CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Quantification of EEG Alpha and Theta Power Density Changes

This section presents findings related to the first research objective, which is to quantify the changes in alpha and theta power density of EEG signals before and after fragrance exposure for three fragrance conditions: (Fragrance A – floral/fruity, Fragrance B – spices/wood, Fragrance C – citrus/floral, and Placebo) and a placebo as a control group. Each group consisted of six subjects. All subjects in this study were Malay male subjects; therefore, demographic analysis focused only on age distribution across the four groups (Fragrance A, Fragrance B, Fragrance C, and Placebo). Table 4.1 presents the descriptive statistics of age, including the mean, median, standard deviation, minimum, and maximum values for each group.

The data collection was conducted using the Unicorn Hybrid EEG system, which features 8 channels, with electrodes positioned according to the standard 10–20 system, and noise reduction was applied. For this analysis, four electrodes were selected based on their relevance to calmness and emotional processing: EEG1 (Fz), EEG5 (Pz), EEG6 (PO7), and EEG8 (PO8). These electrode sites represent the frontal, parietal, and occipitoparietal regions, which have been implicated in studies on calmness and attentional modulation. Recordings were taken in two sessions: before and after fragrance exposure, with a resting state condition under both.

Although the study employed a mixed-design framework, with measurement phase (before vs. after fragrance exposure) as the within-subject factor and fragrance type as the between-subject factor, a mixed-design ANOVA was not conducted due to the small sample size ($n = 6$ per group), which could compromise statistical power and increase the risk of violating parametric assumptions. Instead, paired t-tests were used to examine within-group changes in alpha and theta power density across the two measurement phases for each fragrance condition. While this approach limits the ability to test interaction effects between the measurement phase and fragrance type, it was methodologically justified to ensure more robust, reliable, and interpretable results given the study's sample constraints.

Electrode selection was guided by a region-of-interest (ROI) approach, focusing on brain regions most relevant to calmness and cognitive modulation. Specifically, electrodes Fz, Pz, and PO7/PO8 were retained for analysis. In contrast, electrodes C3, Cz, C4, and Oz were excluded, not due to data quality issues, but to reduce multiple comparison bias and improve statistical sensitivity and interpretability. Although this approach may have limited the exploration of activity in other cortical regions, it was methodologically justified to ensure focused and reliable analysis of the neural correlates of fragrance-induced calmness.

Moreover, although beta power data were available, the present study focused on alpha and theta bands because these frequency ranges are more consistently and directly associated with calmness, relaxation, and affective regulation in the literature. Beta activity is more commonly linked to alertness, active cognition, and anxiety-related arousal, and is therefore less specific as an index of calmness. Including beta would have diluted the construct validity of the calmness measure.

Table 4.1: Descriptive Statistics of Participants' Age Across Experimental Groups

Group	N (Subjects)	Mean Age	Median Age	Std Dev	Min	Max
Fragrance A	6	22.50	22.5	1.87	20	25
Fragrance B	6	21.83	22.0	2.04	18	24
Fragrance C	6	21.50	22.0	2.26	18	24
Placebo	6	21.17	21.0	2.64	18	25

4.1.1 EEG Signal Analysis Using FFT In Brain Analyser

EEG signals were analysed using BrainVision Analyser, where Fast Fourier Transform (FFT) was applied to convert the EEG signals from the time domain into the frequency domain. In the time domain, EEG signals are represented as voltage fluctuations over time, whereas frequency-domain analysis represents the signal as a sum of sinusoidal components at different frequencies. FFT is an efficient computational implementation of the Discrete Fourier Transform (DFT), which decomposes a discrete-time signal into its constituent frequency components according to the Fourier series principle. This transformation enables the estimation of the signal's spectral content by computing the power spectral density (PSD), which reflects how signal power is distributed across different frequency bands (Li & Chen, 2021; Saxena *et al*., 2020).

