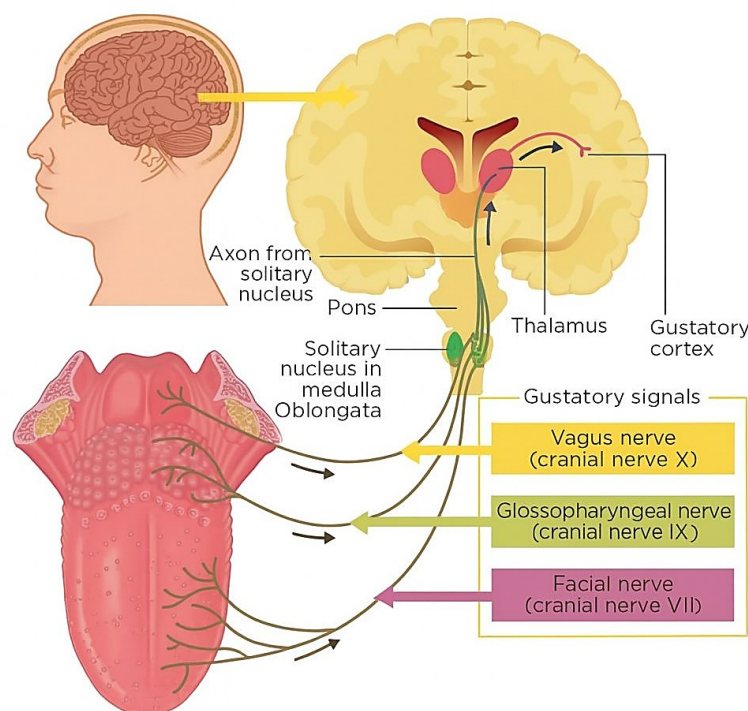


Figure 1. Overview of the gustatory neural circuits [28]

3. BCI APPROACHES FOR DECODING TASTE

The application of BCI technology in the study of taste perception has opened new possibilities for understanding how neural signals represent gustatory information. Among the available BCI modalities, non-invasive techniques such as EEG and fNIRS are the most widely adopted [41]. These methods are preferred

because they are safe, portable, and suitable for repeated testing in healthy participants. EEG provides high temporal resolution, which makes it ideal for capturing fast neural dynamics associated with taste discrimination [42]. In contrast, fNIRS offers better spatial resolution by measuring hemodynamic activity in cortical regions that process taste information, particularly in the insular and orbitofrontal cortices. The combination of these two modalities allows researchers to examine both electrical and metabolic responses, creating a more comprehensive picture of gustatory processing [43].

The general signal processing pipeline in taste-related BCIs is composed of four fundamental stages. The initial stage involves signal acquisition, which entails capturing brain responses while participants are presented with systematically controlled gustatory stimuli [44], including liquid samples that correspond to the five basic taste categories (sweetness, sourness, saltiness, bitterness, and umami). The second step is artifact removal, where non-neural signals caused by eye movement, facial muscles, or swallowing are filtered to improve data quality [45]. The third step is feature extraction, in which meaningful neural characteristics are identified from the recorded signals. These features may include time-domain components such as event-related potentials (P200, P300, and N400), or frequency-domain patterns like alpha and beta power changes [46]. The final step is classification, where machine learning or deep learning models are used to differentiate between various taste conditions or hedonic responses [47]. Classical algorithms such as SVM and Linear Discriminant Analysis remain widely used due to their simplicity and interpretability, while newer approaches like CNNs and LSTM networks offer improved accuracy by capturing spatial and temporal dependencies within the data [48]-[50].

Research on brain-computer interfaces for taste perception has expanded considerably in recent years, beginning with early EEG investigations that explored neural correlates of sweetness and beverage evaluation. Mouillot *et al.* [51] reported that natural sucrose produced stronger and faster gustatory-evoked potentials compared to synthetic sweetening agents like aspartame and stevia. In the same year, Chen *et al.* [52] integrated virtual-reality contexts into EEG experiments and found that visual-taste congruency enhanced the perceived sweetness of beverages although it did not necessarily increase product liking. Alvino *et al.* [53] extended EEG analysis to the evaluation of red wine, revealing beta-band oscillations associated with sensory and reward processing during wine appraisal. These foundational studies demonstrated that EEG could detect subtle variations in hedonic and cognitive responses to different taste conditions.

Subsequent research diversified the stimuli and analytical frameworks. HajiHosseini *et al.* [54] used sixty-four-channel EEG to examine foods differing in health value and taste and observed that alpha-band activity encoded value integration whereas theta-band activity reflected self-regulation during decision making. Huang *et al.* [55] employed intracranial stereotactic EEG in epilepsy patients and discovered that the posterior insula encoded anticipation of food whereas the anterior insula and frontal operculum responded selectively to palatable cues. In a related study, Sinding *et al.* [56] observed that introducing a beef scent intensified participants' perception of the soup's saltiness, and influenced late ERP components such as P3, confirming the role of olfactory-gustatory interaction. Franco *et al.* [57] combined EEG and blood-volume pulse measurements to study group identity and branding effects on taste judgments. Their findings showed that social labeling influenced purchase intention more strongly than physiological taste response, emphasizing contextual modulation in taste perception.

During 2022, researchers further explored multimodal and computational aspects of BCI. Hong *et al.* [58] demonstrated that inhalation of *Agastache rugosa* essential oil increased alertness and freshness through broad-band EEG activation, while Atzingen *et al.* [59] used a CNN with two-channel EEG to distinguish caloric from non-caloric sweeteners, achieving high classification accuracy despite minimal electrode input. Wu *et al.* [60] analyzed umami-related EEG patterns and found low-frequency delta and theta activity with right-hemisphere dominance, suggesting lateralized processing of monosodium glutamate. Arroyo *et al.* [61] used statistical features from dry-electrode EEG to discriminate between sweet and non-sweet stimuli across odor, taste, and flavor conditions, revealing parietal and temporal involvement. Çelik *et al.* [62] applied olfactory event-related potentials in a clinical population and showed that OERP analysis could identify anosmia and malingering, demonstrating potential diagnostic value. Collectively, these 2022 studies highlighted the adaptability of EEG and hybrid systems for both research and applied contexts.

The following year, methodological diversity continued to expand. Stuldreher *et al.* [63] reported that food neophobia heightened attentional ERP responses and reduced consumption volume when participants viewed unfamiliar foods. Hosang *et al.* [64] examined carbohydrate mouth rinsing and observed modulation of visuospatial attention through N1pc and N2pc components without behavioral change. Naser *et al.* [65] introduced a reduced-channel EEG approach using Hilbert Transform and Wavelet Packet Decomposition, which improved accuracy and efficiency. Jing *et al.* [66] investigated cross-modal effects of music on taste evaluation and found that classical music enhanced preference for sweet food while rock music increased

cognitive control over salty food consumption. Ullah *et al.* [67] validated surface electromyography as a potential proxy for taste perception by successfully recognizing six electronic taste states that mirrored real taste experiences. Mastinu *et al.* [68] performed large-scale time–frequency EEG on dysgeusia patients and demonstrated that gustatory event-related potentials provided higher diagnostic sensitivity than traditional assessments. These developments marked a turning point where BCI research began to include clinical diagnostics and emotional modulation alongside sensory decoding.

