NEUROPHYSIOLOGICAL RESPONSES TO VARIABLE LAVENDER FRAGNANCE CONCENTRATION: AN EEG AND SENSORY EVALUATION STUDY

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Abstract. This study aims to evaluate the impact of different concentrations of lavender fragrance on the nervous system, specifically identifying the threshold at which conscious perception of the scent ceases while the nervous system continues to respond. Thirty subjects participated in an olfactory task involving lavender essence diluted in alcohol at three concentrations (1%, 0.1%, and 0.01%). Data were collected using an eight-channel EEG device and a self-report questionnaire, processed with signal processing techniques (Fourier Transform and Ika), and analyzed using SPSS software with a focus on hemispheric asymmetry and alpha, beta, and theta frequencies. The findings reveal that fragrance concentration significantly affects brain electrical activity. Higher concentrations of lavender induced a more stressful effect on subjects, while the lowest concentration (0.01%) was most effective in promoting relaxation, as demonstrated by the largest deviation from the overall mean in the α/β ratio. This study highlights a significant inverse relationship between lavender concentration and its psychophysiological effects, with the minimal concentration proving particularly beneficial for inducing relaxation. These insights suggest that low concentrations of lavender fragrance could be effectively utilized in environments designed to promote well-being.
Keywords: *olfactory stimulation, fragrance concentration, EEG analysis, psychophysiological response, lavender aroma, consumer neuroscience*

Introduction

The olfactory system is one of the most fascinating sensory systems in the human body, playing a crucial role in the modulation of emotions, cognition, and memory (Hermoso and Andrade, 2015). Recent studies indicate that 75% of daily emotions are related to odors, and these olfactory stimuli have a significant influence on memory by enabling people to remember something they smelled more accurately than something they saw, heard, or touched (Dueñas and Gómez-Carmona, 2022). Dueñas and Gómez-Carmona (2022) demonstrate that product recognition occurs through the association of a product's identity with a specific odor, which allows for differentiation from competitors. Consequently, olfaction becomes a crucial sense in the consumer decision-making process, especially in the cosmetics industry. The importance of olfaction is also recognized in marketing, given the powerful capacity of scent diffusion. People can ignore visual and auditory stimuli, but it is almost impossible to ignore olfactory stimuli because this sense is deeply associated with a vital activity: breathing (Elgendi et al., 2018). Although the significance of olfaction is widely recognized, there remains a substantial gap in our understanding of the cognitive effects of different concentrations of olfactory stimuli. This study aims to fill this gap by exploring how variations in fragrance concentrations, particularly lavender, affect brain activity as measured by

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electroencephalogram (EEG). The concentration of a fragrance may be a key factor in determining whether an odor is processed by the sensory and cognitive systems, and whether it is encoded in memory from memory and remembered accurately later.

In a study by Laing et al. (2003), the objective was to determine the detection threshold for various odorants. Participants were tasked with distinguishing which of two vials emitted a more intense odor. A comprehensive set of 146 odor descriptors was employed to allow participants to characterize the nuances of each fragrance across different concentrations. The study concluded that the concentration of an odorant not only influences its perceived intensity but also its sensory qualities. At lower concentrations, descriptors commonly associated with pleasantness were more frequently reported, making these concentrations more appreciated by participants. This finding has significant implications, especially for the cosmetics and beauty products industry, where the creation of complex fragrances is both an art and a science (Thomas-Danguin et al., 2014). Understanding how different levels of concentration affect olfactory perception allows for a more scientifically grounded approach to developing new fragrances. This is particularly relevant in a field where historically; product development has been more a matter of empiricism and intuition than scientific rigor. The shift from an empirical focus to a more scientific approach could revolutionize how fragrances are developed and, by extension, how they are perceived and received by consumers. In this study, lavender essence was selected, as it is a widely used ingredient in the cosmetics industry and still underexplored in studies involving electroencephalography (EEG). EEG, a test that measures the brain's electrical activity, is commonly used to diagnose neurological conditions, monitor brain function, and conduct scientific research. EEG experiments have shown that lavender is an effective compound for improving mood and reducing anxiety. The results indicate an increase in alpha waves, which correspond to increased drowsiness in participants, along with distinct patterns in individuals who feel more comfortable inhaling lavender (Cavanagh and Wilkinson, 2002).