Mathematically, the DFT is defined as:

(1.1)
$$X(k) = \sum_{n=0}^{N-1} x(n)\ e^{-j2\pi kn/N}, k = 0,1,\dots,N-1$$

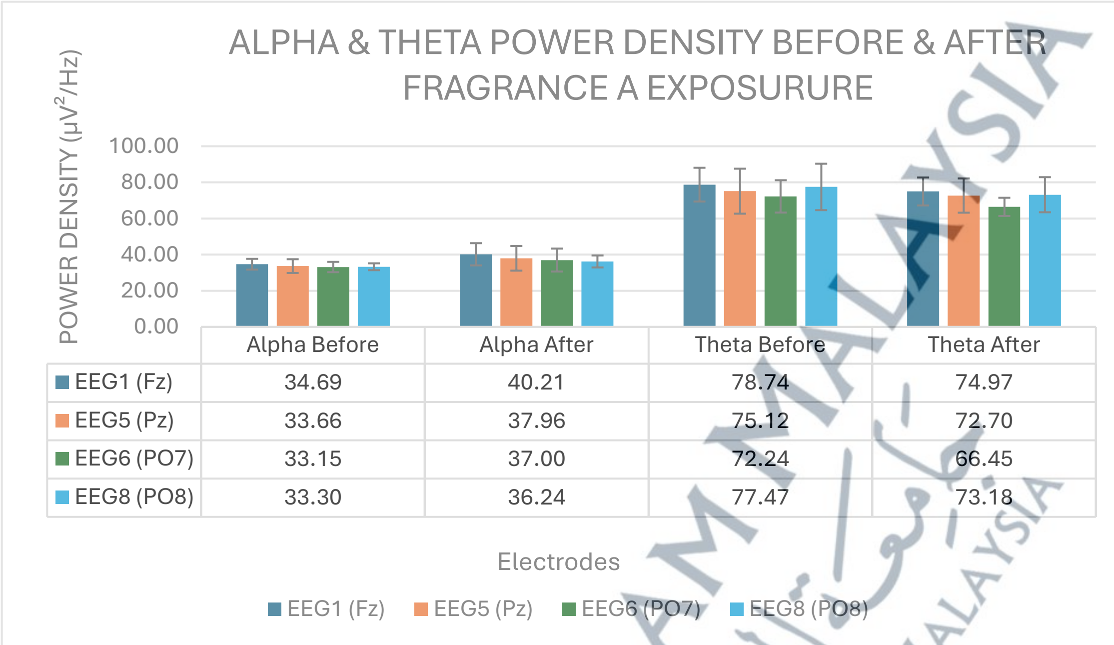
where $x(n)$represents the EEG signal in the time domain, $X(k)$represents the signal in the frequency domain, $N$is the number of samples, and $j$is the imaginary unit. FFT provides a computationally efficient method for calculating this transformation.

Following the FFT transformation, absolute power density values ($\mu V^2/Hz$) were calculated for the alpha (8–12 Hz) and theta (4–7 Hz) bands. The alpha band is commonly associated with relaxed wakefulness and calmness, while the theta band is linked to internal focus and reduced external awareness. By comparing PSD values obtained before and after fragrance exposure, the effectiveness of each fragrance in modulating calmness-related cortical activity was objectively assessed.