From 2025 onward, the field saw a sharp increase in algorithmic innovation and dataset complexity. Xia *et al.* [69] developed a CNN-based channel-spatial attention model that improved recognition of four basic tastes while maintaining high accuracy. Li *et al.* [70] linked EEG band activity to food palatability, showing that more appetizing dishes elevated arousal and motivation levels. Stickel *et al.* [71] used frontal alpha asymmetry to show that explicit liking aligned with implicit neural responses only for taste-labeled drinks, indicating subconscious bias. Another work by Xia *et al.* [72] employed a Local-Global Fusion Transformer to quantify odor-enhanced sweetness, identifying frontal and parietal activation patterns. Albayrak *et al.* [73] combined EEG and EMG signals to test the effects of vagus nerve stimulation and found no direct EEG change but an increased eye-blink rate associated with reward anticipation. Zhao *et al.* [74] examined nine citrus essential oils and revealed that concentrated samples evoked stronger brain activity yet lower subjective acceptability, reflecting the neural basis of flavor intensity.

Further refinement in 2025 involved controlled stimulus delivery and multimodal measurement. Liu *et al.* [75] designed an automated taste-delivery system that improved timing precision and decoding accuracy for salty taste EEG. Stickel *et al.* [76] combined EEG and eye-tracking data to evaluate labeled yogurts and reported that “health” labels reduced perceived tastiness and liking. Wang *et al.* [77] demonstrated that EEG signals could differentiate sweetener types and concentrations even under equal sweetness conditions, indicating fine neural discrimination. De *et al.* [78] introduced TasteNet, an entropy-based deep network capable of classifying six basic tastes with higher accuracy than prior models. Wang *et al.* [79] used EEG microstate analysis to track brain dynamics during exposure to alcoholic beverages of varying alcohol content and found that higher concentrations shifted attentional and evaluative states. Another study by Wang *et al.* [80] combined EEG source localization and connectivity mapping to show that volatile compounds enhanced salty taste perception through olfactory-gustatory integration.

Additional contributions in 2025 explored relaxation, molecular modeling, and affective responses. Park *et al.* [81] applied s-LORETA analysis to EEG data collected during consumption of rice-bran cookies and found that these products promoted relaxation and reduced stress. Yang *et al.* [82] used graph convolutional networks to design safer dairy flavor substitutes and demonstrated cortical activation patterns comparable to standard diacetyl. Pereira *et al.* [83] confirmed that sweet and umami tastes elicited distinct neural and emotional patterns measurable through EEG and self-assessment manikins. Chen *et al.* [84] analyzed Baijiu beverages of varying mouthfeel and observed that intensity levels influenced comfort-related neural activity. Fu *et al.* [85] combined EEG with facial-expression tracking to show that sweet and salty food pairings improved liking and could be predicted by multimodal features. The latest development by Wang *et al.* [86] introduced TEDNet, a transformer-based local–global attention model that achieved state-of-the-art accuracy in decoding the four basic tastes from EEG signals.

Table 1. Summary of recent studies on BCI applications in human taste perception

Author(s)	Year	BCI Modality	Stimuli / Taste Type	Dataset / Participants	Feature Extraction / Analysis	Main Findings
Mouillot <i>et al.</i> [51]	2020	EEG (9 electrodes)	Sweet taste using sucrose, aspartame, and stevia	20 healthy adults aged 19–27	Latency and amplitude of GEP peaks	Natural sugar induced stronger and faster activation than artificial sweeteners
Chen <i>et al.</i> [52]	2020	EEG (9 channels, VR)	Sweet beverage in sweet, bitter, and neutral VR scenes	41 adults aged 27 ± 2	Alpha-band frontal asymmetry and self-report ratings	Visual–taste congruency enhanced sweetness perception without increasing liking
Alvino <i>et al.</i> [53]	2020	EEG (32 electrodes)	Red wines differing in price and origin	26 adults aged 18–40	FFT and beta-band power with ANOVA	Beta oscillations linked to reward and sensory processing during wine evaluation
HajiHosseini <i>et al.</i> [54]	2021	EEG (64 channels)	Food items varying in taste and health	50 adults aged 17–31	ERP and time–frequency analysis of alpha and theta	Alpha encoded value integration while theta reflected self-regulation
Huang <i>et al.</i> [55]	2021	Intracranial SEEG	Palatable and neutral liquids	11 epilepsy patients	Broadband (70–170 Hz) time–frequency analysis	Posterior insula encoded food anticipation and anterior

Author(s)	Year	BCI Modality	Stimuli / Taste Type	Dataset / Participants	Feature Extraction / Analysis	Main Findings
						insula responded to palatable cues
Sinding <i>et al.</i> [56]	2021	EEG (5 electrodes)	Salty soup with or without beef aroma	13 adults aged 18–30	ERP (P1, P3) latency and amplitude	Odor enhanced perceived saltiness and affected late cognitive flavor processing
Franco <i>et al.</i> [57]	2021	EEG and BVP	Watermelon drink with sponsor labels	90 football fans	Alpha power and HRV analysis	Group identity influenced buying intention more than taste
Hong <i>et al.</i> [58]	2022	EEG (29 electrodes)	Agastache rugosa essential oil	38 adults (19 male, 19 female)	Power spectral analysis across theta–gamma bands	Essential oil increased alertness and freshness while reducing drowsiness
Atzingen <i>et al.</i> [59]	2022	EEG (2 electrodes)	Passion fruit juice with various sweeteners	11 adults aged 19–55	Filtered EEG (8–40 Hz) for CNN input	CNN differentiated caloric vs. non-caloric sweeteners with high accuracy
Wu <i>et al.</i> [60]	2022	EEG (8 electrode pairs)	Umami taste (MSG at 3 concentrations)	10 adults aged 24 ± 1	Power spectral density (1–100 Hz)	Umami evoked low-frequency δ and θ activity with right-side dominance
Arroyo <i>et al.</i> [61]	2022	EEG (64 dry electrodes)	Sweet odor, sweet taste, non-sweet flavor	18 adults aged 24–35	Time-domain statistical descriptors	EEG distinguished sweet vs. non-sweet across modalities with parietal involvement
Çelik <i>et al.</i> [62]	2022	EEG (OERP)	Odor stimuli (n-amyl acetate)	98 post-trauma patients	ERP waveform (Fz–Cz–Pz)	OERP helped detect anosmia and malingering in forensic assessment
Stuldreher <i>et al.</i> [63]	2023	EEG (32 electrodes)	Familiar and unfamiliar food images	43 adults aged 19–64	ERP (LPP) and inter-subject correlation	Food neophobia increased attention and reduced sip size for unfamiliar foods
Hosang <i>et al.</i> [64]	2023	EEG (60 electrodes)	Carbohydrate and non-nutritive mouth rinse	53 adults aged 26 ± 4	ERP (N1pc, N2pc) amplitude	Carbohydrate rinse modulated visuospatial attention without behavioral change
Naser <i>et al.</i> [65]	2024	EEG (17–256 channels)	Taste and odor stimuli	10 for taste, 5 for odor, 29 for motor imagery	Hilbert Transform and Wavelet Packet	RSCS improved accuracy with fewer EEG channels
Jing <i>et al.</i> [66]	2024	EEG (64 channels)	Sweet and salty foods under music styles	24 college students	ERP (P2, N2, N3, LPC)	Classical music enhanced sweet preference while rock increased control for salty food
Ullah <i>et al.</i> [67]	2024	Surface EMG	Electronic taste stimuli	17 adults (8 used for data)	Time and frequency features	sEMG recognized six electronic taste states correlating with real tastes
Mastinu <i>et al.</i> [68]	2024	EEG (128 electrodes)	Salty taste (NaCl concentrations)	103 participants (44 dysgeusia, 59 controls)	Time–frequency and canonical averaging	Time–frequency analysis improved dysgeusia diagnosis
Xia <i>et al.</i> [69]	2025	EEG (21 channels)	Sour, Sweet, Bitter, Salty	20 participants, 1600 samples	CNN-CSA with Grad-CAM	CAM-Attention improved recognition efficiency with high accuracy
Li <i>et al.</i> [70]	2025	EEG	Fried rice with varied palatability	46 students aged 19–28	Band analysis of theta–gamma	Delicious food increased arousal and motivation
Stickel <i>et al.</i> [71]	2025	EEG (frontal alpha asymmetry)	Protein chocolate milk with labels	118 adults aged 18–50	PSD of alpha band	Taste label increased liking compared to health label
Xia <i>et al.</i> [72]	2025	EEG	Sucrose mixed with odor compound	16 adults aged 20–30	Local–Global Fusion Transformer	Odor enhanced sweetness with frontal and parietal activation
Albayrak <i>et al.</i> [73]	2025	EEG and EMG	Chocolate milk	15 healthy adults	ICA and artifact removal	tVNS did not alter EEG but sipping increased eye-blink rate linked to reward
Zhao <i>et al.</i> [74]	2025	EEG	Nine citrus essential oils	20 healthy adults	PSD and frequency analysis	Concentrated oils evoked stronger brain responses and lower acceptability

