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Integrating Neuroscience into Sensory Analysis of Cosmetics

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Abstract: The study of olfactory perception and its neurophysiological implications has gained increasing significance, particularly in understanding how fragrances influence brain activity and human behavior. Volatile compounds, commonly found in perfumery and cosmetics, interact with the nervous system, modulating brain function through the electrical activity of the olfactory system. Electroencephalography (EEG), a well-established non-invasive technique, serves as a powerful tool for investigating subconscious processes that affect purchasing decisions and social behavior. This article explores the advanced application of EEG in olfactory studies, focusing on how different olfactory stimuli can modulate brain wave frequencies. Research indicates that EEG not only captures wave patterns associated with specific brain functions but also provides insights into the influence of fragrances on emotional and cognitive states. By surpassing traditional preference evaluations, EEG analysis explores dimensions of valence and arousal reflecting the intensity and pleasantness of odors, which have significant implications for the cosmetics industry. This article presents a novel approach to the importance of EEG in sensory studies of cosmetics proposing parameters to guide regulatory frameworks for cosmetic companies. It emphasizes how neurophysiological data can serve as objective measures to assess the impacts of olfactory stimuli on cognitive function. By integrating EEG methodologies into sensory studies, the article provides a robust foundation that facilitates a deeper understanding of the interactions between fragrances and the brain, ensuring both efficacy and safety for consumers. This integrated approach enhances not only product development but also ensures that new products meet consumer expectations for both functionality and emotional experience.

Keywords: Cosmetic fragrances; Sensory neuroscience; Olfactory responses; Sensory perception; Emotional assessment

1. Introduction

The growing interest in olfactory perception studies and its neurophysiological implications underscores the significance of fragrances in brain activity and human behavior. Volatile compounds, common in perfumery and cosmetics, interact with the nervous system, influencing the brain's functional modulation through the electrical

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activity of the olfactory system (Kim et al., 2019). Electroencephalography is a well-established non-invasive technique and an effective method for investigating subconscious processes that affect purchasing decisions and social behavior (Kim et al., 2019; Ninenko et al., 2023).

Research indicates that EEG not only records wave patterns associated with specific brain functions, such as alpha and beta waves, but also provides insights into the influence of fragrances on emotional and cognitive states (Cherninskii et al., 2009; Hou et al., 2020). EEG analysis surpasses traditional preference evaluations by exploring dimensions of valence and arousal that reflect the intensity and pleasantness of odors (Karmarkar and Plassmann, 2019; Lanata et al., 2016). This has significant implications for the cosmetics industry, paving the way for developing therapeutic interventions and innovative products (Kroupi et al., 2014; Park et al., 2019).

EEG's role in investigating cognitive function and sensory engagement is demonstrated by its ability to decode the psychophysiological impacts of fragrances on emotion and cognition. It offers an objective assessment method, yielding results without requiring active cooperation from participants (Kim et al., 2019). Standardizing methodologies, including rigorous control of fragrance concentration and administration protocols, is crucial for consistent interpretation of responses across different contexts (Diwoux et al., 2024). Advances in research highlight how odors, by interacting with limbic structures—such as the amygdala and hippocampus—can alter interpersonal neural responses and modulate attention and engagement (DeGuzman et al., 2020; Lanata et al., 2016).

This article pioneers a reflection on the importance of electroencephalography (EEG) in sensory studies of cosmetics, proposing parameters to guide the regulatory frameworks of cosmetic companies in identifying key criteria for research of this nature and demonstrating, from a foundational perspective, how physiological responses can be linked to the effects of cosmetics. Specifically, the study emphasizes how neurophysiological data can serve as objective measures to assess the impacts of olfactory stimuli on cognitive function. By integrating EEG methodologies into sensory studies, the article provides a robust foundation that facilitates not only a deeper understanding of the interactions between fragrances and the brain but also the adoption of rigorous standards in developing new products, ensuring both efficacy and safety for consumers.

2. Material and Method

In pursuit of cutting-edge knowledge on the subject, the study employed the ScholarAI platform (https://app.scholarai.io/) as a support tool for searching and analyzing relevant scientific literature, facilitating the efficient identification of articles aligned with the investigated theme. The platform demonstrated greater precision and effectiveness compared to Google Scholar, establishing itself as a valuable resource for selecting publications.