4.1.2 Results Visualization of the Power Density Values

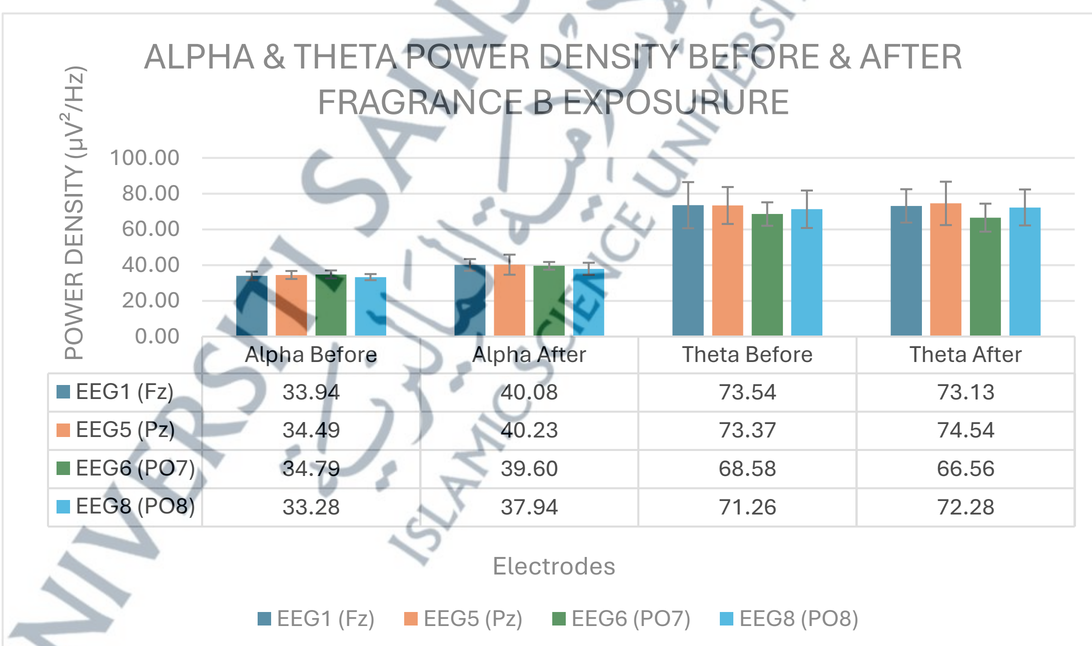
The following bar charts (Figures 4.1 to 4.4) show the average alpha and theta power density values across the four selected electrodes before and after exposure to each fragrance group. These visualizations illustrate how EEG brainwave activity changes in response to various aromatic stimulus. Bars represent the group mean values, and error bars represent the standard deviation (SD) of the mean.

Results reported in this section focus on alpha and theta power changes at the predefined regions of interest. Exploratory analyses of beta activity and other electrodes are provided in Appendix VIII.



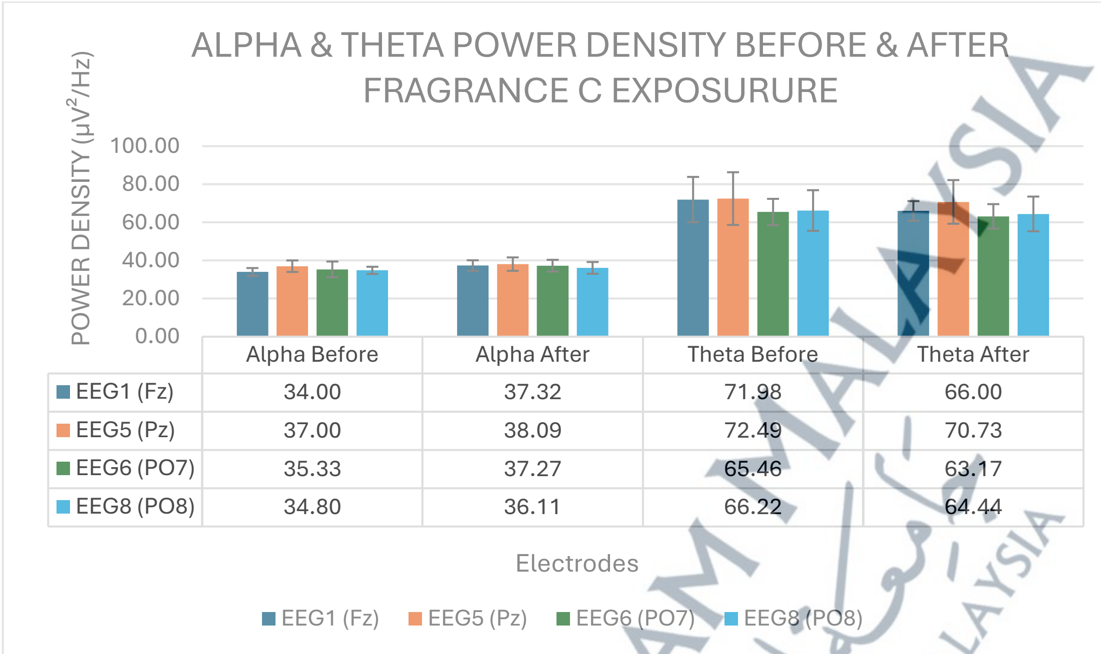
	Alpha Before	Alpha After	Theta Before	Theta After
EEG1 (Fz)	34.69	40.21	78.74	74.97
EEG5 (Pz)	33.66	37.96	75.12	72.70
EEG6 (PO7)	33.15	37.00	72.24	66.45
EEG8 (PO8)	33.30	36.24	77.47	73.18