Author(s)	Year	BCI Modality	Stimuli / Taste Type	Dataset / Participants	Feature Extraction / Analysis	Main Findings
Liu <i>et al.</i> [75]	2025	EEG	NaCl solutions (150 and 200 mmol/L)	20 adults aged 24 ± 1	DWT, GFP, PCA	Automated taste delivery improved precision of EEG decoding
Stickel <i>et al.</i> [76]	2025	EEG and Eye Tracking	Dairy and plant yogurts	154 participants aged 19–65	PSD of alpha band and gaze metrics	Health labels reduced tastiness and liking
Wang <i>et al.</i> [77]	2025	EEG	Sucrose and iso-sweet sweeteners	28 adults aged 18–30	PSD and AUC of bands	Brain differentiated sweetener type and concentration
De <i>et al.</i> [78]	2025	EEG (19 electrodes)	Sweet, Sour, Salty, Bitter, Umami, Neutral	51 adults aged 19–35	CEEMDAN and entropy features	TasteNet classified six basic tastes with superior performance
Wang <i>et al.</i> [79]	2025	EEG (64 channels)	Alcoholic stimuli (various ABV)	20 adults	EEG microstate analysis	Alcohol concentration modulated sensory focus and re-evaluation
Wang <i>et al.</i> [80]	2025	EEG (64 channels)	Salty taste enhanced by volatiles	20 adults aged 19–26	Time–frequency, source localization	Volatiles strengthened olfactory–gustatory integration
Park <i>et al.</i> [81]	2025	EEG (21 channels, s-LORETA)	Rice bran cookies with sugar substitutes	6 adults	Band analysis and source mapping	Cookies promoted relaxation and reduced stress
Yang <i>et al.</i> [82]	2025	EEG (CSD and GCN)	Dairy flavor and diacetyl substitute	177 evaluators	GCN molecular embedding and GA inverse design	Safe dairy flavor substitute matched cortical activation of original DA
Pereira <i>et al.</i> [83]	2025	EEG (32 channels)	Five basic tastes	28 adults aged 18–25	PSD analysis of δ–γ bands	Sweet and umami produced distinct neural and emotional patterns
Chen <i>et al.</i> [84]	2025	EEG (64 channels)	Baijiu with varied mouthfeel	10 adults	PSD and time–frequency	Mouthfeel intensity affected neural comfort and perception
Fu <i>et al.</i> [85]	2025	EEG and facial tracking	Baijiu flavors and food pairing	53 total participants	EEG rhythm and FaceReader metrics	Sweet and salty pairings improved liking and predicted preference
Wang <i>et al.</i> [86]	2025	EEG (21 electrodes)	Sweet, Sour, Salty, Bitter	30 adults, 2400 samples	TEDNet with Local–Global Attention	Model achieved state-of-the-art decoding accuracy

4. BRAIN-COMPUTER INTERFACE APPLICATIONS IN TASTE PERCEPTION

Recent developments in BCI research have demonstrated that decoding neural signals can provide valuable insights into how the human brain perceives and evaluates taste. Across multiple studies, EEG-based BCIs have been applied to classify different taste modalities, integrate sensory cues, measure hedonic experiences, evaluate consumer products, support clinical diagnosis, and monitor affective states. These diverse applications highlight the growing potential of BCI technology to serve as both a research and engineering tool in sensory neuroscience and food science can be seen in Figure 2.

Taste classification represents the most direct and widely explored application of BCIs in gustatory research. Several studies have successfully decoded neural signatures corresponding to the five basic tastes (sweet, sour, salty, bitter, and umami) using EEG and advanced learning algorithms. Early work by Mouillot *et al.* [51] and Wu *et al.* [60] identified distinct temporal and frequency-domain EEG patterns for sweet and umami stimuli, confirming the feasibility of objective taste discrimination. Later, De *et al.* [78] introduced TasteNet, which used entropy-based features to classify six basic tastes with high precision, while Xia *et al.* [69] and Wang *et al.* [86] demonstrated that deep models such as CNNs and Transformer-based networks could achieve state-of-the-art decoding accuracy. These findings indicate that EEG-based BCIs can reliably recognize taste-related brain activity, providing the foundation for automated flavor recognition systems.

Multisensory integration has also become a central theme in BCI-based taste studies. The perception of flavor arises not only from gustatory inputs but also from the interaction of taste, smell, and vision. Studies by Sinding *et al.* [56] and Wang *et al.* [80] revealed that the addition of aroma compounds or volatile cues enhanced taste perception by engaging both gustatory and olfactory cortical regions. Chen *et al.* [52] confirmed that visual context presented through virtual reality could modify the perceived sweetness of beverages, illustrating how cross-modal congruency shapes neural taste processing. Arroyo *et al.* [61] further

demonstrated that EEG patterns could differentiate between sweet and non-sweet stimuli across taste and odor modalities, highlighting the brain's ability to integrate sensory information dynamically.