However, lavender is known for its aromatic properties and its potential to influence relaxation and well-being in some people. It is frequently used in aromatherapy and other complementary treatments to promote relaxation and relieve stress and anxiety (Cardoso et al., 2021). According to Silva and Souza (2022), lavender acts as an inhibitor in the hypothalamus-pituitary-adrenal axis (composed of the hypothalamus, pituitary gland, and adrenal gland) by reducing cortisol release and promoting the release of serotonin (which plays a role in sensations of pleasure and well-being). Classified as a calming odor, it can reduce stress and anxiety. Given the complex nature of the reactions to variations in olfactory concentrations, it is imperative to use technologies that can quantify these effects on brain activity. The electroencephalogram (EEG), a neurometric device, serves as a valuable tool for capturing the responses of the central and peripheral nervous systems when exposed to different fragrance concentrations. This method involves placing a cap with multiple electrodes on the participant's scalp and has been used in sensory studies of fragrances (Oliveira et al., 2019). The EEG is particularly effective in measuring brain waves in various regions of the brain, including the frontal, prefrontal, and occipital lobes, in both hemispheres (Park et al., 2019). According to Park et al. (2019), EEG frequency bands are classified as delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-13 Hz), beta (13-30 Hz), and gamma (30-50 Hz). This study endeavors to explore the nuanced interplay between fragrance and neurophysiology, specifically examining how aromas influence mood and personal

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preferences as indicated by brainwave activity. The primary objective is to elucidate the relationship between varying levels of fragrance concentration and the corresponding neurophysiological responses, as recorded by EEG technology. The hypothesis under scrutiny suggests that even minimal sensory responses may elicit measurable neurophysiological responses.

To achieve this, the study proposes a series of tests employing EEG equipment to detect potential fluctuations in cerebral activity elicited by olfactory stimuli, particularly at minimal concentrations. The aim of these findings is to bridge the gap between olfactory neuroscience and scent marketing, providing crucial experimental data on olfactory perception thresholds. Such knowledge may wield influential power within the marketing realm, potentially bolstering sales and production figures by leveraging the emotional and sensory-based purchasing tendencies exhibited by consumers. Additionally, in the therapeutic context, these insights could be invaluable, informing aromatherapy practices that utilize the curative, calming, and stimulating characteristics of certain plant-derived fragrances, with lavender being a notable example. Indeed, lavender's capacity for promoting tranquility, reducing stress and anxiety, and fostering healing has been previously documented (Silva and Souza, 2022).

Materials and Methods

The experiment was conducted in specialized sensory booths at the Fatec Diadema (SP, Brazil) facilities. The sample consisted of 30 volunteers, both men and women, ranging in age from 18 to 50 years, recruited through a public call targeted to the students of the institution. All participants were in good physical health and did not exhibit anosmia (loss of the sense of smell). *Figure 1* illustrates a scene from the experiment.

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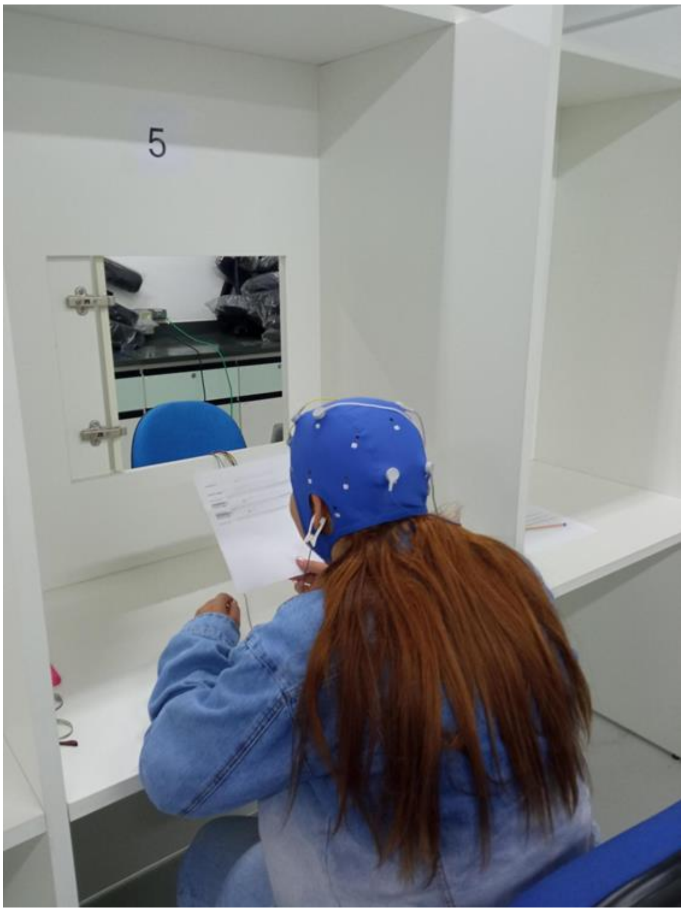

