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Development and Efficacy Evaluation of a Natural Fragrance Base with Emotional Relieving Properties

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1. Introduction

With the rapid development of modern society, individuals face an increasing amount of stress in their daily lives, especially due to challenges arising from social interactions, the accelerated pace of life, and economic uncertainty. These factors often lead to emotional distress and have a significant impact on mental health [1]. Therefore, exploring effective emotional regulation methods has become one of the hot topics in psychology and related fields. Among various ways to regulate emotions, olfactory-based aromatherapy has attracted attention due to its natural, safe, and widely applicable potential [2].

Flavor and fragrance, commonly found in food, cosmetics, and everyday products, are frequently encountered by individuals. Olfactory signals enter the olfactory pathway through the nasal mucosa, with olfactory neurons transmitting the signals to the olfactory bulb. The output from the olfactory bulb is directly projected via axons to the hippocampus, amygdala, and other brain regions associated with emotions. Through these pathways, aroma can potentially have positive effects on emotions, such as alleviating anxiety, enhancing feelings of pleasantness, and improving sleep quality [3]. Moreover, compared to pharmacological interventions, the regulatory effects of aroma are milder, with a lower risk of side effects and dependence [4].

Many essential oils have already been proven to have emotional relieving effects and are used in aromatherapy for inhalation or massage relaxation. However, the effectiveness of essential oils depends on their concentration, with increased relaxation characteristics observed for lavender oil as the concentration rises, while the relaxing effect of lemon oil does not increase with higher concentrations [5]. Additionally, single essential oil has relatively simple aroma profile, which encourages consumers to exhibit highly personalized and unique preferences [6]. Therefore, it is possible to develop an aromatic product that not only has relieving effects but also enjoys broader acceptability, better catering to the aroma preferences of different consumers.

To enhance the richness, relieving effects, and acceptability of fragrance products, this study used eight essential oils selected from the Chinese Functional Aromatic Plant Database

(AromaHub, http://aroma-hub.org.cn/) to create a functional fragrance base. Sensory evaluation of the eight essential oils and the functional fragrance base revealed that the fragrance base offers superior richness and harmony in its aroma, delivering greater pleasantness and more effective emotional relief. Subsequently, electroencephalogram (EEG) and functional near-infrared spectroscopy (fNIRS) techniques were used to further verify the relieving effects of the functional fragrance base.

2. Materials and Methods

2.1. Materials

Table 1 presents the natural aromatic materials and their effects used in this study.

Table 1. Introduction to the natural aromatic materials used in the formulation and their effects.

Materials	Funtional Introduction	Ref
Jinshan rose oil	The aroma triggered a significant decrease in the concentration of oxygenated hemoglobin in the right prefrontal cortex, along with an increase in feelings of "comfort," "relaxation," and "naturalness."	[7]
Osmanthus absolute	Osmanthus aroma improves physiological changes caused by chronic stress by regulating dietary intake, restoring tissue weight, and adjusting hormone and cholesterol levels.	[8]
Lavender oil	Lavender oil significantly lowered blood pressure, heart rate, and skin temperature, indicating a reduction in autonomic nervous system activity.	[9]
Rosemary oil	Inhalation of rosemary oil led to a significant increase in the relative α power spectrum of the brain, indicating a state of relaxation and rest.	[10]
Roman chamomile oil	Inhalation of Roman chamomile or its main component, α-pinene, alleviated depressive-like behavior in rats.	[11]
Geranium oil	Under the stimulation of geranium oil, there was an increase in relative low β power and a significant decrease in systolic blood pressure, suggesting a reduction in stress.	[10]
Lemon oil	Limonene, citral, and terpenes inhibit the elevation of serum corticosterone levels and brain monoamine levels.	[12]
Peppermint oil	The olfactory stimulation of peppermint oil has a stabilizing effect on the prefrontal cortex and brain activity, and it lowers systolic blood pressure.	[10]

2.2. Sensory Evaluation

A sensory evaluation panel consisting of 30 participants was organized to assess eight aromatic materials and the functional fragrance base. The participants were asked to rate the samples based on five criteria: "coordination," "richness," "pleasantness," "preference," and "relief," with scores ranging from 0 to 10. Radar charts were used to visually analyze the collected sensory data.