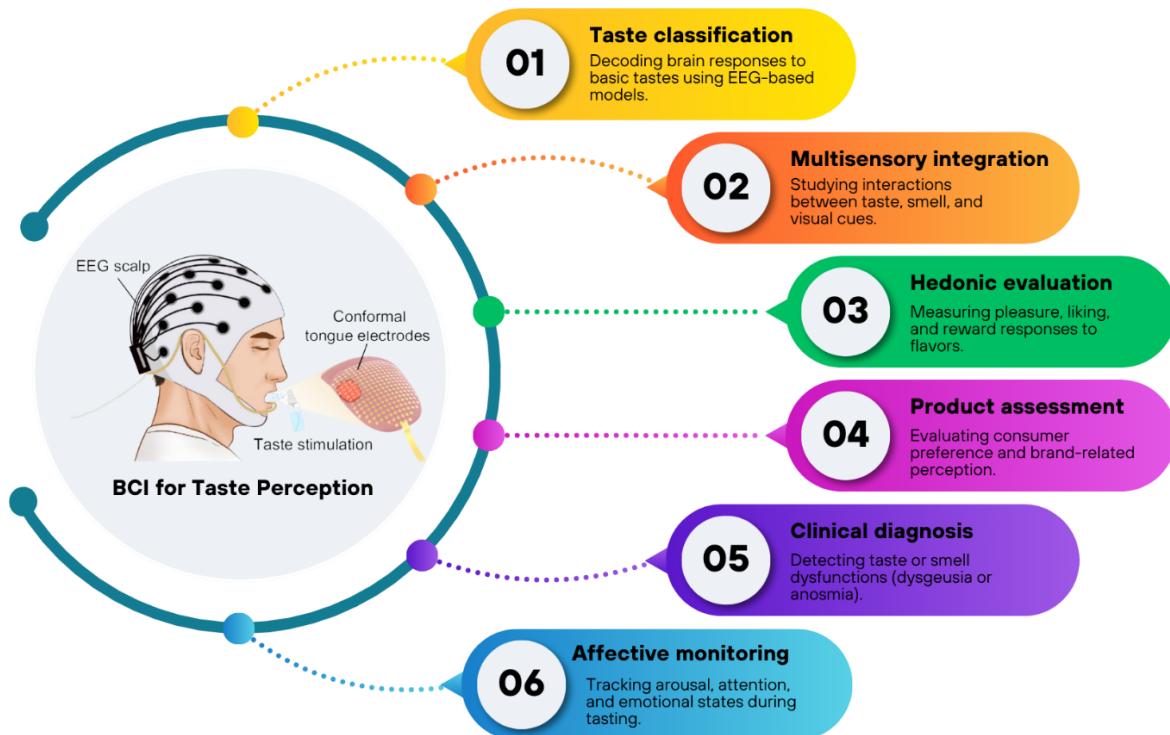


Figure 2. BCI applications in Taste Perception

In terms of hedonic evaluation, BCIs have proven effective for measuring subjective pleasure and reward responses linked to flavor consumption. Alvino *et al.* [53] and HajiHosseini *et al.* [54] showed that beta- and theta-band oscillations corresponded to reward processing and self-regulation during food evaluation tasks. Li *et al.* [70] and Pereira *et al.* [83] observed that more palatable or umami-rich foods produced stronger emotional engagement and cortical activation associated with liking and motivation. Zhao *et al.* [74] added that intense citrus aromas evoked powerful neural responses correlated with lower subjective acceptability, reflecting the brain's nuanced encoding of sensory pleasure and discomfort. These results underline the potential of EEG to objectively assess hedonic experience and preference formation.

BCI technology has also been utilized for product assessment, offering valuable tools for neuromarketing and sensory product design. Franco *et al.* [57] demonstrated that group identity and product labeling could modulate consumer purchase intention more than the taste itself, as reflected in EEG and physiological measures. Stickel *et al.* [71],[76] explored the influence of “health” versus “taste” labels and found that implicit neural responses, captured through frontal alpha asymmetry, often diverged from explicit self-reports of liking. Fu *et al.* [85] combined EEG with facial expression analysis and found that sweet and salty food pairings increased positive emotional responses and accurately predicted consumer preference. Together, these studies show that BCIs can reveal subconscious evaluations that traditional questionnaires may overlook, enabling data-driven approaches to product testing.

In clinical and diagnostic contexts, BCIs have shown promise in detecting gustatory and olfactory dysfunctions. Çelik *et al.* [62] used olfactory event-related potentials to identify anosmia and malingering among patients with post-traumatic smell loss, providing an objective electrophysiological tool for forensic evaluation. Mastinu *et al.* [68] applied EEG-based time–frequency analysis to patients with dysgeusia and found altered gustatory activity compared with healthy controls, which improved diagnostic sensitivity beyond standard gustatory event-related potentials. These findings suggest that BCIs can complement medical diagnostics by quantifying neural responses in patients with sensory impairments.

Finally, affective and cognitive state monitoring represents another emerging application of BCI in taste research. EEG markers of arousal, attention, and relaxation have been successfully measured during food consumption. Hong *et al.* [58] reported that exposure to aromatic essential oils increased alertness and reduced

drowsiness, while Park *et al.* [81] showed that rice-bran cookies induced relaxation and lowered stress-related brain activity. Hosang *et al.* [64] found that carbohydrate mouth rinsing influenced visuospatial attention networks without altering behavior, and Wang *et al.* [79] demonstrated that varying alcohol concentrations modulated attentional and evaluative brain states. Such findings highlight the value of BCIs for tracking real-time emotional and attentional changes, paving the way for adaptive sensory environments and personalized food experiences.

5. CHALLENGES AND EMERGING DIRECTIONS

Despite significant progress in applying brain-computer interfaces (BCIs) to the study of taste perception, several technical and methodological challenges remain unresolved. Most existing studies still rely on relatively small and homogeneous participant groups, often fewer than thirty individuals, which limits the statistical generalizability of their findings. Differences in electrode placement, recording duration, and taste delivery methods across studies introduce additional variability that complicates cross-study comparisons. Environmental control also plays a critical role, as taste responses can be influenced by external cues such as room odor, visual context, and even participant hunger state. These inconsistencies highlight the urgent need for standardized experimental protocols, shared datasets, and unified benchmarks to ensure reproducibility and comparability across laboratories.

Signal quality and interpretability present another key limitation. EEG and fNIRS signals used in taste-related BCIs are prone to low signal-to-noise ratios caused by motion artifacts, swallowing, and facial muscle activity during tasting. Although preprocessing techniques such as independent component analysis and adaptive filtering have improved data clarity, they cannot fully eliminate non-neural contamination. Moreover, the transient and overlapping nature of gustatory-evoked potentials makes it difficult to isolate specific neural components associated with individual taste qualities. The majority of studies, including those by Mouillot *et al.* [51] and Wu *et al.* [60], focused on single or binary taste classifications, whereas more complex and mixed flavor experiences remain largely unexplored. Future BCIs should therefore incorporate more robust artifact rejection algorithms and multimodal acquisition systems that can synchronize EEG, fNIRS, EMG, and behavioral measures for higher fidelity in taste decoding.

Another major challenge concerns data scarcity and model generalization. Although deep learning models such as CNN, Transformer, and entropy-based networks have achieved impressive accuracy in single-study settings [69],[78],[86], their generalizability across individuals and experimental setups remains limited. Many datasets are proprietary or collected under highly specific conditions, preventing meaningful cross-validation and meta-analysis. Building large, open-access, and well-annotated databases of taste-related EEG and fNIRS recordings is therefore an essential step toward developing transferable and explainable models. Transfer learning and domain adaptation techniques may help overcome subject variability, allowing BCIs to function reliably across different user populations.

Beyond technical barriers, future research must also address the interpretability and ethical implications of taste decoding. Current deep neural models, while accurate, often behave as black boxes, providing little insight into the underlying neurophysiological mechanisms. Approaches using explainable artificial intelligence such as Grad-CAM and SHAP could visualize the cortical regions and frequency bands that drive classification decisions, enabling a deeper comprehension of the neural processes through which the brain represents and interprets gustatory perception. At the same time, the collection and analysis of neural data raise critical ethical concerns related to data privacy, participant consent, and the risk of information misuse. Taste preferences are closely tied to individual identity, emotion, and cultural background, and therefore require careful data governance and transparent use policies in both research and industry applications.

Several emerging directions are already shaping the next generation of BCI-based sensory systems. The integration of multimodal technologies, including EEG–fNIRS hybrids, electromyography, and eye-tracking, offers the potential to capture richer representations of taste-related brain activity. Studies such as Atzingen *et al.* [59] and Fu *et al.* [85] demonstrated that combining neural and peripheral physiological signals enhances model performance and emotional interpretation. Advances in portable and wireless EEG devices will further support real-world experiments beyond laboratory environments, enabling mobile monitoring of flavor perception in natural eating contexts. Additionally, immersive media technologies encompassing VR and AR, previously explored by Chen *et al.* [52], can be merged with BCI systems to simulate and manipulate multisensory dining experiences, contributing to both research and interactive food design.