Figure 1. *After signing the informed consent form, each participant was fitted with a cap containing eight electrodes. Once the equipment was calibrated, the stimuli were presented in random order.*

Instrumentation and procedure

After signing the informed consent form, each participant was fitted with an EEG cap containing eight electrodes, positioned according to the international 10-20 system at the locations F1, F3, FP3, FP4, C3, C4, O1, and O2, as illustrated in *Figure 2*. These positions were chosen to encompass brain areas involved in decision-making, sensory perception, and visual processing. Each participant was exposed to three variants of the fragrance Lavender Provence 33.096, with concentrations of 1%, 0.1%, and 0.01%. The order of presentation of the fragrances was randomized to minimize biases. The experimental protocol included the following steps: (1) Reception and signing of the informed consent form; (2) Fitting of neurometric and biometric devices; (3) Baseline monitoring (analysis without olfactory stimuli; where the participant is in a relaxed state without sensitization) of the neurological state for 60 seconds; (4) Exposure to the first fragrance, as determined by random selection; (5) Olfactory sensitization for 15 seconds; (6) Rest period and subsequent monitoring for 2 minutes; (7) Subjective evaluation using a semantic differential scale regarding the intensity of fragrance perception; (8) Written test for validation of sensory data. Participants were instructed to mark the level of odor intensity, with 1 being "no smell" and 50 being "very strong smell"; and (9) Interval of 2 minutes before the next fragrance exposure.

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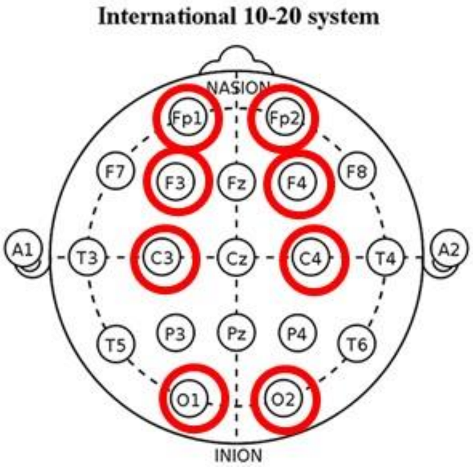

Figure 2. *Electrode positions for data collection, according to the international 10/20 system.*

All fragrance manipulations were conducted at a minimum distance of 2.5 meters to avoid pre-sensitization. The EEG data were analyzed using Matlab software with the EEGLab library. The spectral power was calculated to decompose the EEG signal into different frequency bands (delta, theta, alpha, beta, and gamma) associated with various cognitive and emotional states. Specifically, the Fourier Transform was applied to decompose the raw signals into their respective frequencies. The use of lavender fragrance was justified by its efficacy in inducing calm states, as evidenced in previous literature reviews. The study aims to understand how different concentrations of this fragrance influence brain activity and sensory perception. Finally, it is important to note that the project complies with the principles of the Helsinki Declaration and was approved by the Ethics Committee under protocol number 61077722.6.0000.8120.

Results and Discussion

The comparison of self-reported (50 points) data indicates that only the mildest fragrance (concentration=0.01%) had a significantly different mean (p=0.00) and a lower score than the two higher concentrations. This data demonstrates that there was no clear differentiation (at least in the self-reported sphere) between the fragrances with concentrations of 0.1% and 1%, as shown in *Figure 3*. These findings are relevant as they will serve as a parameter for understanding the results of the electroencephalogram. A primary measure to be compared is the beta wave activation level, without considering hemispheric asymmetry. *Table 1* presents the analysis for the 15-second olfactory task. For the 0.1% vs. 1% comparison, the mean difference is 1.42E+08 with a standard error of 5.17E+07, yielding a significance value of 0.017, which is below the 0.05 threshold, indicating statistical significance. The 0.01% vs. 1% comparison shows a mean difference of 2.51E+08 with a standard error of 4.23E+07 and a significance value of 0.000, demonstrating a highly significant difference. Lastly, the 0.01% vs. 0.1% comparison reveals a mean difference of 1.10E+08 with a standard error of 4.22E+07 and a significance value of 0.026, again below the 0.05 threshold, indicating statistical significance.

