IFSCC 2025 full paper (IFSCC2025-193)

Relaxation Effects of Natural and Compound Essential Oil Based on Electroencephalography and Electrocardiography

Hye-Ran Cheon [1,2], Byeongbae Jeon [3], Myunghee Choi [3], Miyeon Baek [3] and Han-Jeong Hwang [1,2]*

[1] Department of Electronics and Information Engineering, Korea University, Sejong, Republic of Korea; [2] Interdisciplinary Graduate Program for Artificial Intelligence Smart Convergence Technology, Korea University, Sejong, Republic of Korea; [3] Hanbit Flavor&Fragrance co., Ltd., Suwon, Republic of Korea

1. Introduction

Traditionally, preferences for essential oils have been assessed using self-report questionnaires and subjective rating scales [1–3]. Although these methods facilitate the collection of diverse data from large populations, they lack the capacity to capture real-time responses and are prone to biases such as memory distortion, self-report inaccuracies, and time-related degradation of information. Additionally, the accuracy of such evaluations can be compromised when participants consciously conceal their emotional states or reactions.

To address these limitations, recent studies have increasingly employed neurophysiological measures to assess essential oil preferences [4,5]. These approaches enable the detection of affective responses that may not be consciously recognized by participants and offer more objective and quantifiable data compared to traditional self-report methods.

Electroencephalography (EEG), in particular, is a widely used neuroimaging modality due to its high temporal resolution, relatively low cost, and minimal spatial constraints. EEG has been applied in various olfactory studies to investigate rapid neural responses to essential oil stimuli [6,7].

However, most existing research has focused on responses to individuals, isolated essential oil stimuli, while studies examining EEG responses to compound essential oils—those that combine a primary oil with other components—remain limited. Investigating compound essential oils is critical for understanding how preferred oils interact with others at the neurophysiological level.

Moreover, previous studies have reported that essential oil stimuli can influence not only brain activity but also autonomic and physiological indicators such as skin temperature, electrodermal activity, respiration, and heart rate [8,9].

Accordingly, this study aims to compare EEG and electrocardiogram (ECG) responses to natural essential oils and their corresponding compound blends. This investigation is intended to reveal how natural, and compound essential oils differentially affect neurophysiological response patterns.

2. Materials and Methods

2.1. Olfactory Stimuli

Seven olfactory stimuli were used in this experiment: three natural essential oils, three compound essential oils, and one negative essential oil. The natural essential oils included lavender oil, orange oil, and cedarwood oil. The compound essential oils were formulated to include each of the natural essential oils as the primary aromatic component and were labeled as lavender(C), orange(C), cedarwood(C), respectively, based on the initial letter of the corresponding 'compound'. Valerian root essential oil (hereafter referred to as valerian) was used as the negative control to provide a contrast to the natural and compound essential oils.

2.2. Participants

Twenty-five healthy participants (14 males and 11 females; mean age 22.0 ± 1.9 years) with no history of physical or psychological disorders participated in this experiment. Participants who met any of the following exclusion criteria were excluded from the study:

1) Hypersensitivity to odors or a history
2) Current or long-term use of neuropsychiatric or cardiovascular medications
3) History of major neurological or cognitive impairments, including stroke
4) History of major psychiatric disorders, particularly claustrophobia that may interfere with the use of an enclosed testing booth
5) Presence of substance use disorders such as alcohol dependence (excluding smoking)
6) Alcohol consumption withing 24 hours prior to the experiment
7) Sleep deprivation, defined as less than four hours of sleep the night before the experiment
8) Presence of fever or infectious disease (e.g., COVID-19, influenzas)

This study was approved by the Institutional Review Board (IRB). All participants were fully informed about the purpose and procedures of the study and voluntarily signed a written consent form.