Looking forward, the convergence of neuroscience, machine learning, and sensory engineering is expected to transform BCIs from experimental tools into practical systems for health and industry. Clinical applications such as the detection of dysgeusia and anosmia [62],[68] may evolve into real-time diagnostic platforms capable of monitoring taste recovery in neurological patients. In parallel, affective BCIs could guide

the development of personalized nutrition and adaptive flavor modulation that responds to users' emotional and physiological states. The field is thus moving toward a future where taste is no longer evaluated solely through subjective experience but decoded objectively through brain signals, paving the way for a new generation of intelligent, human-centered sensory technologies.

6. CONCLUSIONS

Research on brain-computer interfaces for taste perception has evolved rapidly, transforming the study of gustatory processing from subjective observation to objective neural decoding. EEG and fNIRS technologies have proven effective in capturing brain responses to basic tastes, emotional valence, and cognitive evaluation, enabling quantifiable insights into how the brain encodes flavor experiences. Advances in signal processing and machine learning have made it possible to classify multiple taste modalities with increasing precision, marking a shift from exploratory neuroscience toward applied neuroengineering. Beyond taste classification, BCIs have provided new perspectives on multisensory integration, emotional processing, and consumer perception. Findings show that taste perception is influenced by visual and olfactory cues, as well as by cognitive and affective contexts such as reward, motivation, and product labeling. These insights have positioned BCIs as valuable tools for sensory analysis, neuromarketing, and affective computing, while also demonstrating potential in clinical applications for diagnosing taste and smell disorders.

Despite this progress, several challenges remain. Many studies are limited by small datasets, non-standardized experimental designs, and variability in signal quality caused by motion artifacts or individual differences. Deep learning architectures deliver high precision but often lack clarity in their decision-making, emphasizing the need for more transparent and interpretable methods. Future research should focus on building open-access databases, refining multimodal acquisition systems, and developing portable BCIs for real-world sensory environments. In summary, BCIs offer a promising and interdisciplinary framework for decoding human taste perception. By merging neuroscience, engineering, and artificial intelligence, they pave the way for objective and personalized evaluation of flavor experiences. Continued innovation in this field will enable the creation of neuroadaptive sensory systems capable of understanding and enhancing the complex relationship between the human brain and the sense of taste.

DECLARATION

Author Contribution

All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

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Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

- [1] B. Chen, X. Lin, Z. Liang, X. Chang, Z. Wang, M. Huang, and X.-A. Zeng, "Advances in food flavor analysis and sensory evaluation techniques and applications: Traditional vs emerging," *Food Chemistry*, vol. 494, p. 146235, 2025, <https://doi.org/10.1016/j.foodchem.2025.146235>.
- [2] J. Wang *et al.*, "From Traditional to Intelligent, A Review of Application and Progress of Sensory Analysis in Alcoholic Beverage Industry," *Food Chemistry X*, vol. 23, pp. 101542–101542, 2024, <https://doi.org/10.1016/j.fochx.2024.101542>.
- [3] Y. Shu, H. Gao, Y. Wang, and Y. Wei, "Food Emotional Perception and Eating Willingness Under Different Lighting Colors: A Preliminary Study Based on Consumer Facial Expression Analysis," *Foods*, vol. 14, no. 19, p. 3440, 2025, <https://doi.org/10.3390/foods14193440>.
- [4] G. Wang, X. Wang, H. Cheng, H. Li, Z. Qin, F. Zheng, X. Ye, and B. Sun, "Application of electroencephalogram (EEG) in the study of the influence of different contents of alcohol and Baijiu on brain perception," *Food Chemistry*, vol. 462, pp. 140969–140969, 2024, <https://doi.org/10.1016/j.foodchem.2024.140969>.
- [5] L. Pallante *et al.*, "On the human taste perception: Molecular-level understanding empowered by computational methods," *Trends in Food Science & Technology*, vol. 116, pp. 445–459, 2021, <https://doi.org/10.1016/j.tifs.2021.07.013>.