***Table 1**. The table analyzes the beta wave activity for three fragrance concentrations (1%, 0.1%, 0.01%), comparing the mean differences, standard errors, and significance values for each pairwise comparison.*

Concentration	Mean	Comparison	Mean difference	Error	Sig.
1%	4.46E+08	0.1%	1.42E+08	5.17E+07	0.017
		0.01%	2.51E+08	4.23E+07	0.000
0.1%	3.04E+08	1%	-1.42E+08	5.17E+07	0.017
		0.01%	1.10E+08	4.22E+07	0.026
0.01%	1.95E+08	1%	-2.51E+08	4.23E+07	0.000
		0.1%	-1.10E+08	4.22E+07	0.026

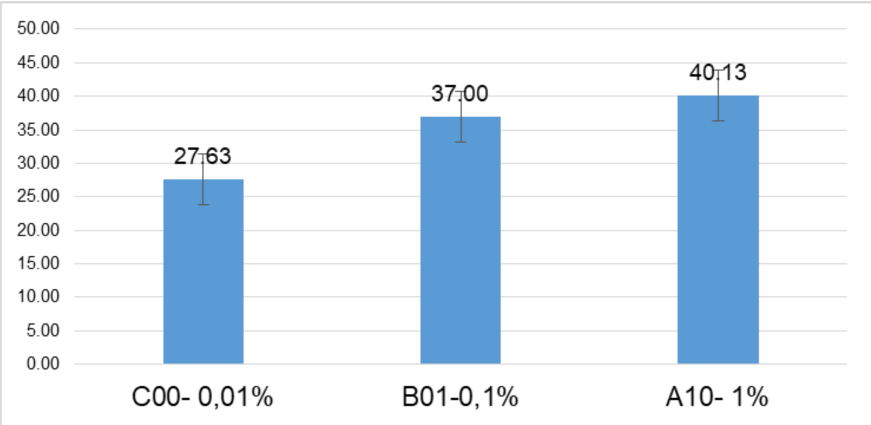

***Figure 3.** Mean perception of fragrance intensity as reported in a self-report questionnaire. C00 represents the sample with a fragrance concentration of 0.01%; B01 represents the sample with a fragrance concentration of 0.1%; A10 represents the sample with a fragrance concentration of 1%.*

These results indicate that different concentrations of fragrance can have distinct impacts on brain activity, potentially influencing consumer purchasing decisions. Table 1 presents the results, and an example interpretation is as follows: a mean difference of 1.42E+08 with a standard error of 5.17E+07 and a significance value of 0.017 indicates statistical significance. Practically, this suggests that the higher concentration of 1% results in a significant increase in brain activity related to attention and stress, as measured by beta frequency. Beta waves in EEG (electroencephalogram) readings are typically associated with states of alertness, concentration, and cognitive activation (Newson and Thiagarajan, 2019). The increase in beta waves in response to higher fragrance concentrations may indicate heightened attention or cognitive activation. Affanni et al. (2022) associate elevated beta frequencies with increased stress. Consequently, it is plausible to conclude that higher concentrations (1% and 0.1%) induced stress in participants, unlike the lower concentration (0.01%). However, when considering the thirty seconds of monitoring, no statistical difference was found between the scores. A primary effect observed here is the direct relationship between concentration level and stress level. However, this effect is not fully reflected in the applied self-report questionnaire. Considering that the questionnaire was completed after the monitoring period, there is always the possibility of an emotional dilution of the fragrance effect (as there is a clear difference only in the stimulation phase). Nevertheless, the discriminative power remains evident even after this period. The fragrance with the lowest concentration, and consequently the least beta frequency activation, was recognized as the mildest. To better understand this stress-relaxation effect, the recommendation of Wen and Aris (2020) was applied: using an alpha/beta ratio to identify how stressful or relaxing a product can be. The results show that the lowest concentration had the greatest deviation from the overall mean, thus offering the most relaxation (*Table 2*).

***Table 2**. ANOVA analysis of alpha/beta ratio for baseline and different lavender fragrance concentrations (1%, 0.1%, 0.01%).*

Concentration	Mean	Comparison	Mean difference	Error	Sig.
1%	9,75	0,1%	-,50946*	,10135	,000
		BASAL	,15994	,10948	,864
		0,01%	-1,32286*	,09254	,000
0,1%	10,26	1%	,50946*	,10135	,000
		BASAL	,66940*	,10948	,000
		0,01%	-,81340*	,09254	,000
0,01%	11,08	1%	1,32286*	,09254	,000
		0,1%	,81340*	,09254	,000
		BASAL	1,48280*	,10138	,000