The selection of articles was guided by three primary criteria, prioritized by relevance: comprehensive alignment with the scope of cosmetic science, publication within the last five years, and presentation of a robust conceptual or experimental framework. Although the last criterion involves a subjective component, it proved essential for a more comprehensive and integrated delineation of the different issues and approaches explored in this study, resulting in a corpus of 19 articles.

A key parameter to consider in EEG studies is the configuration of electrodes according to the international 10-20 system. This system is a standardized method for electrode placement on the scalp, ensuring comprehensive and accurate collection of brain data. Named for the percentage distances (10% or 20%) between electrode placement sites, it covers specific regions such as the frontal, temporal, and parietal areas of the brain, which are crucial for effectively capturing neuronal electrical activity (Sowndhararajan and Kim, 2016). Implementing this system aims to ensure that responses related to psychophysiological states are accurately identified.

3. Results and Discussion

3.1. Results

Electroencephalography (EEG) plays a critical role in capturing brain signals, converting analog signals into digital form for analysis. The standard data collection procedure covers a frequency range from 0.5 Hz to 70 Hz, with equipment operating at sampling rates ranging from 250 Hz to 1000 Hz (Cerf and Garcia-Garcia, 2017). The sampling rate, which refers to the number of samples collected per second, is vital for accurately capturing the rapid dynamics of brain waves. This capability ensures the temporal resolution necessary for detailed analysis of complex mental processes. Thus, instrumental precision stands out as one of the fundamental pillars in assessing the quality and reliability of a study.

A second essential pillar for ensuring rigor in data collection in sensory studies is the precise control of sensor impedance levels. Impedance refers to the resistance a circuit offers to the flow of electricity, and it is recommended to keep it low, typically below 5 kΩ, to minimize noise and artifacts, ensuring maximum accuracy in reading brain activities (Cerf and Garcia-Garcia, 2017; Kim et al., 2019; Sowndhararajan and Kim, 2016). Rigorous impedance control is vital in sensory studies using EEG, as it ensures that data are collected with minimal interference. This control should be conducted before data collection, during the calibration of electrodes in contact with the scalp, using validated software or technology. Low impedance results from a combination of factors, including the environment, the type of electrode used, the quality of the EEG amplifier, and, when necessary, the use of materials that enhance conductance, such as saline solution or conductive paste.

Artifact control represents the third critical pillar in ensuring the quality of data collected in EEG studies. These unwanted components in the recorded electrical signals have the potential to mask or mimic genuine neural oscillations of interest, thereby affecting the accuracy of analyses. The identification and removal of artifacts are fundamental to data quality. Artifacts can be categorized into three main sources in the context of neuro-sensory studies (La Marca et al., 2018):

• Physiological: Includes eye movements, blinks, facial and body muscle movements, and cardiac activities, which induce changes in the electromagnetic potential detected by the electrodes.

• Environmental: Encompasses interference caused by nearby electrical devices or noise in the collection environment.

• Instrumental: Results from equipment imperfections, such as improperly connected electrodes or instabilities in electrical connections.

In this context, advanced methods like Independent Component Analysis (ICA) are frequently employed to isolate and remove artifacts from raw EEG data while preserving the validity of recorded brain activities (La Marca et al., 2018). ICA is a mathematical algorithm used in data processing to clean artifacts. Both MATLAB and Python have libraries with this algorithm. ICA's effectiveness lies in its ability to distinguish between spurious activities and genuine signals of interest, ensuring that the interpretation of brain states is based on uncontaminated data. Effective artifact mitigation, therefore, not only enhances the quality of the collected data but also strengthens the reliability of inferences made from EEG recordings, playing a critical role in the robustness of neuroscientific studies.

Before proceeding, it is useful to recap the points addressed so far. Initially, we highlighted the importance of applying neuroscience, particularly EEG, in sensory testing of cosmetics. The analysis then addressed the three essential pillars for ensuring data robustness: sampling rate, impedance control, and artifact management. Sampling rate and impedance are monitored during data collection, while artifact control is integrated into signal processing. It is crucial to understand that data collected via EEG in sensory studies are not immediately ready for analytical use. They require a method called signal processing, which involves using mathematical equations to prepare the data for analysis. Various techniques are available for this purpose, but in this article, we emphasize spectral power analysis, one of the most used methods.