2.3. Experimental Procedure

Before the experiment, each essential oil was prepared by inserting essential oil-treated paper strip into a small bottle. Each bottle was delivered with the lid closed, in accordance with the predetermined order, and participants placed the bottle just below their nose. After a 15-second baseline resting period, participants were instructed to repeat a four-cycle sequence consisting of opening the bottle to inhale the essential oil and then closing it to rest, with each phase lasting 5 seconds to minimize olfactory fatigue. Each participant completed one trial for each of the seven essential oils and were guided to maintain steady breathing throughout the experiment. At the end of each essential oil trial, the door and circulator were turned on to ventilate the enclosed testing booth. During this time, participants completed a 9-point scale questionnaire to assess their level of satisfaction with the presented essential oil.

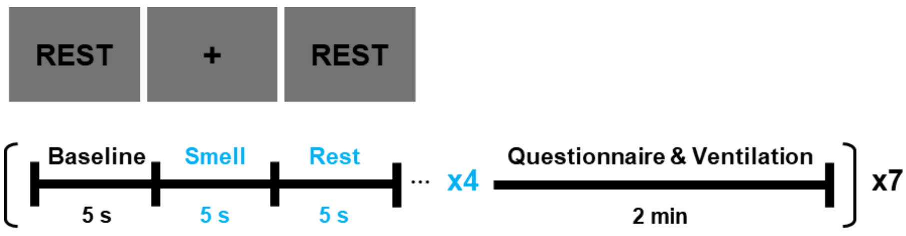

Figure 1. Schema of the experimental paradigm.

To minimize order effects, the natural and compound essential oils were categorized into separate groups, and the order of groups was counterbalanced across participants. Furthermore, the individual essential oils within each group (lavender, orange, cedarwood) were also presented in a randomized order. However, to avoid an excessive number of order combinations, the order of individual essential oils within the natural and compound groups was kept identical (e.g., natural: lavender – orange – cedarwood & compound: lavender(C) – orange(C) – cedarwood(C)). In addition, the negative essential oil, valerian, was consistently presented at the end of the experiment for all participants. This consideration was based on the possibility that exposure immediately following valerian may increase the relative pleasantness and preference, as well as feedback from a preliminary experiment indicating that its scent lingered longer than the other essential oils.

Table 1. All possible combinations of olfactory stimulus orders.

Natural			Compound			Negative
Lavender	Orange	Cedarwood	Lavender(C)	Orange(C)	Cedarwood(C)	Valerian
Lavender	Cedarwood	Orange	Lavender(C)	Cedarwood(C)	Orange(C)	Valerian
Orange	Lavender	Cedarwood	Orange(C)	Lavender(C)	Cedarwood(C)	Valerian
Orange	Cedarwood	Lavender	Orange(C)	Cedarwood(C)	Lavender(C)	Valerian
Cedarwood	Orange	Lavender	Cedarwood(C)	Orange(C)	Lavender(C)	Valerian
Cedarwood	Lavender	Orange	Cedarwood(C)	Lavender(C)	Orange(C)	Valerian
Compound			Natural			Negative
Lavender(C)	Orange(C)	Cedarwood(C)	Lavender	Orange	Cedarwood	Valerian
Lavender(C)	Cedarwood(C)	Orange(C)	Lavender	Cedarwood	Orange	Valerian
Orange(C)	Lavender(C)	Cedarwood(C)	Orange	Lavender	Cedarwood	Valerian
Orange(C)	Cedarwood(C)	Lavender(C)	Orange	Cedarwood	Lavender	Valerian
Cedarwood(C)	Orange(C)	Lavender(C)	Cedarwood	Orange	Lavender	Valerian
Cedarwood(C)	Lavender(C)	Orange(C)	Cedarwood	Lavender	Orange	Valerian

2.4. EEG Data Acquisition and Analysis

EEG data were recorded using thirty-two electrodes placed on the scalp according to the international 10-20 system (Brain products, GmbH Ltd., Gilching, Germany). The reference and ground electrodes were attached to FCz and AFz, respectively (Figure 2(a)). For some participants (Sub 12, Sub 20, Sub 25), significant noise was detected in channels Fp1 or Fp2, and channel interpolation was performed using signals from neighboring electrodes. The raw EEG data were re-referenced using common average reference (CAR), band-pass filtered between 0.5 – 50 Hz, and down-sampled from 1,000 Hz to 200 Hz for computational efficiency. Epochs were extracted from -5 to 40 seconds relative to the stimulus onset. Independent component analysis (ICA) was used to remove physiological artifacts. Epochs with amplitudes exceeding ±75 μV were considered noisy and excluded from analysis