- [6] J. Peksa and D. Mamchur, "State-of-the-Art on Brain-Computer Interface Technology," *Sensors*, vol. 23, no. 13, p. 6001, 2023, <https://doi.org/10.3390/s23136001>.
- [7] S. G. H. Meyerding, X. He, and A. Bauer, "Neuronal correlates of basic taste perception and hedonic evaluation using functional Near-Infrared Spectroscopy (fNIRS)," *Applied Food Research*, vol. 4, no. 2, p. 100477, 2024, <https://doi.org/10.1016/j.afres.2024.100477>.
- [8] A. Byrne, E. Bonfiglio, C. Rigby, and N. Edelstyn, "A systematic review of the prediction of consumer preference using EEG measures and machine-learning in neuromarketing research," *Brain Informatics*, vol. 9, no. 1, 2022, <https://doi.org/10.1186/s40708-022-00175-3>.
- [9] X. Xia, Y. Yang, Y. Shi, W. Zheng, and H. Men, "Decoding human taste perception by reconstructing and mining temporal-spatial features of taste-related EEGs," *Applied Intelligence*, vol. 54, no. 5, pp. 3902–3917, 2024, <https://doi.org/10.1007/s10489-024-05374-5>.
- [10] J. Mai, S. Li, Z. Wei, and Y. Sun, "Implicit Measurement of Sweetness Intensity and Affective Value Based on fNIRS," *Chemosensors*, vol. 13, no. 2, pp. 36–36, 2025, <https://doi.org/10.3390/chemosensors13020036>.
- [11] H. Ahuja, S. Badhwar, H. Edgell, M. Litoiu, and L. E. Sergio, "Machine learning algorithms for detection of visuomotor neural control differences in individuals with PASC and ME," *Frontiers in Human Neuroscience*, vol. 18, 2024, <https://doi.org/10.3389/fnhum.2024.1359162>.
- [12] Y. Gao, N. Lewis, V. D. Calhoun, and R. L. Miller, "Interpretable LSTM model reveals transiently-realized patterns of dynamic brain connectivity that predict patient deterioration or recovery from very mild cognitive impairment," vol. 161, pp. 107005–107005, 2023, <https://doi.org/10.1016/j.compbimed.2023.107005>.
- [13] A. D. Wibawa, N. Fatih, Y. Pamungkas, M. Pratiwi, P. A. Ramadhani and Suwadi, "Time and Frequency Domain Feature Selection Using Mutual Information for EEG-based Emotion Recognition," *2022 9th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, pp. 19-24, 2022, <https://doi.org/10.23919/EECSI56542.2022.9946522>.
- [14] H. Zhang, L. Jiao, S. Yang, H. Li, X. Jiang, J. Feng, S. Zou, Q. Xu, J. Gu, X. Wang, and B. Wei, "Brain-computer interfaces: The innovative key to unlocking neurological conditions," *International Journal of Surgery*, vol. 110, no. 9, 2024, <https://doi.org/10.1097/js9.0000000000002022>.
- [15] X.-Y. Liu *et al.*, "Recent applications of EEG-based brain-computer-interface in the medical field," *Military Medical Research*, vol. 12, no. 1, 2025, <https://doi.org/10.1186/s40779-025-00598-z>.
- [16] C. Spence, "The tongue map and the spatial modulation of taste perception," *Current Research in Food Science*, vol. 5, pp. 598–610, 2022, <https://doi.org/10.1016/j.crfs.2022.02.004>.
- [17] M. L.-Jiménez *et al.*, "On the Cranial Nerves," *NeuroSci*, vol. 5, no. 1, pp. 8–38, 2024, <https://doi.org/10.3390/neurosci5010002>.
- [18] V. Tereshenko *et al.*, "Axonal mapping of the motor cranial nerves," *Frontiers in Neuroanatomy*, vol. 17, Jun. 2023, <https://doi.org/10.3389/fnana.2023.1198042>.
- [19] M. M. Ottaviani and V. G. Macefield, "Structure and Functions of the Vagus Nerve in Mammals," *Comprehensive physiology*, vol. 12, no. 4, pp. 3989–4037, 2022, <https://doi.org/10.1002/j.2040-4603.2022.tb00237.x>.
- [20] J. Forstenpointner, A. M. S. Maallo, I. Elman, S. Holmes, R. Freeman, R. Baron, and D. Borsook, "The solitary nucleus connectivity to key autonomic regions in humans," *European Journal of Neuroscience*, vol. 56, no. 2, pp. 3938–3966, 2022, <https://doi.org/10.1111/ejn.15691>.
- [21] E. R. Delay and S. D. Roper, "Umami Taste Signaling from the Taste Bud to Cortex," *Food and Health*, pp. 43–71, 2023, https://doi.org/10.1007/978-3-031-32692-9_3.
- [22] K. Jezierska, A. C.-Ploska, J. Zaleska, and W. Podraza, "Gustatory-Visual Interaction in Human Brain Cortex: fNIRS Study," *Brain Sciences*, vol. 15, no. 1, pp. 92–92, 2025, <https://doi.org/10.3390/brainsci15010092>.
- [23] J. A. Avery, A. G. Liu, J. E. Ingeholm, C. D. Riddell, S. J. Gotts, and A. Martin, "Taste Quality Representation in the Human Brain," *The Journal of Neuroscience*, vol. 40, no. 5, pp. 1042–1052, 2019, <https://doi.org/10.1523/jneurosci.1751-19.2019>.
- [24] P. Han, M. Mohebbi, H.-S. Seo, and T. Hummel, "Sensitivity to sweetness correlates to elevated reward brain responses to sweet and high-fat food odors in young healthy volunteers," *NeuroImage*, vol. 208, p. 116413, 2020, <https://doi.org/10.1016/j.neuroimage.2019.116413>.
- [25] J. D. Boughter and M. Fletcher, "Rethinking the role of taste processing in insular cortex and forebrain circuits," *Current Opinion in Physiology*, vol. 20, pp. 52–56, 2021, <https://doi.org/10.1016/j.cophys.2020.12.009>.
- [26] A. Rosa, F. Loy, I. Pinna, and C. Masala, "Role of Aromatic Herbs and Spices in Salty Perception of Patients with Hyposmia," *Nutrients*, vol. 14, no. 23, pp. 4976–4976, 2022, <https://doi.org/10.3390/nu14234976>.
- [27] S. D. Roper, "Encoding Taste: From Receptors to Perception," *Handbook of experimental pharmacology*, vol. 275, pp. 53–90, 2022, https://doi.org/10.1007/164_2021_559.
- [28] M. Andrade, "The senses 3: exploring the interrelated senses of smell and taste," *Nursing Times*, vol. 21, 2022, <https://www.nursingtimes.net/neurology/the-senses-3-exploring-the-interrelated-senses-of-smell-and-taste-21-11-2022/>.
- [29] C.-L. Shen *et al.*, "P50, N100, and P200 Auditory Sensory Gating Deficits in Schizophrenia Patients," *Frontiers in Psychiatry*, vol. 11, 2020, <https://doi.org/10.3389/fpsy.2020.00868>.
- [30] G. R.-Bermúdez, B. Naret, and A. R. Teixeira, "Analysis of P300 Evoked Potentials to Determine Pilot Cognitive States," *Sensors*, vol. 25, no. 19, p. 6201, 2025, <https://doi.org/10.3390/s25196201>.

- [31] C. Guida, M. J. B. Kim, O. A. Stibolt, A. Lompadó, and J. E. Hoffman, "The N400 component reflecting semantic and repetition priming of visual scenes is suppressed during the attentional blink," *Attention, perception & psychophysics*, vol. 87, no. 4, pp. 1199–1218, 2025, <https://doi.org/10.3758/s13414-024-02997-1>.
- [32] J. Gallina, G. Marsicano, V. Romei, and C. Bertini, "Electrophysiological and Behavioral Effects of Alpha-Band Sensory Entrainment: Neural Mechanisms and Clinical Applications," *Biomedicines*, vol. 11, no. 5, p. 1399, May 2023, <https://doi.org/10.3390/biomedicines11051399>.
- [33] J. Chmiel and A. Malinowska, "The Neural Correlates of Chewing Gum—A Neuroimaging Review of Its Effects on Brain Activity," *Brain Sciences*, vol. 15, no. 6, p. 657, 2025, <https://doi.org/10.3390/brainsci15060657>.
- [34] M. Maram, M. A. Khalil and K. George, "Analysis of Consumer Coffee Brand Preferences Using Brain-Computer Interface and Deep Learning," *2023 IEEE 7th International Conference on Information Technology, Information Systems and Electrical Engineering (ICITISEE)*, pp. 227-232, 2023, <https://doi.org/10.1109/ICITISEE58992.2023.10404368>.
- [35] S. Y. Ki and Y. T. Jeong, "Neural circuits for taste sensation," *Molecules and Cells*, vol. 47, no. 7, pp. 100078–100078, 2024, <https://doi.org/10.1016/j.mocell.2024.100078>.
- [36] E. T. Rolls, "Emotion, motivation, decision-making, the Orbitofrontal cortex, Anterior Cingulate cortex, and the Amygdala," *Brain Structure and Function*, vol. 228, no. 5, 2023, <https://doi.org/10.1007/s00429-023-02644-9>.
- [37] C. A. Zimmerman *et al.*, "A neural mechanism for learning from delayed postingestive feedback," *Nature*, pp. 1–10, 2025, <https://doi.org/10.1038/s41586-025-08828-z>.
- [38] M. E. Doyle, H. U. Premathilake, Q. Yao, C. H. Mazucanti, and J. M. Egan, "Physiology of the tongue with emphasis on taste transduction," *Physiological Reviews*, vol. 103, no. 2, pp. 1193–1246, 2023, <https://doi.org/10.1152/physrev.00012.2022>.
- [39] A. K.-Sterniuk, N. Browarska, A. Al-Bakri, M. Pelc, J. Zygarlicki, M. Sidikova, R. Martinek, and E. J. Gorzelanczyk, "Summary of over Fifty Years with Brain-Computer Interfaces—A Review," *Brain Sciences*, vol. 11, no. 1, p. 43, 2021, <https://doi.org/10.3390/brainsci11010043>.
- [40] Y. Guo, X. Xia, Y. Shi, Y. Ying, and H. Men, "Olfactory EEG induced by odor: Used for food identification and pleasure analysis," *Food Chemistry*, vol. 455, pp. 139816–139816, 2024, <https://doi.org/10.1016/j.foodchem.2024.139816>.
- [41] A. Tonin, M. Semprini, P. Kiper, and D. Mantini, "Brain-Computer Interfaces for Stroke Motor Rehabilitation," *Bioengineering*, vol. 12, no. 8, pp. 820–820, 2025, <https://doi.org/10.3390/bioengineering12080820>.
- [42] T. Yang *et al.*, "Exploring the neural correlates of fat taste perception and discrimination: Insights from electroencephalogram analysis," *Food Chemistry*, vol. 450, p. 139353, 2024, <https://doi.org/10.1016/j.foodchem.2024.139353>.
- [43] E. Boot *et al.*, "fNIRS a novel neuroimaging tool to investigate olfaction, olfactory imagery, and crossmodal interactions: a systematic review," *Frontiers in Neuroscience*, vol. 18, 2024, <https://doi.org/10.3389/fnins.2024.1266664>.
- [44] A. M. Dietsch, R. M. Westemeyer, and D. H. Schultz, "Brain activity associated with taste stimulation: A mechanism for neuroplastic change?," *Brain and Behavior*, vol. 13, no. 4, p. e2928, 2023, <https://doi.org/10.1002/brb3.2928>.
- [45] A. Farizal, A. D. Wibawa, D. P. Wulandari and Y. Pamungkas, "Investigation of Human Brain Waves (EEG) to Recognize Familiar and Unfamiliar Objects Based on Power Spectral Density Features," *2023 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, pp. 77-82, 2023, <https://doi.org/10.1109/ISITIA59021.2023.10221052>.
- [46] N. Huidobro, R. M.-Andrade, I. M.-Balbuena, C. Trenado, M. T. Bello, and E. T. Rodríguez, "Electroencephalographic Biomarkers for Neuropsychiatric Diseases: The State of the Art," *Bioengineering*, vol. 12, no. 3, p. 295, 2025, <https://doi.org/10.3390/bioengineering12030295>.
- [47] R. Aziza, E. Alessandrini, C. Matthews, S. R. Ranmal, Z. Zhou, E. H. Davies, and C. Tuleu, "Using facial reaction analysis and machine learning to objectively assess the taste of medicines in children," *PLOS Digital Health*, vol. 3, no. 11, pp. e0000340–e0000340, 2024, <https://doi.org/10.1371/journal.pdig.0000340>.
- [48] S. R. M.-Castelblanco, M. A. V.-Guerrero, and M. C.-Cuervo, "Artificial Intelligence Approaches for EEG Signal Acquisition and Processing in Lower-Limb Motor Imagery: A Systematic Review," *Sensors*, vol. 25, no. 16, pp. 5030–5030, 2025, <https://doi.org/10.3390/s25165030>.
- [49] Y. Pamungkas and U. W. Astuti, "Comparison of Human Emotion Classification on Single-Channel and Multi-Channel EEG using Gate Recurrent Unit Algorithm," *2023 International Conference on Computer Science, Information Technology and Engineering (ICCoSITE)*, pp. 1-6, 2023, <https://doi.org/10.1109/ICCoSITE57641.2023.10127686>.
- [50] A. Jovic, N. Frid, K. Brkic, and M. Cifrek, "Interpretability and accuracy of machine learning algorithms for biomedical time series analysis – a scoping review," *Biomedical Signal Processing and Control*, vol. 110, p. 108153, 2025, <https://doi.org/10.1016/j.bspc.2025.108153>.
- [51] T. Mouillot *et al.*, "Differential Cerebral Gustatory Responses to Sucrose, Aspartame, and Stevia Using Gustatory Evoked Potentials in Humans," *Nutrients*, vol. 12, no. 2, p. 322, 2020, <https://doi.org/10.3390/nu12020322>.
- [52] Y. Chen, A. X. Huang, I. Faber, G. Makransky, and F. J. A. P.-Cueto, "Assessing the Influence of Visual-Taste Congruency on Perceived Sweetness and Product Liking in Immersive VR," *Foods*, vol. 9, no. 4, p. 465, 2020, <https://doi.org/10.3390/foods9040465>.