2.3. Participant Recruitment for Neuroinformatics Tests

A total of 100 participants were recruited for EEG and fNIRS testing in this study. The average age of the participants was 27.01 years, with a standard deviation of 3.56 years. Among them, 34 participants were aged 20-25 years, 45 participants were aged 26-30 years, and 21 participants were aged 31-35 years. The youngest participant was 22 years old, and the oldest was 35 years old, with an age range of 14 years. All participants were right-handed, free of respiratory, neurological, or olfactory disorders, and had no history of drug abuse. The study strictly adhered to all relevant ethical standards and received ethical approval from the Ethics Committee of the Shanghai Institute of Technology (Approval Number: SIT-2024-LL26).

2.4. Short Form of Profile of Mood States (POMS) Scale

The POMS scale is primarily used to assess current or recent emotional states, making it suitable for tests with short time intervals. In this study, the short form of the POMS scale, published by Grove et al., was used [13]. This simplified version consists of 40 emotional terms, evaluating seven different states: tension, anger, depression, fatigue, confusion, vigor, and esteem. Each emotional term is rated on a 5-point scale, ranging from "not at all" to "very noticeable," corresponding to scores of 1 to 5. Among these, tension, anger, depression, fatigue, and confusion are considered negative factors, while vigor and esteem are considered positive factors.

2.5. Experimental Procedure

The testing was conducted in a well-ventilated laboratory. Prior to the test, all participants were thoroughly informed about the experimental procedure, and their participation was ensured to be voluntary. Each participant was required to make two visits: one for EEG and another for fNIRS signal collection. During the experiment, participants were asked to sit in a comfortable position on an ergonomically designed chair. Before the formal signal collection began, participants were required to complete the short form of the POMS scale [13]. After completing the questionnaire, the EEG or fNIRS signal collection commenced, with the test consisting of a 30-second rest period and a 60-second aroma exposure period. The scent was delivered to the participant's face at a distance of approximately 5 to 7 cm using a gas pump device with a flow rate of 5 L/min (Figure 1). Participants were asked to press the green button on the SAGA synchronization module at the moment they detected the aroma, recording the event as the signal to start the aroma exposure period. After the signal collection, participants were required to complete the short form of the POMS scale again.

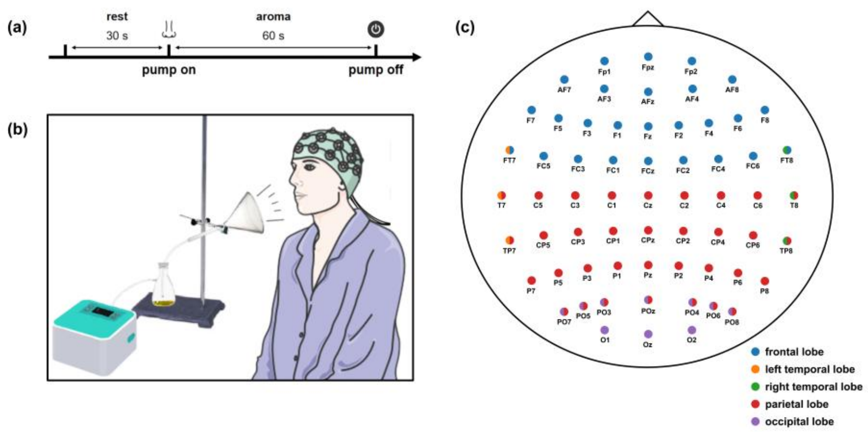

Figure 1. (a) Schematic diagram of the experimental procedure; (b) The spatial distribution and partitioning of the EEG scalp electrodes

2.6. EEG Settings

EEG data were collected using the TMSI SAGA EEG device (Twente Medical Systems International BV, the Netherlands). A 64-channel EEG cap, arranged according to the international 10-20 system as shown in Figure 1 (c), was used to record EEG signals at a sampling rate of 500 Hz. The impedance of all EEG electrodes was maintained below 5 kΩ.