Spectral power is a measure in signal processing that quantifies the distribution of a signal's energy with respect to its frequency (Smith, 2003). This measure provides a detailed analysis of which frequencies contain the most energy in the signal, revealing patterns and specific characteristics across various frequency bands. In the context of EEG, spectral power is used to decompose brain activity into frequency components, such as Delta, Theta, Alpha, Beta, and Gamma waves, each associated with different brain states and mental processes.

In cosmetic neuro-sensory testing, spectral power analysis via EEG is applied to evaluate the impact of products, especially fragrances, on brain electrical activity. By measuring the neurological response to different fragrances, it is possible to identify changes in specific frequency bands associated with states of attraction or repulsion (Di Gruttola et al., 2021). For instance, an increase in Alpha wave power might indicate relaxation induced by a particular aroma

(Ninenko et al., 2023). This information is essential for understanding consumers' perceptions and emotional reactions to cosmetic products, allowing companies to develop formulations that promote well-being and produce the desired effects on consumers.

Another analytical approach is the use of event-related potentials (ERPs) to analyze neural responses to olfactory stimuli. This method has emerged as an area of great interest in sensory research and could be one of the analytical orientations in sensory tests using EEG. ERP is a measurement technique derived from electroencephalography (EEG) that enables the identification of precise temporal changes in brain electrical activity in response to specific sensory, cognitive, or motor stimuli (Pei and Li, 2021). It represents voltage fluctuations in the brain that occur in a specific temporal pattern relative to an event, reflecting neural processing related to perception, attention, or judgment. Using ERP allows for the decomposition of cortical responses into distinct components, each associated with stages of cognitive processing, such as stimulus detection (P200, N200) or emotional and attentional response (Pei and Li, 2021). Here, we are capturing cognitive processes at a very rapid speed, below the threshold of consciousness. ERP components, such as the P200, which appears between 200-300 milliseconds after the onset of a stimulus, are fundamental for studying attention and stimulus relevance, being particularly significant when dealing with odors (Ninenko et al., 2023).

A detailed analysis of each frequency band (alpha, beta, theta, delta, and gamma) provides significant insights into cognitive and emotional processes, allowing for a deeper understanding of the overall impact of stimuli on human cognition and mood (Sowndhararajan and Kim, 2016). Below, we describe the effects of the activation of each of the five frequencies resulting from spectral power processing in olfactory tests. While not a comprehensive review due to the scarcity of research in the area, this information offers a basic perspective on the interpretation of wave frequencies in such tests.

Alpha Frequency

Activity in the alpha waves (8 to 12 Hz), often associated with states of relaxation and cortical inhibition, has been extensively studied in various sensory and emotional contexts. Studies demonstrate that both genders show an increase in alpha waves in the prefrontal cortex during exposure to olfactory stimuli, suggesting a state of emotional relaxation. However, gender differences emerge in the occipital lobe, related to concentration and cognitive functions, with variations observed in reaction time and memory activities in response to different aromas (Son et al., 2024).

Pleasant odors tend to increase alpha power, indicating relaxation, while unpleasant odors may reduce it, leading to heightened arousal (Kroupi et al., 2014). Exposure to fragrances like lavender is associated with an increase in alpha waves, reinforcing the known calming effect of the fragrance (Park et al., 2019). Conversely, stimuli that evoke initial romantic attraction cause a decrease in alpha power, reflecting heightened alertness and cognitive processing (Yuan and Liu, 2022).

These effects are not limited to aromas and are also observed in the application of cosmetics, where an increase in alpha power suggests relaxation during beauty rituals (Diwoux et al., 2024). Despite these trends, not all studies have found significant modulation of alpha waves in response to different stimuli, indicating that while they may influence attention and engagement, they do not substantially alter the state of relaxation (DeGuzman et al., 2020).

These findings underscore the complexity of brain responses to multisensory stimuli, emphasizing the importance of considering gender nuances in sensory research and product development such as aromatherapy. With careful interpretation, these responses provide valuable insights into how sensory stimuli influence cognition and psychological well-being, highlighting promising areas for future investigations (Abbasi et al., 2020; Sowndhararajan and Kim, 2016).

Beta Frequency

The analysis of beta waves (12 to 30 Hz) highlights their critical role in states of alertness and active cognitive processing, serving as a central focus for investigating brain responses to olfactory and visual stimuli. Studies indicate that unpleasant and complex odors significantly increase beta power, reflecting a state of heightened alertness and the need for precise discrimination, associated with aversive emotions and intensified vigilance (Kim et al., 2019; Kroupi et al., 2014).