- [53] L. Alvino, R. van der Lubbe, R. A. M. Joosten, and E. Constantinides, "Which wine do you prefer? An analysis on consumer behaviour and brain activity during a wine tasting experience," *Asia Pacific Journal of Marketing and Logistics*, vol. 32, no. 5, pp. 1149–1170, 2019, <https://doi.org/10.1108/apjml-04-2019-0240>.
- [54] A. HajiHosseini and C. A. Hutcherson, "Alpha oscillations and event-related potentials reflect distinct dynamics of attribute construction and evidence accumulation in dietary decision making," *eLife*, vol. 10, 2021, <https://doi.org/10.7554/elife.60874>.
- [55] Y. Huang, B. W. Kakusa, A. Feng, S. Gattas, R. S. Shivacharan, E. B. Lee, J. J. Parker, F. M. Kuijper, D. A. N. Barbosa, C. J. Keller, C. Bohon, A. Mikhail, and C. H. Halpern, "The insulo-opercular cortex encodes food-specific content under controlled and naturalistic conditions," *Nature Communications*, vol. 12, no. 1, 2021, <https://doi.org/10.1038/s41467-021-23885-4>.
- [56] C. Sinding, H. Thibault, T. Hummel, and T. T.-Danguin, "Odor-Induced Saltiness Enhancement: Insights Into The Brain Chronometry Of Flavor Perception," *Neuroscience*, vol. 452, pp. 126–137, 2021, <https://doi.org/10.1016/j.neuroscience.2020.10.029>.
- [57] S. Franco, A. M. Abreu, R. Biscaia, and S. Gama, "Sports ingroup love does not make me like the sponsor's beverage but gets me buying it," *PLOS ONE*, vol. 16, no. 7, p. e0254940, 2021, <https://doi.org/10.1371/journal.pone.0254940>.
- [58] M. Hong, H. Jang, S. Bo, M. Kim, P. Deepa, J. Park, K. Sowndhararajan, and S. Kim, "Changes in Human Electroencephalographic Activity in Response to Agastache rugosa Essential Oil Exposure," *Behavioral sciences*, vol. 12, no. 7, pp. 238–238, 2022, <https://doi.org/10.3390/bs12070238>.
- [59] G. Voltani, H. Arteaga, A. Rodrigues, N. F. Ortega, J. Xavier, and A. Carolina, "The convolutional neural network as a tool to classify electroencephalography data resulting from the consumption of juice sweetened with caloric or non-caloric sweeteners," *Frontiers in Nutrition*, vol. 9, 2022, <https://doi.org/10.3389/fnut.2022.901333>.
- [60] B. Wu, X. Zhou, I. Blank, and Y. Liu, "Investigating the influence of monosodium L-glutamate on brain responses via scalp-electroencephalogram (scalp-EEG)," *Food Science and Human Wellness*, vol. 11, no. 5, pp. 1233–1239, 2022, <https://doi.org/10.1016/j.fshw.2022.04.019>.
- [61] E. R.-Arroyo, J. Soria, M. Mora, F. Laport, A. M.-F.-de-Leceta, and L. V.-Araújo, "Exploratory Research on Sweetness Perception: Decision Trees to Study Electroencephalographic Data and Its Relationship with the Explicit Response to Sweet Odor, Taste, and Flavor," *Sensors*, vol. 22, no. 18, pp. 6787–6787, 2022, <https://doi.org/10.3390/s22186787>.
- [62] C. Çelik, H. Güler, and M. Pehlivan, "Medicolegal aspect of loss of smell and olfactory event-related potentials," *Egyptian Journal of Forensic Sciences*, vol. 12, no. 1, 2022, <https://doi.org/10.1186/s41935-022-00306-1>.
- [63] I. V. Stuldreher, D. Kaneko, H. Hiraguchi, J. B. F. van Erp, and A.-M. Brouwer, "EEG measures of attention toward food-related stimuli vary with food neophobia," *Food Quality and Preference*, vol. 106, p. 104805, 2023, <https://doi.org/10.1016/j.foodqual.2022.104805>.
- [64] T. Hosang, S. Laborde, A. Löw, M. Sprengel, N. Baum, and T. Jacobsen, "How Attention Changes in Response to Carbohydrate Mouth Rinsing," *Nutrients*, vol. 15, no. 13, pp. 3053–3053, 2023, <https://doi.org/10.3390/nu15133053>.
- [65] A. Naser and Ö. Aydemir, "Enhancing EEG Signal Classification With a Novel Random Subset Channel Selection Approach: Applications in Taste, Odor, and Motor Imagery Analysis," *IEEE Access*, vol. 12, pp. 145608–145618, 2024, <https://doi.org/10.1109/access.2024.3473810>.
- [66] Y. Jing, Z. Xu, Y. Pang, X. Liu, J. Zhao, and Y. Liu, "The Neural Correlates of Food Preference among Music Kinds," *Foods*, vol. 13, no. 7, pp. 1127–1127, 2024, <https://doi.org/10.3390/foods13071127>.
- [67] A. Ullah, F. Zhang, Z. Song, Y. Wang, S. Zhao, W. Riaz, and G. Li, "Surface Electromyography-Based Recognition of Electronic Taste Sensations," *Biosensors*, vol. 14, no. 8, pp. 396–396, 2024, <https://doi.org/10.3390/bios14080396>.
- [68] M. Mastinu, L. S. Grzeschuchna, C. Mignot, C. Guducu, V. Bogdanov, and T. Hummel, "Time–frequency analysis of gustatory event related potentials (gERP) in taste disorders," *Scientific Reports*, vol. 14, no. 1, 2024, <https://doi.org/10.1038/s41598-024-52986-5>.
- [69] X. Xia, Q. Wang, H. Wang, C. Liu, P. Li, Y. Shi, and H. Men, "Optimizing Food Taste Sensory Evaluation Through Neural Network-Based Taste Electroencephalogram Channel Selection," *IEEE Transactions on Instrumentation and Measurement*, vol. 74, pp. 1–9, 2025, <https://doi.org/10.1109/tim.2025.3551994>.
- [70] H. Li, S. Li, K. Matsuo, and T. Okamoto, "Brain activity during a cognitive task after consuming food of varying palatability," *Frontiers in Psychology*, vol. 16, 2025, <https://doi.org/10.3389/fpsyg.2025.1522812>.
- [71] L. Stickel, K. G. Grunert, and L. Lähteenmäki, "Implicit and explicit liking of a snack with health- versus taste-related information," *Food Quality and Preference*, vol. 122, p. 105293, 2025, <https://doi.org/10.1016/j.foodqual.2024.105293>.
- [72] X. Xia, Y. Cheng, Z. Zhang, Z. Hua, Q. Wang, Y. Shi, and H. Men, "Advancing research on odor-induced sweetness enhancement: A EEG local-global fusion transformer network for sweetness quantification combined with EEG technology," *Food Chemistry*, vol. 463, p. 141533, 2025, <https://doi.org/10.1016/j.foodchem.2024.141533>.
- [73] S. Albayrak, B. Aydin, G. Özen, F. Yalçın, M. Balık, H. Yanık, B. A. Urgan, and M. G. Veldhuizen, "Transcutaneous Vagus Nerve Stimulation Effects on Flavor-Evoked Electroencephalogram and Eye-Blink Rate," *Brain and Behavior*, vol. 15, no. 3, 2025, <https://doi.org/10.1002/brb3.70355>.
- [74] Q. Zhao, P. Yang, X. Wang, Z. Ye, Z. Xu, J. Chen, S. Chen, X. Ye, and H. Cheng, "Unveiling brain response mechanisms of citrus flavor perception: An EEG-based study on sensory and cognitive responses," *Food Research International*, vol. 206, pp. 116096–116096, 2025, <https://doi.org/10.1016/j.foodres.2025.116096>.