The alpha/beta wave ratio can provide interesting insights into the processing of different fragrance concentrations. Alpha waves, which occur in the 8-12 Hz range, are generally associated with states of relaxation, attention, and, in some cases, sensory processing. They are more prominent when a person is in a relaxed wakeful state but have also been linked to the processing of sensory information, including visual and olfactory stimuli. As mentioned, alpha waves are related to attenuation and relaxation processes, like the common perception of lavender, which is known for these properties. *Table 3* shows the results for the total alpha waves activated throughout the experiment. The stimulation phase lasted 10 seconds, corresponding to olfactory sensitization, and the monitoring phase (the state after olfaction, without any stimulation, to evaluate the impact of fragrance inhalation on the body) lasted 30 seconds, representing the post-stimulation effect. The 1% concentration showed a marginal effect (p=0.05) on alpha activation compared to the lowest concentration (0.01%). However, when considering the post-olfactory process, it becomes evident that the lower concentration promotes a higher level of relaxation. This is a particularly interesting effect, as it demonstrates that the highly significant difference may indicate that the lower concentration is strongly affecting cognitive or sensory processes. Moreover, it shows that lavender's activation occurs not synchronously with sensitization, but over the course of the nervous system's information processing.

***Table 3**. Comparative ANOVA of alfa waves between the stimulation and monitoring phases, considering the three concentration levels used in the study.*

Category	Control (I)	Comparison (J)	Mean difference (I-J)	Error	Sig.
Stimulation	1%	0,1%	2,89E+08	2,45E+08	0,466
		0,01%	4,69E+08	2,00E+08	0,050
	0,1%	1%	-2,89E+08	2,45E+08	0,466
		0,01%	1,80E+08	2,00E+08	0,640
	0,01%	1%	-4,69E+08	2,00E+08	0,050
		0,1%	-1,80E+08	2,00E+08	0,640
Monitoring	1%	0,1%	9,42E+07	8,68E+07	0,523
		0,01%	-2,79E+08	8,68E+07	0,004
	0,1%	1%	-9,42E+07	8,68E+07	0,523
		0,01%	-3,73E+08	8,68E+07	0,000
	0,01%	1%	2,79E+08	8,68E+07	0,004
		0,1%	3,73E+08	8,68E+07	0,000

This latter result demonstrates an inverse relationship between concentration level and the expected fragrance effect. Lavender proves to be more relaxing at the lowest concentration. Higher concentrations increased beta levels, which may be associated

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with increased attention and perception of the fragrance but could also be linked to higher stress levels. Despite being a fragrance empirically perceived as relaxing, the lowest concentration showed the greatest deviation from the overall mean in the alpha/beta ratio, indicating the highest relaxation. This is corroborated by the fact that the lowest concentration had the highest alpha activity, generally associated with relaxation and focused attention. The 0.01% concentration not only reduced stress but also showed a lasting effect, suggesting that the effects of the fragrance are not immediate and may be more subtle and prolonged than initially perceived. The data suggest that the perception scale did not fully capture the emotional and cognitive impact of the different concentrations, especially considering that the scale was completed after the monitoring period.

Conclusion

The conclusive findings of this study reveal a remarkable inverse relationship between the concentration of lavender fragrance and its psychophysiological impact. Surprisingly, the lowest concentration of 0.01% was most effective in maximizing relaxation, as evidenced by the greatest deviation from the overall mean in the alpha/beta ratio. This effect was sustained over time and corroborated by the predominance of alpha brainwave activity, which is traditionally associated with states of relaxation and focused attention. In contrast, higher concentrations of the fragrance induced an increase in beta frequency, which can be interpreted as both heightened attention and perception as well as elevated stress levels. This latter point is particularly intriguing, considering that lavender is commonly associated with relaxation. It is crucial to note that these complex neurophysiological dynamics were not entirely captured in the self-reported portion of the study, namely, the questionnaire completed by participants after the monitoring period. This suggests that conventional perception metrics may not be sufficiently sensitive to fully capture the emotional and cognitive impact of different fragrance concentrations. Thus, this study not only sheds light on the intricate interaction between fragrance concentration and sensory experience but also underscores the need for more comprehensive evaluation methods in consumer neuroscience. The study presents several limitations that should be considered when interpreting the results. Firstly, the sample consisted solely of healthy, non-smoking individuals without a recent history of COVID-19, which may limit the generalizability of the findings to a more diverse population. Additionally, the research focused exclusively on lavender fragrance, which restricts the applicability of the findings to other types of aromas. The use of questionnaires to assess sensory and emotional perception may also not have fully captured the impact of different fragrance concentrations, especially given that the scale was completed after the EEG monitoring period. These limitations highlight the need for future, more comprehensive studies and complementary evaluation methods.

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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