The cleaned EEG data were further divided into 2-second windows with 1-second (50%) overlap, and time–frequency analysis was conducted using the short-time Fourier transform (STFT). Frequency power was computed for the theta (4 – 8 Hz) [10,11], alpha (8 – 12 Hz) [12,13], and beta (12 – 30 Hz) [14–16] bands, with a focus on six frontal channels (Fp1, Fp2, F3, F4, F7, F8) known to be associated with olfactory and relaxation responses [17,18]. Power differences between the baseline and stimulation periods were calculated to evaluate the neural effects of each essential oil.

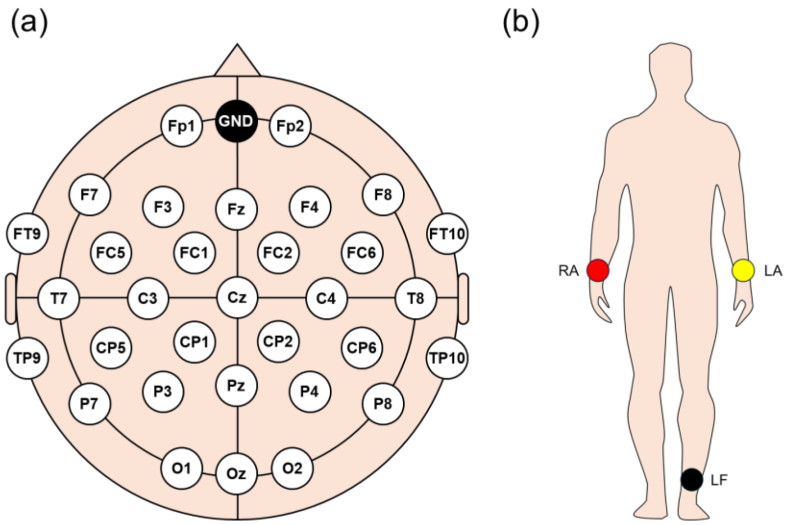

Figure 2. The attachment location of electrodes. (a) EEG: international 10–20 system; (b) ECG: Lead-I configuration

2.5. ECG Data Acquisition and Analysis

ECG signals were recorded using a Lead-I configuration, with electrodes attached to the right wrist (+), left wrist (–), and left ankle (ground). One participant (Sub 17) was excluded due to severe signal noise. The ECG data were down-sampled to 200 Hz and band-pass filtered between 4 – 30 Hz. Epoching was performed from -15 to 40 seconds relative to the olfactory stimulus onset.

R-peaks were detected, and the intervals between R-peaks (R–R intervals) were used to calculate heart rate variability (HRV). Heart rate variability (HRV) reflects the interaction between the sympathetic and parasympathetic branches of the autonomic nervous system [19]. A decrease in HRV indicates reduced temporal variability between heartbeats, which is interpreted as diminished physiological adaptability to changing environments. In contrast, an increase in HRV suggests greater variability in heart rate, indicating enhanced responsiveness and adaptability to external stimuli.

Among various HRV indices, the standard deviation of NN intervals (SDNN) –where NN is equivalent to the R-R interval– was selected for analysis, as it is a widely accepted indicator of autonomic nervous system balance and stress-related responses. SDNN is known to decrease under stress and to increase during states of relaxation [20–22]. Thus, SDNN changes were used to quantify the physiological response to each essential oil stimulus.

3. Results

3.1. Questionnaire Results

Figure 3 shows the mean satisfaction scores for each essential oil condition (natural and compound). Orange essential oil elicited high satisfaction ratings in both the natural and compound conditions. In contrast, Valerian, used as the negative stimulus, resulted in notably low satisfaction ratings. Furthermore, compound essential oils tended to produce higher satisfaction than their natural counterparts. This trend was particularly evident in the case of lavender essential oil, where compound lavender essential oil was rated significantly higher than natural lavender essential oil. Although the compound conditions of orange and cedarwood generally received more favorable scores, no statistically significant differences were found between the natural and compound conditions.