2.7. fNIRS Settings

The Artinis OxyMon near-infrared spectroscopy device was installed on the participant's head, with 16 optical sensor heads (8 light emitters and 8 receivers) covering the frontal cortex (the distance between the optical sensors was 30 mm). A total of 20 channels were used, and the central optical sensor group was placed approximately at FPz according to the 10/20 international system. Optical signal data from the brain were monitored in real-time at a sampling rate of 10 Hz.

2.8. EEG Data Analysis

EEG data were preprocessed and feature-extracted using MATLAB and the EEGLAB toolbox [14]. The re-referencing was done using the average reference, and the filter bandwidth was set to 0.1-70 Hz. To avoid power line interference, a 50 Hz notch filter was applied. After a window preview, independent component analysis was used to remove ocular artifacts.

The extraction of spectral features followed the method of Gil Ávila et al. , using the multitaper fast fourier transform to calculate the power spectral density (PSD) of the EEG signals [15]. The area under the curve (AUC) of the PSD in different frequency bands—δ (1-4 Hz), θ (4-8 Hz), α (8-13 Hz), β (13-30 Hz), and γ (30-70 Hz)—was calculated for different brain regions during the rest and aroma exposure phases. The spatial distribution and partitioning of the EEG scalp electrodes are shown in Figure 1 (c). After removing outliers using boxplots in IBM SPSS Statistics 27, an independent samples t-test was conducted on the average AUC of different brain regions and the AUC of different frequency bands in the frontal lobe.

Furthermore, to further identify and locate the sources of EEG signals during aroma perception, the LORETA software was used to estimate the distribution of the brain's electrical signal sources [16].

2.9. fNIRS Data Analysis

fNIRS data were preprocessed and feature-extracted using MATLAB, along with the NIRS-SPM and Homer2 toolboxes [17]. The preprocessing steps included signal amplification and filtering, motion artifact correction, conversion of optical density changes, and baseline correction. Subsequently, statistical analysis of the changes in the mean concentration of oxygenated hemoglobin under rest and aroma exposure conditions was performed using an independent samples t-test in IBM SPSS Statistics 27.

3. Results

3.1. Sensory Evaluation Result

Figure 2 shows radar charts of the sensory evaluation for the nine samples. The functional fragrance base outperformed the eight essential oils in terms of coordination, richness, pleasantness, and relieving effects, with only a slightly lower preference rating compared to lemon oil.

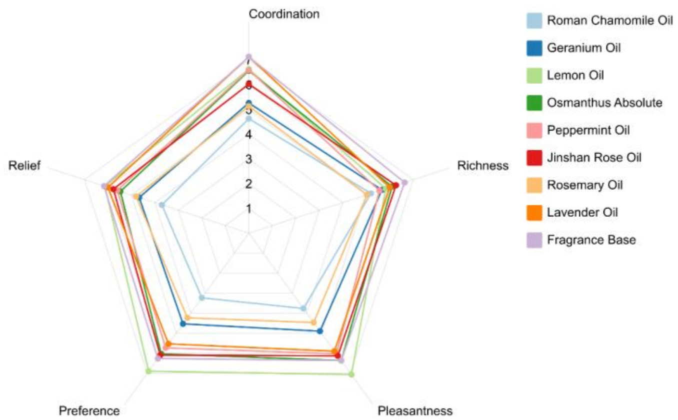

Figure 2. Sensory evaluation results for eight aromatic materials and the functional fragrance base.

3.2. Short Form POMS Scale Result

Figure 3 presents the average scores for the seven dimensions of the short form POMS scale. Compared to the rest state, the aroma condition significantly reduced levels of tension, fatigue, and confusion, while significantly enhancing vigor ($p<0.05$). However, no significant changes were observed in the dimensions of anger, depression, and esteem.