Figure 4.1: Alpha and Theta Power Density After Exposure to Fragrance A



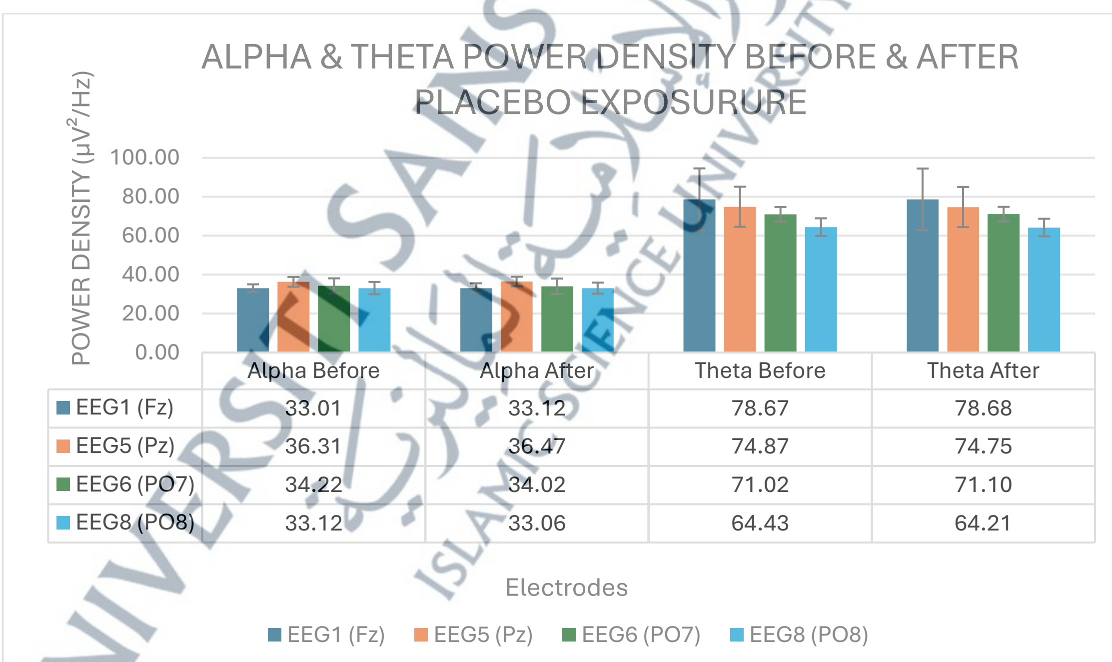
	Alpha Before	Alpha After	Theta Before	Theta After
EEG1 (Fz)	33.94	40.08	73.54	73.13
EEG5 (Pz)	34.49	40.23	73.37	74.54
EEG6 (PO7)	34.79	39.60	68.58	66.56
EEG8 (PO8)	33.28	37.94	71.26	72.28