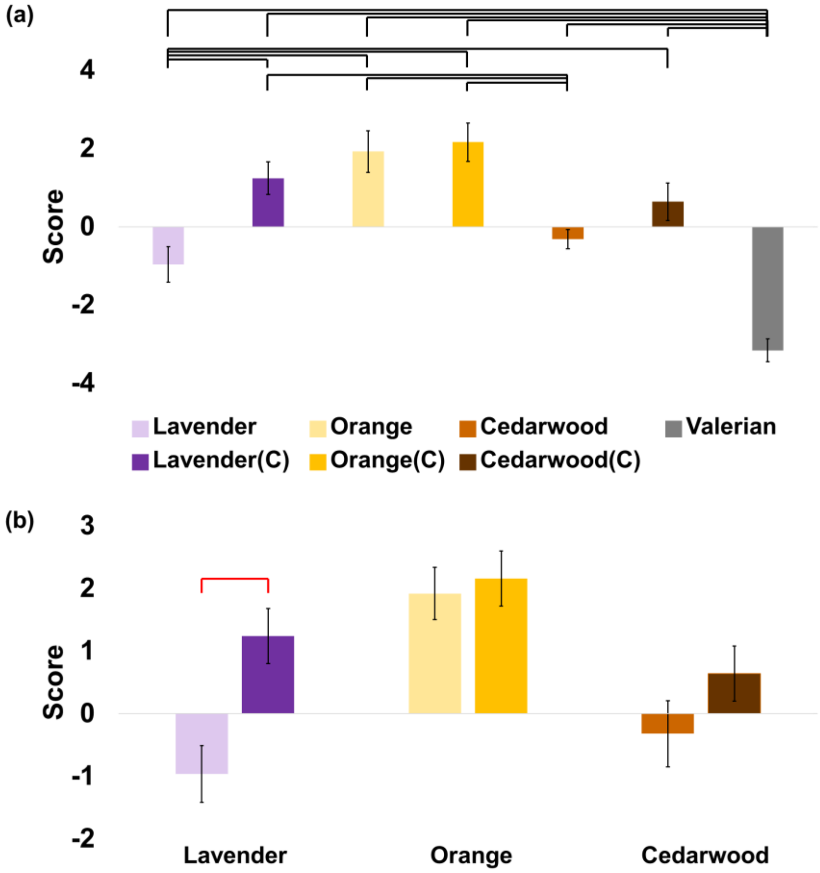

Figure 3. Results of the questionnaire on satisfaction with essential oils: (a) comparison among all essential oils, (b) comparison between natural and compound essential oils. Error bars represent standard errors of the mean. Lines connecting pairs indicate statistically significant differences between essential oils.

3.2. EEG Results

Figure 4(a) shows changes in spectral power between pre-inhalation (BL) and during-inhalation across three frequency bands: theta (4 – 8 Hz), alpha (8 – 12 Hz), and beta (12 – 30 Hz). Increases in theta and alpha power, along with decreases in beta power during the inhalation, were interpreted as indicators of physiological relaxation. In the theta band, significant increases in power were observed for lavender and cedarwood compound essential oils, suggesting that these compound oils elicited relaxation responses. Alpha activity showed a positive effect for natural lavender essential oil, with increased power during inhalation, whereas orange compound essential oil showed a decrease in alpha activity, indicating a divergent pattern. In the beta band, power decreased during inhalation for all three compound oils, reflecting reduced stress or relaxation.