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- [75] J. Liu, Y. Xu, X. Lian, T. Liu, H. Ning, X. Jiang, S. Yu, S. Liu, L. Huang, X. Sun, J. Li, and D. Xu, "A comprehensive framework for decoding salty taste information from electroencephalography signals: distinguishing brain reactions to saltiness of comparable intensity," *Food Science and Human Wellness*, vol. 14, no. 4, p. 9250099, 2025, <https://doi.org/10.26599/fshw.2024.9250099>.
 - [76] L. Stickel, S. Poggesi, K. G. Grunert, L. Lähteenmäki, and J. Hort, "Do you remember? Consumer reactions to health-related information on snacks in repeated exposure," *Food Quality and Preference*, pp. 105431–105431, 2025, <https://doi.org/10.1016/j.foodqual.2025.105431>.
 - [77] X. Wang, G. Wang, and D. Liu, "EEG-Based Analysis of Neural Responses to Sweeteners: Effects of Type and Concentration," *Foods*, vol. 14, no. 14, pp. 2460–2460, 2025, <https://doi.org/10.3390/foods14142460>.
 - [78] S. De, P. Mukherjee, and A. H. Roy, "TasteNet: A novel deep learning approach for EEG-based basic taste perception recognition using CEEMDAN domain entropy features," *Journal of Neuroscience Methods*, vol. 419, p. 110463, 2025, <https://doi.org/10.1016/j.jneumeth.2025.110463>.
 - [79] G. Wang, X. Wang, T. Zhang, Z. Qin, F. Zheng, X. Ye, B. Sun, and H. Cheng, "Advancing flavor perception research with EEG microstate analysis: A dynamic approach to understanding brain responses to alcoholic stimuli," *Food Chemistry*, pp. 144218–144218, 2025, <https://doi.org/10.1016/j.foodchem.2025.144218>.
 - [80] Q. Wang *et al.*, "Mechanistic study of saltiness enhancement induced by three characteristic volatiles identified in Jinhua dry-cured ham using electroencephalography (EEG)," *Food Chemistry*, pp. 144180–144180, 2025, <https://doi.org/10.1016/j.foodchem.2025.144180>.
 - [81] H. Park *et al.*, "Elucidation of chemosensory and neurophysiological approaches of rice (*Oryza sativa* L.) bran foods with sugar substitutes through permutation and machine learning-assisted screening methods," *Food Bioscience*, vol. 71, p. 107090, 2025, <https://doi.org/10.1016/j.fbio.2025.107090>.
 - [82] J. Yang, J. Zhang, J. Xu, Q. Ke, X. Kou, and X. Huang, "SensoryGAN: AI-driven design of low-toxicity dairy flavor alternatives with integrated neurosensory and cellular safety validation," *Food Research International*, vol. 218, pp. 116785–116785, 2025, <https://doi.org/10.1016/j.foodres.2025.116785>.
 - [83] D. R. Pereira, H. R. Pereira, M. L. Silva, P. Pereira, and H. A. Ferreira, "Impact of five basic tastes perception on neurophysiological response: Results from brain activity," *Food Quality and Preference*, vol. 131, p. 105572, 2025, <https://doi.org/10.1016/j.foodqual.2025.105572>.
 - [84] P. Chen *et al.*, "Electroencephalography (EEG) design for flavor perception of Baijiu: An investigation into the influence of full-bodied mouthfeel on brain rhythms," *Food Chemistry*, pp. 145864–145864, 2025, <https://doi.org/10.1016/j.foodchem.2025.145864>.
 - [85] Y. Fu *et al.*, "Neurophysiological and multimodal sensory evaluation of baijiu and food pairing liking," *Food Research International*, pp. 117451–117451, 2025, <https://doi.org/10.1016/j.foodres.2025.117451>.
 - [86] X. Wang and L. Guoce, "TEDNet: Cascaded CNN-Transformer with Dual Attentions for Taste EEG Decoding," *Journal of Neuroscience Methods*, vol. 424, pp. 110594–110594, 2025, <https://doi.org/10.1016/j.jneumeth.2025.110594>.
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