Figure 4.2: Alpha and Theta Power Density After Exposure to Fragrance B



	Alpha Before	Alpha After	Theta Before	Theta After
EEG1 (Fz)	34.00	37.32	71.98	66.00
EEG5 (Pz)	37.00	38.09	72.49	70.73
EEG6 (PO7)	35.33	37.27	65.46	63.17
EEG8 (PO8)	34.80	36.11	66.22	64.44

Figure 4.3: Alpha and Theta Power Density After Exposure to Fragrance C



	Alpha Before	Alpha After	Theta Before	Theta After
EEG1 (Fz)	33.01	33.12	78.67	78.68
EEG5 (Pz)	36.31	36.47	74.87	74.75
EEG6 (PO7)	34.22	34.02	71.02	71.10
EEG8 (PO8)	33.12	33.06	64.43	64.21

Figure 4.4: Alpha and Theta Power Density After Placebo Exposure

4.1.3 Statistical Significance Testing

Across all fragrance groups, the alpha and theta power density before and after exposure were tabulated. To statistically verify whether the observed changes in alpha and theta power densities before and after fragrance exposure were significant, paired sample t-tests were conducted for each fragrance group (Fragrance A, B, C, and Placebo). This test compares the Means of two related groups (pre- and post-exposure) to determine whether the difference is statistically meaningful (Guo & Yuan, 2017; Ali & Bhaskar, 2016).

The tests were performed for the average values of alpha and theta power across four selected electrodes: Fz (EEG1), Pz (EEG5), PO7 (EEG6), and PO8 (EEG8) for each subject. Results with a p-value of less than 0.05 were considered statistically significant, indicating that the observed EEG changes were unlikely due to random variation and were likely caused by fragrance exposure.

In addition, the t-value was also calculated to show how great the change is relative to the variability in the data, and shows how many standard errors the mean difference was away from zero (no change). The large t-value means strong evidence of a real change, and a small t-value means weak evidence that the change is likely due to random variation (Brydges, 2019; Lee, 2016). In this study, the value was interpreted with the degrees of freedom (df = n -1 = 5) and the corresponding p-value. In the paired t-test, the difference between *before* and *after* was computed:

(1.2) $$d_i = \text{Before}_i - \text{After}_i$$

Then, the mean, standard deviation, standard errors, and t-value were calculated:

1. **Mean of differences**:

(1.3) $$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$$

2. **Standard deviation of differences**:

(1.4) $$s_d = \sqrt{\frac{\sum(d_i - \bar{d})^2}{n-1}}$$

3. **Standard error of the mean difference**:

(1.5) $$SE = \frac{s_d}{\sqrt{n}}$$

4. **t-value**:

(1.6) $$t = \frac{\bar{d}}{SE}$$

Moreover, Cohen's d value was also calculated to show the effect size with this formula:

(1.7) $$d = \frac{\bar{d}}{s_d}$$

Where:

- $\bar{d}$= mean of the paired differences,
- s_d= standard deviation of the paired differences.

Alternatively, from the t-value:

(1.8) $$d = \frac{t}{\sqrt{n}}$$

Where:

- d ≈ 0.2 → small effect
- d ≈ 0.5 → medium/moderate effect
- d ≥ 0.8 → large effect
- d ≈ 0.0 → negligible effect

4.1.4 Statistical Results of EEG Alpha and Theta Power Density

4.1.4.1 Fragrance A (Alpha Power)

Table 4.2: Fragrance A Alpha Power Density Across ROI Electrodes

ALPHA BEFORE				ALPHA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
35.321	28.655	30.183	33.744	40.872	30.212	32.49	36.943
36.772	32.841	30.115	34.553	35.121	31.973	29.507	34.014
38.727	37.801	37.8	33.309	48.098	42.741	47.012	37.834
30.276	38.564	33.702	35.793	47.027	48.157	36.872	41.816
34.242	32.574	33.932	31.978	35.923	39.51	41.434	33.276
32.773	31.55	33.181	30.451	34.221	35.174	34.713	33.552

1. Paired t-test (Alpha):

Table 4.3: Fragrance A Electrode-level paired t-test results (Alpha)