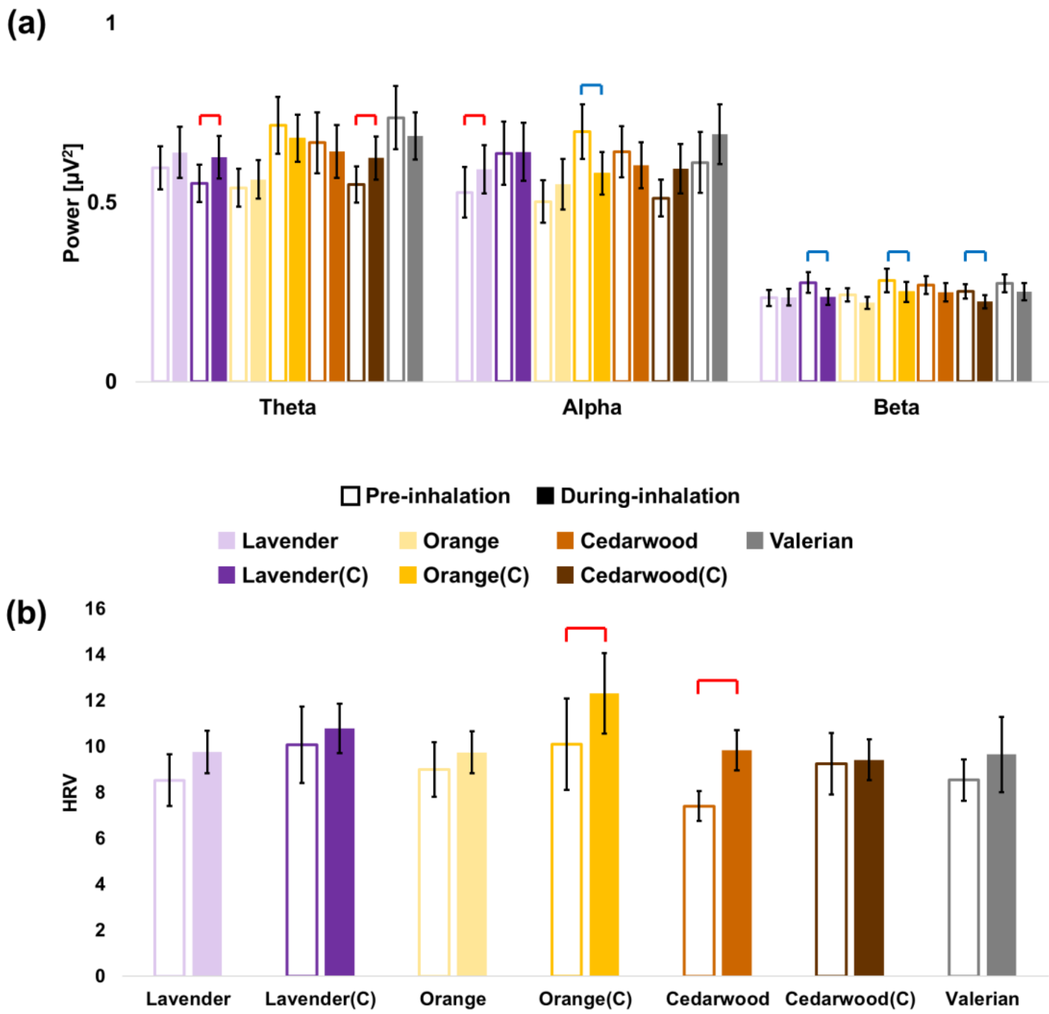

Figure 4. Results of (a) EEG frequency power in the frontal lobe and (b) ECG HRV during pre-inhalation and during-inhalation of essential oils. Error bars represent standard errors of the mean.

3.3. ECG Results

ECG data were used to calculate HRV based on R-peak detection. An increase in HRV during the inhalation compared to pre-inhalation was interpreted as a physiological indicator of relaxation. Statistically significant increases in HRV were observed during inhalation of natural cedarwood and compound orange essential oils, suggesting that these essential oils elicited a relaxation effect (Figure 4(b)).

4. Discussion

This study aimed to investigate the subjective and neurophysiological responses to natural and compound essential oils using self-reported satisfaction measures and neurophysiological measures, EEG and ECG signals. Our findings provide valuable insights into how different essential oil formulations influence emotional and physiological relaxation.

Overall, subjective satisfaction ratings indicated that compound essential oils were preferred over natural essential oils. Compound lavender received significantly higher satisfaction scores compared to its natural counterpart. Orange essential oils, regardless of formulation, consistently received high satisfaction scores, whereas valerian was rated the lowest satisfaction scores.