Interestingly, the increase in beta activity during the inhalation of aromas such as peppermint and coffee suggests a stimulating effect, promoting alertness and sustained attention, demonstrating these fragrances' ability to activate the nervous system (Park et al., 2019). Conversely, exposure to visual stimuli of attractive faces or calming fragrances results in reduced beta activity, implying lower arousal and alertness, and suggests a deeper, more introspective processing of sensory impressions (Kim et al., 2019; Yuan and Liu, 2022). Similarly, combinations of strong fragrances and congruent colors have demonstrated calming effects, underscoring the potential of multisensory stimuli to stabilize emotional responses and decrease arousal (Lee et al., 2018).

Additionally, changes in beta activity are revealing in the context of cosmetic experiences, where tactile contact during shopping significantly enhances cognitive and emotional engagement, as evidenced by intensified beta waves (Balconi et al., 2021). However, some studies have not found significant variations in beta power under different odor conditions, indicating that, despite interindividual correlations, the stimuli did not significantly alter participants' levels of alertness (DeGuzman et al., 2020).

Generally associated with active thinking, focus, and high cognition, beta waves illustrate how different stimuli, whether cosmetic or olfactory, can modulate alertness and cognitive engagement, serving as valuable indicators of sensory and emotional impact (Diwoux et al., 2024; Sowndhararajan and Kim, 2016).

Theta Frequency

Activity in theta waves (4 to 8 Hz) is linked to attention and sensory integration processes (DeGuzman et al., 2020), as well as attention and memory (Abbasi et al., 2020). The literature on the relationship between EEG and olfactory processing still presents a diversity of methods and findings, challenging the establishment of a clear consensus to date (Ninenko et al., 2023). Studies have shown that the perception of odors, particularly unpleasant ones, can reduce power in the theta band, suggesting an impact on states of alertness and emotional load (Kroupi et al., 2014).

Conversely, there are observations that pleasant odors facilitate episodic memory, implying a fundamental role of theta waves in sensory integration and emotional information processing (Abbasi et al., 2020). Also related to states of meditation and relaxed focus, changes in theta frequencies may indicate a transition to meditative or creative states, as observed in responses to olfactory and visual stimuli (Lee et al., 2018).

Moreover, these waves are often associated with relaxed states and the transition between wakefulness and sleep, potentially reflecting emotional calm induced by certain fragrances during sensory tests (Sowndhararajan and Kim, 2016). In the cosmetic context, an increase in theta power suggests a state of emotional relaxation or meditation, evoked by a product's sensory attributes (Diwoux et al., 2024).

Delta Frequency

Delta waves (0.5 to 4 Hz), typically associated with deep sleep in adults, signal areas of the brain entering restorative states. In sensory studies, an increase in these waves may suggest deep processing or relaxation responses induced by fragrances. Changes in delta waves can indicate subconscious processing influenced by olfactory stimuli (Sowndhararajan and Kim, 2016). An increase in delta activity during wakefulness is less common and may suggest profoundly calming effects. However, delta waves are generally not the focus in cosmetic analyses unless assessing impacts on sleep (Diwoux et al., 2024).

Gamma Frequency

Activity in the gamma band (30 to 100 Hz) has been analyzed to explore its relationship with sensory perception and information integration. Studies indicate that gamma activity increases in response to complex odors, reflecting heightened cognitive processing and greater sensory integration, suggesting its involvement in conscious perception and detailed evaluation of olfactory stimuli (Kroupi et al., 2014). In contrast, unpleasant odors intensify brain activity, especially in the beta and gamma bands and the right hemisphere, aligning with research on emotions and affective styles. Generally associated with high-level information processing, problem-solving, and consciousness, variations in gamma waves can indicate deep cognitive processing and sharp focus due to certain fragrances (Sowndhararajan and Kim, 2016).

These findings underscore the potential of EEG as an effective tool for assessing emotional responses to olfactory stimuli, opening new perspectives in affective neuroscience and psychophysiology (Kroupi et al., 2014). However, some research shows that gamma activity, although associated with high-level cognitive processes, did not show significant changes in all scenarios, indicating that stimuli affect frequencies related more to relaxation and attention than to complex cognitive processing (Kim et al., 2019).