Electrode	t-value	p-value	Interpretation
Fz	2.02	0.099	Not significant
Pz	2.81	0.037	Significant
PO7	2.52	0.053	Not significant
PO8	3.10	0.027	Significant

2. Combined ROI approach (average across 4 electrodes per subject)

- t (5) = 2.77
- p = 0.033 → Statistically significant (< 0.05)
- Cohen's d = 1.13, Large effect size

3. Scientific Interpretation:

At the ROI level, a statistically significant increase in alpha power was observed following exposure to Fragrance A (t (5) = −2.77, p = 0.033, Cohen's d = 1.13). At the electrode level, significant increases were found at Pz (p = 0.037) and PO8 (p = 0.027), while Fz (p = 0.099) and PO7 (p = 0.053) showed non-significant trends. Overall, the alpha band demonstrated both statistical significance and a large effect size, indicating a robust and reliable neural response to fragrance exposure. This pattern suggests a relaxation-related neural response predominantly in posterior and parietal regions.

4.1.4.2 Fragrance A (Theta Power)

Table 4.4: Fragrance A Theta Power Density Across ROI Electrodes

THETA BEFORE				THETA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
70.881	64.713	60.373	62.109	65.228	60.884	58.415	59.76
68.941	66.123	63.411	61.896	70.236	67.453	64.89	63.17
83.737	75.16	81.586	85.75	75.507	73.331	71.315	84.502
84.595	68.235	74.169	84.858	86.12	68.463	64.563	74.883
92.033	98.076	81.769	92.39	81.514	88.073	67.464	80.198
72.223	78.422	72.115	77.823	71.221	77.996	72.034	76.552

1. Paired t-test (Theta):

Table 4.5: Fragrance A Electrode-level paired t-test results (Theta)

Electrode	t-value	p-value	Interpretation
Fz	-1.81	0.131	Not significant
Pz	-1.44	0.210	Not significant
PO7	-2.20	0.079	Not significant
PO8	-1.93	0.111	Not significant

2. Combined ROI approach (average across 4 electrodes per subject)

- $t(5) = -2.21$
- $p = 0.079$ → Not statistically significant ($p > 0.05$)
- Cohen's $d = 0.90$, Large effect size

3. Scientific Interpretation:

At the ROI level, theta power did not show a statistically significant change following exposure to Fragrance A ($t(5) = 2.21$, $p = 0.079$, Cohen's $d = 0.90$). At the electrode level, no electrodes demonstrated statistically significant changes (all $p > 0.05$). The change does not meet conventional criteria for statistical significance, suggesting that theta activity was not robustly modulated by the fragrance. Moreover, a large effect size without statistical significance suggests a potentially meaningful effect that may have been underpowered due to the small sample size.

4.1.4.3 Fragrance B (Alpha Power)

Table 4.6: Fragrance B Alpha Power Density Across ROI Electrodes

ALPHA BEFORE				ALPHA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
30.187	36.205	35.944	33.87	38.421	43.354	42.721	40.556
37.511	35.643	34.93	32.762	44.794	41.242	40.814	38.623
35.261	31.711	38.551	33.078	38.261	32.11	37.772	31.212
33.11	35.604	32.422	31.51	41.231	44.58	38.278	39.583
34.321	36.216	33.106	32.133	42.226	45.622	40.771	38.66
33.224	31.552	33.779	36.332	35.553	34.467	37.223	38.992

1. Paired t-test (Alpha)

Table 4.7: Fragrance B Electrode-level paired t-test results (Alpha)

Electrode	t-value	p-value	Interpretation
Fz	5.52	0.002	Significant
Pz	3.98	0.011	Significant
PO7	3.82	0.012	Significant
PO8	3.11	0.027	Significant

2. Combined ROI approach (average across 4 electrodes per subject)

- $t(5) = 4.17$
- $p = 0.008$ → Statistically significant ($p < 0.05$)
- Cohen's d = 1.7, Large effect size

