CHAPTER 5
CONCLUSION

5.1 Conclusion

This study explored the neurophysiological and cognitive effects of commercial fragrances on EEG patterns and working memory performance in healthy male participants. Using EEG power density analysis with the statistical analysis of paired t-test, it was observed that Fragrance B (spice–woody profile) produced a statistically significant increase in alpha power across ROI with a p-value of 0.008 (< 0.05) but did not show any significant results on theta power, suggesting a calming effect with alpha act as an indicator. Fragrance A also showed a statistically significant increase in alpha power with a p-value of 0.033 (< 0.05), suggesting a mild calming effect, although no significant results were observed on theta power. Fragrance C did not show any significant results in alpha and theta power, indicating no meaningful calming effect. The placebo condition did not show statistically significant EEG changes. These findings suggest that alpha power may serve as a useful indicator of calmness in response to fragrance exposure, although further comparative and larger-scale analyses are needed to clarify differences across fragrance types.

Moreover, fragrance compositions were analysed using Gas Chromatography-Mass Spectrometry (GC-MS), allowing identification of the dominant volatile constituents. Notably, Ethylene Brassylate and Lilial were major contributors in Fragrance A (fruityfloral), while Cedrol, Piperonal, and Thujopsene were prominent in Fragrance B. Fragrance C featured compounds such as Octanal, Cyclopentaneacetic acid derivatives, and 1R-α-Pinene, contributing to its fresh and herbal characteristics. These dominant compounds, identified through Agilent Mass Hunter software, are known in the literature for their calming or cognition-related olfactory properties. Compound profiles suggest potential neuroactive effects based on fragrance composition, though interpretations were made based on compound properties rather than statistical correlations.

Working memory was assessed using the CogniFit digital platform, which measured non-verbal and visual short-term memory through accuracy and reaction time. For Fragrance B, a statistically significant improvement in memory accuracy was observed (mean score increase from 94.67% to 97.33%, $p = 0.021$). Participants exposed to Fragrance C demonstrated a statistically significant reduction in reaction time (from 0.713s to 0.617s, $p = 0.013$). Fragrance A showed no meaningful changes in either the accuracy score or reaction time based on non-statistically significant results ($p > 0.05$), and the placebo group also did not show significant improvement in either metric. These findings indicate that certain fragrance exposures were associated with specific cognitive changes within their respective groups, although further comparative analyses would be required to establish differences across fragrance types.

Altogether, this research contributes to the growing field of olfactory neuroscience, demonstrating that selected fragrances can modulate brain oscillations linked to calmness and cognitive enhancement. The use of EEG and GC-MS enabled a multi-dimensional approach, bridging neurophysiological data with chemical analysis. These findings support the potential of fragrance-based interventions for promoting mental clarity, emotional regulation, and performance enhancement in environments requiring calm and focus. The findings can also support the perfumery industry by offering scientific evidence in the production of fragrance personalized to consumer interest in promoting relaxation.

5.2 Integration and Implications

The findings of this research suggest that fragrance exposure, particularly to spice-woody and musky-floral profiles, can modulate brain oscillatory patterns associated with calmness and selectively enhance cognitive functions such as working memory performance. These results indicate that olfactory interventions may have practical applications in stress management, learning, and therapeutic environments, especially when tailored to individual or potentially gender-specific preferences.

Furthermore, the combined use of EEG and GC-MS techniques provides a novel and integrative approach to understanding the neurochemical mechanisms underlying scent-induced psychological and cognitive effects. The inclusion of only male participants ensured hormonal consistency and reduced variability associated with menstrual cycle fluctuations, thereby strengthening internal validity within a homogeneous sample, although this also limits generalizability.

5.3 Limitations

While the present study successfully demonstrated EEG and cognitive effects of fragrance exposure, several limitations must be acknowledged. First, the study was limited by a small sample size and the inclusion of only male participants, which restricts statistical power and limits the generalizability of the findings to broader populations. The small sample size reduces the ability to detect subtle cognitive and neurophysiological effects of fragrance exposure, particularly for working memory performance. Additionally, the exclusion of female participants prevents examination of potential sex-related differences in olfactory processing and cognitive response.

Second, the EEG analysis was constrained by the limited number of electrodes available in the 8-channel system, which restricted full coverage of brain regions critical for higher executive functions and working memory, particularly the prefrontal cortex and temporal lobe. Although a region-of-interest approach was applied, the absence of electrodes over key cortical areas, together with the exclusion of beta band analysis, which is also important in the regulation of calmness and cognitive processing, may have limited the ability to capture neural activity associated with executive control, memory encoding, and retrieval processes.

Third, the statistical approach relied primarily on paired t-tests, whereas a stronger analytical framework, such as repeated-measures ANOVA, could have provided more robust comparisons across multiple conditions and outcomes. The use of simpler statistical methods was influenced by sample size constraints but may have limited the depth of inference regarding interaction effects and condition-specific differences.

Lastly, the reliance on subjective preferences and emotional associations with fragrance, which were not measured via questionnaires or self-reports, may have influenced the individual response to each scent, but these factors were not formally included in the analysis.

5.4 Suggestions for Future Research

Further research should take into consideration expanding the participant pool to include a more diverse population, particularly across genders and age groups. Given that olfactory sensitivity and preferences differ by sex hormones and cultural background, future studies should assess how these factors influence EEG and memory responses to fragrance. Incorporating a wider range of fragrance types, including herbal, aquatic, gourmand, or synthetic scents, could deepen our understanding of olfactory neural modulation. Including subjective measures of pleasantness, familiarity, and perceived intensity of fragrances would also provide valuable complementary data for interpreting EEG and cognitive effects.

In addition, future research should employ EEG systems with a greater number of electrodes to achieve more comprehensive brain coverage, particularly over regions associated with higher executive functions and working memory, such as the prefrontal cortex and temporal lobe. This would allow for more precise localization of neural activity and facilitate stronger conclusions regarding the neural mechanisms underlying fragrance-related cognitive modulation. Moreover, inclusion of beta band analysis is recommended, as beta oscillations are closely associated with attentional engagement, cognitive control, and emotional regulation, and may provide additional insights into the neural mechanisms underlying both calmness modulation and working memory performance following fragrance exposure.

Furthermore, future studies should adopt stronger statistical approaches, such as repeated-measures ANOVA or mixed-effects models, to enable simultaneous comparison across multiple fragrance conditions, outcome measures, and interaction effects. Moreover, future research should also calculate and report more informative effect sizes (e.g., partial eta-squared) to provide a clearer understanding of the magnitude of changes in memory performance and EEG activity, beyond statistical significance alone.

Finally, additional physiological measures such as heart rate variability, skin conductance, or salivary cortisol could be integrated to provide a more holistic view of relaxation or arousal in response to fragrance. The inclusion of functional neuroimaging, such as fMRI, in future studies could help localize specific brain areas influenced by olfactory compounds. Finally, long-term exposure or repeated trials could examine the potential for olfactory conditioning or the sustained cognitive benefits of aroma-based interventions in real-world settings such as schools, workplaces, or therapy environments.