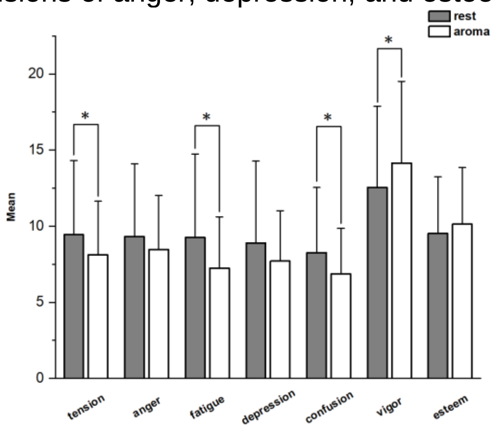

Figure 3. Short form POMS scale result under rest and aroma condition.

3.3. EEG Results

3.3.1. Region Differences in PSD

In the aroma condition, the PSD of the frontal lobe was significantly higher than in the rest condition ($p<0.05$), while no significant differences were observed in other brain regions (left temporal, right temporal, parietal and occipital lobe) between the two conditions (Figure 4, a).

3.3.2 Band differences in the Frontal PSD

The results (Figure 4, b) showed that, in the aroma condition, the AUC of the θ wave was significantly higher than in the rest condition ($p<0.05$), while no significant differences were observed in other frequency bands (δ, α, β, γ).

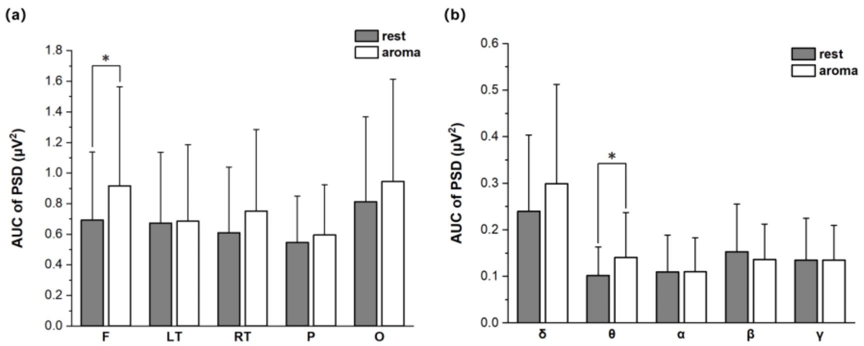

Figure 4. The mean AUC of the PSD in different brain regions (a) and in different frequency bands within the frontal lobe (b) under both rest and aroma exposure conditions (*, p<0.05).

3.3.3 EEG Source Localization

An independent samples t-test revealed significant differences in the signal source distribution between the aroma and rest conditions during the 0-0.4 second period (p<0.05). A total of 34 voxels exhibited significant differences between the two conditions, with these voxels primarily concentrated in the anterior cingulate gyrus of the limbic lobe, the subcallosal gyrus of the frontal lobe, the medial frontal gyrus, and the straight gyrus (Figure 5).

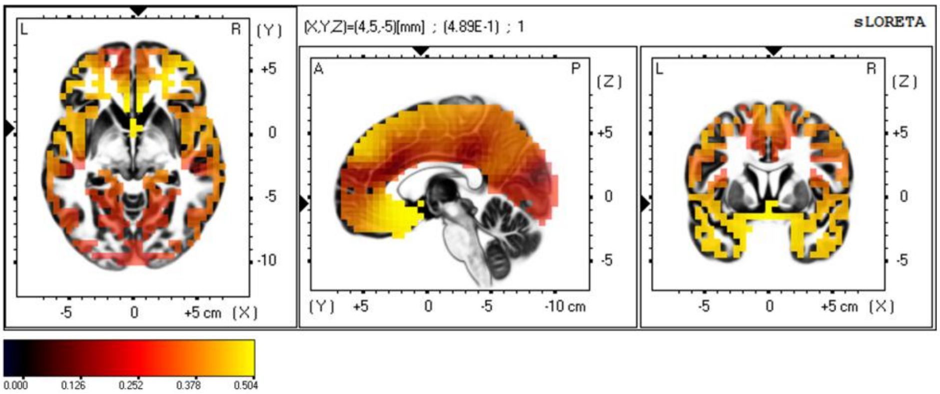

Figure 5. Differences in source localization activation in the aroma condition compared to the rest condition.