EEG results revealed that compound essential oils, particularly compound lavender and compound cedarwood essential oils, induced significant increases in theta and alpha power during olfactory stimulation compared to baseline. These frequency bands have been associated with states of relaxation, suggesting that compound essential oils may enhance these effects more effectively than their natural counterparts. Additionally, the reduction in beta power observed for all compound oils further supports the notion of decreased stress and relaxation. EEG findings indicate a strong correspondence with subjective evaluations, reflecting the cognitive and emotional processing of olfactory stimuli.

ECG analysis provided complementary insights. Significant increases in SDNN, a standard HRV index associated with parasympathetic activity, were observed for natural cedarwood and compound orange essential oil, suggesting enhanced parasympathetic activity and acute physiological relaxation. Notably, HRV results did not always align with subjective evaluations or EEG patterns, likely due to the unconscious and reflexive nature of autonomic regulation.

Interestingly, the overall pattern observed in both EEG and ECG data suggests that compound essential oils may be more effective than their natural counterparts in eliciting neurophysiological markers of relaxation. By employing both EEG and ECG, this study offered complementary perspectives and enabled a more comprehensive understanding of olfactory-induced responses.

Future research should explore combinations of multiple EEG frequency bands to identify robust biomarkers of relaxation and examine their correlations with subjective evaluations. Furthermore, applying machine learning techniques could enable the development of predictive models that infer psychological states or preferences using only EEG and ECG data, ultimately supporting personalized and adaptive essential oil-based interventions. These findings have potential implications for aromatherapy, product development, and personalized wellness interventions targeting stress and relaxation.

5. Conclusion

This study provides a framework for evaluating the effects of natural and compound essential oils by integrating subjective assessments with neurophysiological measures. By employing both EEG and ECG, the research highlights the complementary nature of central and autonomic nervous system responses to olfactory stimulation. The findings underscore the potential of compound essential oils in modulating emotional and physiological states, and suggests that such effects may vary depending on the formulation of the essential oil.

These insights lay the groundwork for future applications in personalized aromatherapy and wellness interventions. Further research incorporating advanced analytical approaches, such as biomarker identification and machine learning, may deepen our understanding of essential oil-induced responses and support the development of adaptive essential oil -based technologies.

References

[1] Consumer Survey Insights: Fragrance Preferences. In-Cosmetics Connect 2021. https://connect.in-cosmetics.com/trends-en/marketing/consumer-survey-insights-fragrance-preferences/ (accessed April 28, 2025).

[2] Sorokowska A, Chabin D, Hummel T, Karwowski M. Olfactory Perception Relates to Food Neophobia in Adolescence. Nutrition 2022;98:111618. https://doi.org/10.1016/j.nut.2022.111618.

[3] Farahani M, Razavi-Termeh SV, Sadeghi-Niaraki A, Choi S-M. People's Olfactory Perception Potential Mapping Using a Machine Learning Algorithm: A Spatio-Temporal Approach. Sust Cities Soc 2023;93:104472. https://doi.org/10.1016/j.scs.2023.104472.

[4] Doi S, Kamesawa K, Wada T, Kobayashi E, Karaki M, Mori N. Basic Study on Individual Preference for Scents and the Arousal Level for Brain Activity Using Mnirs. IEEE/ICME International Conference on Complex Medical Engineering, 2010, p. 119–24. https://doi.org/10.1109/ICCME.2010.5558859.

[5] Pichon AM, Coppin G, Cayeux I, Porcherot C, Sander D, Delplanque S. Sensitivity of Physiological Emotional Measures to Odors Depends on the Product and the Pleasantness Ranges Used. Front Psychol 2015;6. https://doi.org/10.3389/fpsyg.2015.01821.

[6] Park KH, Kim HJ, Oh B, Seo M, Lee E, Ha J. Evaluation of Human Electroencephalogram Change for Sensory Effects of Fragrance. Skin Res Technol 2019;25:526–31. https://doi.org/10.1111/srt.12682.