3. Scientific Interpretation

At the ROI level, alpha power showed a statistically significant increase following exposure to Fragrance B ($t(5) = 4.17$, $p = 0.008$, Cohen's $d = 1.70$). This indicates a robust enhancement in alpha activity, suggesting a strong calming effect associated with this fragrance. The large effect size reflects a substantial magnitude of change, supporting the practical and physiological relevance of the finding despite the small sample size. At the electrode level, all four electrodes (Fz, Pz, PO7, and PO8) demonstrated statistically significant increases in alpha power (all $p < 0.05$), indicating that the effect was spatially consistent across frontal and posterior regions. This strengthens the interpretation that Fragrance B produced a widespread modulation of alpha activity rather than a localized or spurious effect.

4.1.4.4 Fragrance B (Theta Power)

Table 4.8: Fragrance B Theta Power Density Across ROI Electrodes

THETA BEFORE				THETA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
62.812	62.144	61.462	62.771	58.62	58.243	57.93	58.341
65.55	63.923	64.109	64.307	69.812	68.551	68.917	68.86
97.754	78.765	76.361	61.71	87.523	89.784	57.92	68.69
77.609	88.809	77.131	86.305	75.211	86.54	75.577	84.441
67.209	78.362	66.705	81.82	74.982	76.9	74.66	83.807
70.332	68.221	65.723	70.664	72.643	67.221	64.332	69.512

1. Paired t-test (Theta)

Table 4.9: Fragrance B Electrode-level paired t-test results (Theta)

Electrode	t-value	p-value	Interpretation
Fz	-0.16	0.882	Not significant
Pz	0.51	0.632	Not significant
PO7	-0.54	0.611	Not significant
PO8	0.58	0.588	Not significant

2. Combined ROI approach (average across 4 electrodes per subject)

- $t(5) = -0.04$
- $p = 0.967$ → Not statistically significant ($p > 0.05$)
- Cohen's d = 0.02, Negligible effect size

3. Scientific Interpretation

At the ROI level, theta power did not show a statistically significant change following exposure to Fragrance B ($t(5) = -0.04$, $p = 0.967$, Cohen's d = 0.02). At the electrode level, none of the electrodes (Fz, Pz, PO7, PO8) demonstrated statistically significant changes (all $p > 0.05$). The negligible effect size indicates that Fragrance B did not meaningfully modulate theta activity. This suggests that the calming effect observed for this fragrance was primarily reflected in alpha modulation rather than theta-related neural processes.

4.1.4.5 Fragrance C (Alpha Power)

Table 4.10: Fragrance C Alpha Power Density Across ROI Electrodes

ALPHA BEFORE				ALPHA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
31.304	34.522	30.049	37.556	41.659	34.822	42.335	37.749
34.921	40.072	42.335	32.168	38.861	42.879	39.751	39.482
36.827	40.413	37.201	34.854	33.442	39.804	35.012	30.575
32.434	37.971	34.222	33.25	35.607	39.365	36.291	35.2
33.273	32.916	34.366	35.711	37.109	33.227	34.921	35.969
35.223	36.117	33.831	35.277	37.217	38.445	35.298	37.664

1. Paired t-test (Alpha)

Table 4.11: Fragrance C Electrode-level paired t-test results (Alpha)

Electrode	t-value	p-value	Interpretation
Fz	1.85	0.124	Not significant
Pz	2.02	0.099	Not significant
PO7	0.87	0.422	Not significant
PO8	0.85	0.436	Not significant

2. Combined ROI approach (average across 4 electrodes per subject)

- t (5) = 1.72
- p = 0.146 → Not statistically significant (p > 0.05)
- Cohen's d = 0.70, Medium effect size

3. Scientific Interpretation

At the ROI level, alpha power did not show a statistically significant change following exposure to Fragrance B ($t(5) = 1.72$, $p = 0.146$, Cohen's $d = 0.70$), indicating the absence of a robust relaxation-related neural response. At the electrode level, none of the electrodes (Fz, Pz, PO7, PO8) demonstrated statistically significant changes (all $p > 0.05$). Although a medium effect size was observed, the change did not reach statistical significance, suggesting that the fragrance did not robustly induce a relaxation-related neural response, possibly due to limited statistical power from the small sample size.