3.4. fNIRS Results

In the aroma condition, the aroma stimulation of functional fragrance base led to a significantly lower concentration of oxyhemoglobin in the right prefrontal cortex compared to the rest condition (p<0.05). No significant difference was observed in the oxyhemoglobin concentration in the left prefrontal cortex (Figure 6).

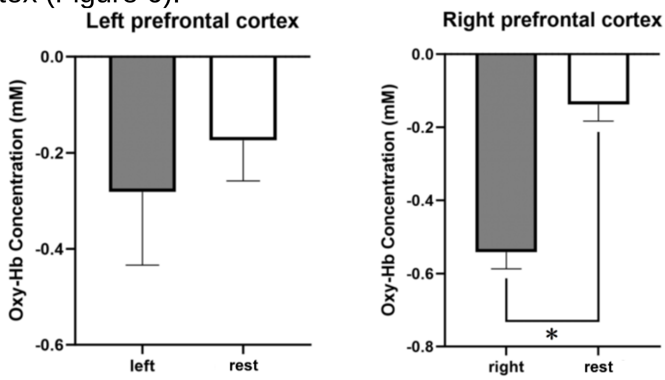

Figure 6. Comparison of mean oxyhemoglobin concentration in the prefrontal cortex under aroma and rest conditions.

4. Discussion

The results of the sensory evaluation indicate that the functional fragrance base complement each other through scientific proportioning, creating a more balanced, multi-layered olfactory experience. The fragrance can effectively alleviate some negative emotions and enhance positive emotions. By quantifying the subjective emotional experience of individuals, the short form POMS results provide a reference standard and validation basis for the subsequent analysis of EEG data, enhancing the interpretability of the data and the accuracy of the validation of emotional efficacy.

Under the aroma stimulation of functional fragrance base, the PSD in the prefrontal cortex significantly increased. The activity of the frontal cortex is closely related to olfactory activity [10, 18]. Furthermore, as the frontal cortex is a brain region closely associated with emotional regulation and cognitive functions, its increased activity may be related to the enhancement of positive emotions or attention during the olfactory process [19]. Considering the critical role of the frontal cortex in emotional regulation, this finding further supports the hypothesis that the fragrance of functional fragrance bases may have a positive regulatory effect on emotional and cognitive functions.

θ waves are typically associated with deep meditation, early stages of sleep, deep introspection, and quiet bodily states, emotional, and cognitive processes. Therefore, the increase in θ wave power in the aroma condition suggests that the fragrance may induce a more relaxed or focused mental state. Research has shown that when participants smell lavender essential oil, the power in the θ band at AF3, T7, and T8 channels significantly increases, specifically reflecting a relaxed state and a reduction in perceived academic stress after experiencing aromatherapy [20]. Similarly, studies by Winai et al. and Lee also found that when participants reported feeling relaxed while smelling fragrances, theta wave power significantly increased in the frontal brain regions [9, 21].

Source localization revealed that the activated brain regions have clear functional associations with emotional changes. The processing of olfactory signals mainly occurs in the orbitofrontal cortex [22], which is activated by pleasant touch, painful touch, taste, smell, and more abstract reinforcers (such as winning or losing money) [23]. Post-traumatic stress disorder is associated with diminished reactivity in the cingulate gyrus and adjacent ventromedial prefrontal cortex [24]. Studies using positron emission tomography to measure brain blood flow changes while listening to music with varying harmony found that, as music became more discordant, activity increased in the right parahippocampal gyrus and precuneus; however, as the music became more harmonious, activity increased in the orbitofrontal cortex, subcallosal cingulate gyrus, and prefrontal cortex [25]. This finding suggests that when positive emotions are perceived, activity in the orbitofrontal cortex and subcallosal cingulate gyrus increases. This result is consistent with the brain source activation observed in this study when smelling the fragrance sample, providing indirect evidence that the functional fragrance base can induce positive emotions in participants. Additionally, meditation induces relaxation, with fMRI studies showing significant signal enhancement in regions such as the dorsolateral prefrontal cortex, parietal cortex, hippocampus, temporal lobe, anterior cingulate cortex, basal ganglia, and both the anterior and posterior central gyri [26]. The changes in source localization signals induced by meditation share similarities with those induced by the fragrance base, which, together with the subjective short form POMS scale results, can further validate the relieving effects of the fragrance base.