3.2. Discussion

A primary perspective to discuss is the role of neuroscience as a resource for evaluating and predicting behaviors. Within this scope, it is necessary to distinguish between two mental processes that, in common usage, are often considered interchangeable but constitute entirely different constructs: emotions and feelings. According to Cerf and Garcia-Garcia (2017):

• Emotion refers to short, coordinated episodes of brain, autonomic, and behavioral changes in response to relevant internal or external events.

• Feeling is the conscious and subjective representation of an emotional experience. Feelings arise as conscious interpretations of underlying emotions and are more prolonged and introspective, often shaped by social and cultural contexts.

The definitions of emotion and feeling are crucial for a deep understanding of the neurophysiological impacts on consumer behavior and the design of sensory tests using neuroscience. Emotions are automatic and subconscious responses to sensory stimuli, such as olfactory ones, while feelings emerge as conscious representations of these experiences, influencing preferences and conscious perceptions. In this context, EEG plays a central role by recording changes in brain wave patterns associated with emotional and cognitive states. This technique provides a robust tool for investigating the interaction between unconscious emotional responses and the feelings that shape consumer behavior.

The distinction between emotion and feeling allows for a clear definition of the scope of neuroscience. Traditional sensory studies face significant limitations in measuring emotions, while neuroscience encounters challenges in evaluating complex processes like feelings. Therefore, the use of neuroscience has a well-defined scope and clear limitations: EEG data reveal processes that precede the rational judgment of a product, playing a crucial role in consumer decisions, while self-reported information offers a contextualization of the product from a rational and social perspective.

The integration of classical sensory and neuroscientific methodologies should be seen as complementary. Self-report scales and questionnaires are effective for framing products in rational dimensions, while neuroscience provides valuable insights into subconscious emotional reactions. In marketing, it is essential to translate the emotional responses captured by tools like EEG into product and communication strategies that emotionally resonate with the consumer. This includes developing products that meet rational needs and evoke positive emotional responses, as well as creating marketing campaigns that deeply connect with consumers.

In the regulatory sphere, establishing quality parameters for the collection of neuroscientific data is imperative. Regulatory agencies may require studies to follow strict ethical guidelines, ensuring that the data are of high quality and relevance. It is suggested that studies for validating sensory claims using EEG include detailed descriptions of essential pillars such as equipment sampling rate, impedance control method, and data cleaning technique. In any scientific study, the importance lies not only in the results but in how they were obtained. The work of Diwoux and colleagues (2024) can offer a clear vision of what EEG can do in sensory studies and the possibilities of claims to be communicated by cosmetics. They conduct a comprehensive review of neurophysiological emotional responses to cosmetic stimuli, identifying studies that analyze dimensions such as well-being, emotional valence, relaxation, price sensitivity, anti-stress, stimulation, and alertness. This article significantly contributes by mapping research that supports sensory experiments in a scientific and rigorous manner (9). The possibilities are not limited to these behavioral effects, as new studies and experiments are conducted in this area.

4. Conclusion

The harmonious integration between neuroscience insights and traditional approaches provides a comprehensive understanding of consumer behavior, allowing companies to develop products that not only meet functional expectations but also create memorable emotional experiences. This integrated approach is vital for innovation and standing out in a competitive market, where a deep understanding of consumers' emotional needs and desires becomes an essential differentiator for brands.

The use of EEG to evaluate real-time emotional responses during the application of cosmetic products reveals that psychophysiological methods can overcome limitations of traditional approaches, such as surveys and focus groups, which are often influenced by cognitive biases. This technique provides an objective and precise measure of the emotional impact of products, allowing companies to validate and adjust their emotional appeals based on concrete data from consumer experiences. The direct connection between emotional experience and marketing campaigns can amplify the effectiveness of advertising strategies that rely on emotional consumer engagement.

The article presents limitations, including the need for greater diversity in the literature and the replicability of studies, which may restrict the generalization of results. Additionally, the complexity of emotional processes captured by techniques like EEG demands more standardized and rigorous protocols to ensure data validity and reliability. Current approaches may not fully capture the richness of emotional experiences associated with cosmetics, suggesting a significant opportunity for new research that explores hybrid methodologies, combining neuroscience with behavioral and cultural insights. Future studies may focus on the diversity of products and technologies/methodologies that allow a more detailed and real-time analysis of emotional responses, thus offering a deeper and holistic understanding of the interactions between consumers and cosmetics.

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