[7] Sowndhararajan K, Kim S. Influence of Fragrances on Human Psychophysiological Activity: With Special Reference to Human Electroencephalographic Response. Sci Pharm 2016;84:724–51. https://doi.org/10.3390/scipharm84040724.

[8] Ohira H, Hirao N. Analysis of Skin Conductance Response During Evaluation of Preferences for Cosmetic Products. Front Psychol 2015;6. https://doi.org/10.3389/fpsyg.2015.00103.

[9] Sarid O, Zaccai M. Changes in Mood States Are Induced by Smelling Familiar and Exotic Fragrances. Front Psychol 2016;7. https://doi.org/10.3389/fpsyg.2016.01724.

[10] Jacobs GD, Friedman R. EEG Spectral Analysis of Relaxation Techniques. Appl Psychophysiol Biofeedback 2004;29:245–54. https://doi.org/10.1007/s10484-004-0385-2.

[11] Wen TY, Aris SAM. Electroencephalogram (EEG) Stress Analysis on Alpha/Beta Ratio and Theta/Beta Ratio. Indones J Electr Eng Comput Sci 2020;17:175–82. https://doi.org/10.11591/ijeecs.v17.i1.pp175-182.

[12] Sharma A, Singh M. Assessing Alpha Activity in Attention and Relaxed State: An EEG Analysis. 2015 1st International Conference on Next Generation Computing Technologies (NGCT), 2015, p. 508–13. https://doi.org/10.1109/NGCT.2015.7375171.

[13] Al-Shargie F, Kiguchi M, Badruddin N, Dass SC, Hani AFM, Tang TB. Mental stress assessment using simultaneous measurement of EEG and fNIRS. Biomed Opt Express 2016;7:3882–98. https://doi.org/10.1364/BOE.7.003882.

[14] Kim S, Park H, Choo S. Effects of Changes to Architectural Elements on Human Relaxation-Arousal Responses: Based on VR and EEG. Int J Environ Res Public Health 2021;18:4305. https://doi.org/10.3390/ijerph18084305.
[15] Jacobs GD, Benson H, Friedman R. Topographic EEG Mapping of the Relaxation Response. Biofeedback and Self-Regulation 1996;21:121–9. https://doi.org/10.1007/BF02284691.
[16] TuerxunWaili, Sa'ad Alshebly Y, Azami Sidek K, Md Johar MG. Stress Recognition Using Electroencephalogram (EEG) Signal. J Phys: Conf Ser 2020;1502:012052. https://doi.org/10.1088/1742-6596/1502/1/012052.
[17] Sowndhararajan K, Cho H, Yu B, Kim S. Effect of Olfactory Stimulation of Isomeric Aroma Compounds, (+)-Limonene and Terpinolene on Human Electroencephalographic Activity. Eur J Integr Med 2015;7:561–6. https://doi.org/10.1016/j.eujim.2015.08.006.
[18] Wu Y-T, Lee A-Y, Choi N-Y, Park S-A. Psychophysiological Responses of Cut Flower Fragrances as an Olfactory Stimulation by Measurement of Electroencephalogram in Adults. Int J Environ Res Public Health 2022;19:11639. https://doi.org/10.3390/ijerph191811639.
[19] Shaffer F, McCraty R, Zerr CL. A Healthy Heart Is Not a Metronome: An Integrative Review of the Heart's Anatomy and Heart Rate Variability. Front Psychol 2014;5. https://doi.org/10.3389/fpsyg.2014.01040.
[20] Punita P, Saranya K, Kumar SS. Gender Difference in Heart Rate Variability in Medical Students and Association with the Level of Stress. Natl J Physiol Pharm Pharmacol 1970;6:431–431. https://doi.org/10.5455/njppp.2016.6.0102325042016.
[21] Evaluation of Cardiac Responses to Stress in Healthy Individuals a Non Invasive Evaluation by Heart Rate Variability and Stroop Test n.d.
[22] E-Fatema M, Begum N, Ferdousi S. Effect of Deep Relaxation on Heart Rate Variability in Sedentary Females. J Bangladesh Soc Physiol 2013;8:65–9. https://doi.org/10.3329/jbsp.v8i2.18656.