Under the aroma stimulation of the fragrance base, the concentration of oxyhemoglobin in the right prefrontal cortex was significantly lower than in the rest condition. When smelling rose and citrus essential oils, the fragrance stimulation significantly reduced the oxyhemoglobin concentration in the right frontal lobe, and participants were in a "comfortable," "relaxed," and "natural" state after smelling the fragrance[7]. Similarly, Miho et al. also found that during aroma exposure, the oxyhemoglobin concentration in the prefrontal cortex significantly decreased [27]. Furthermore, according to Harumi's study, olfactory stimulation caused by pine needle oil significantly reduced the oxyhemoglobin concentration in the right prefrontal cortex and increased parasympathetic nervous system activity, leading to physiological relaxation [28]. Additionally, Sin et al.'s study found that participants who observed plants had a significantly lower oxyhemoglobin concentration in the right prefrontal cortex compared to participants who did not observe plants, indicating that the participants who observed plants were in a state of physiological relaxation [29]. Moreover, in Chie et al.'s research, an increase in oxyhemoglobin levels in the prefrontal cortex was associated with feelings of fatigue, while a decrease in oxyhemoglobin levels on the right side was associated with relaxation and comfort. This suggests that, in certain cases, the reduction in oxyhemoglobin concentration may be linked to enhanced psychological relaxation and pleasure [30]. The experimental results suggest that smelling essential oils may produce specific psychological and physiological effects by influencing brain activity and the autonomic nervous system. The significant decrease in oxyhemoglobin concentration in the right prefrontal cortex may be associated with the activation of the parasympathetic nervous system. Specifically, the decrease in oxyhemoglobin concentration in the right prefrontal cortex may reflect reduced brain activity or a decrease in energy metabolism, which is consistent with the activation of the parasympathetic nervous system. This phenomenon reflects the regulatory effect of essential oils on the autonomic nervous system and brain activity, thereby generating feelings of relaxation and comfort.

To sum up, the integration of sensory evaluation and neuroimaging establishes a robust framework for validating aroma based interventions. The functional fragrance base holds promise for integration into aromatherapy protocols, stress-relief cosmetics, and daily use products targeting mental well-being. Looking ahead, future research should prioritize longitudinal studies to assess sustained emotional benefits and potential habitation effects across diverse populations. Expanding investigations into personalized formulations tailored to individual or cultural preferences. Additionally, exploring multisensory interactions between olfactory stimuli and complementary modalities including auditory or visual relaxation cues may amplify relieving outcomes.

5. Conclusion

This study aimed to develop a natural fragrance base combining eight essential oils with enhanced emotional relieving properties. Sensory evaluation findings demonstrate that the fragrance base outperformed individual essential oils, achieving superior coordination, richness, pleasantness, and emotional relief. The short form POMS scale results showed that exposure to the fragrance significantly reduced tension, fatigue, and confusion while enhancing vigor, providing a subjective assessment of its emotional regulating effects.

EEG analysis revealed that the aroma stimulation significant increases in frontal cortex PSD and elevated θ band activity in the frontal lobe. Source localization further demonstrated that the activated brain regions were closely related to emotional changes, suggesting that the fragrance base could positively regulate emotional and cognitive functions. fNIRS results showed that the aroma stimulation of the functional fragrance base led to a significant decrease in the concentration of oxyhemoglobin in the right prefrontal cortex, which may be associated with the activation of the parasympathetic nervous system, resulting in relaxation and comfort.

In conclusion, this study successfully developed a natural fragrance base with emotional relieving properties. The combination of multiple essential oils in the fragrance base not only provides a more balanced and pleasant olfactory experience but also effectively alleviates negative emotions and promotes positive emotions. These findings suggest that the developed functional fragrance base has the potential to be applied in various fields such as aromatherapy, mental health related products, and stress relieving consumer goods, offering a natural and effective approach for emotional regulation. Further research is needed to explore its long term effects.

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