4.1.4.6 Fragrance C (Theta Power)

Table 4.12: Fragrance C Theta Power Density Across ROI Electrodes

THETA BEFORE				THETA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
81.667	89.883	76.819	86.925	65.227	90.498	61.147	80.835
75.227	72.11	68.571	60.22	70.546	73.22	69.232	59.34
88.669	88.845	62.644	61.731	67.439	71.072	54.923	57.381
61.507	62.643	60.421	61.821	70.855	70.271	69.58	63.657
58.557	58.236	57.511	58.423	56.71	56.985	56.9	57.107
66.225	63.221	66.822	68.214	65.221	62.334	67.216	68.322

1. Paired t-test (Theta)

Table 4.13: Fragrance C Electrode-level paired t-test results (Theta)

Electrode	t-value	p-value	Interpretation
Fz	− 1.31	0.246	Not significant

Pz	− 0.51	0.633	Not significant
PO7	− 0.66	0.536	Not significant
PO8	− 1.49	0.196	Not significant

2. Combined ROI approach (average across 4 electrodes per subject)

- $t(5) = -1.02$
- $p = 0.353$ → Not statistically significant ($p > 0.05$)
- Cohen's d = 0.42, Medium effect size

3. Scientific Interpretation

At the ROI level, theta power did not show a statistically significant change following exposure to Fragrance C ($t(5) = -1.02$, $p = 0.353$, Cohen's d = 0.42). At the electrode level, none of the electrodes (Fz, Pz, PO7, PO8) demonstrated statistically significant changes (all $p > 0.05$). Although a medium effect size was observed, the change did not reach statistical significance, suggesting that the fragrance did not robustly engage deeper internal or meditative neural processing, potentially due to limited statistical power from the small sample size.

4.1.4.7 Placebo (Alpha Power)

Table 4.14: Placebo Alpha Power Density Across ROI Electrodes

ALPHA BEFORE				ALPHA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
34.122	39.881	30.12	35.451	34.99	39.912	29.883	35.682
30.907	38.121	39.014	36.874	31.011	38.2	38.883	36.55
32.455	37.55	30.507	30.11	32.505	37.442	30.553	30.092

36.512	34.051	36.511	30.202	37.175	33.704	36.842	30.004
31.503	34.065	37.472	30.542	30.995	35.583	37.022	31.705
32.583	34.211	31.688	35.521	32.032	33.988	30.916	34.332

1. Paired t-test (Alpha)

Table 4.15: Placebo Electrode-level paired t-test results (Alpha)

Electrode	t-value	p-value	Interpretation
Fz	0.48	0.679	Not significant
Pz	0.59	0.595	Not significant
PO7	− 1.23	0.254	Not significant
PO8	− 0.16	0.866	Not significant

2. Combined ROI approach (average across 4 electrodes per subject)

- $t(5) = 0.02$
- $p = 0.984$ → Not statistically significant ($p > 0.05$)
- Cohen's d = 0.01, negligible effect size

3. Scientific Interpretation

At the ROI level, alpha power did not show a statistically significant change following exposure to the placebo ($t(5) = 0.02$, $p = 0.984$, Cohen's d = 0.01), indicating the absence of a robust relaxation-related neural response. At the electrode level, none of the electrodes (Fz, Pz, PO7, PO8) demonstrated statistically significant changes (all $p > 0.05$). As the placebo contained no scent and served purely as a control condition, the absence of significant alpha modulation supports the conclusion that the observed neural effects in the fragrance conditions are attributable to olfactory stimulation rather than experimental artifacts or repeated testing effects.

4.1.4.8 Placebo (Theta Power)

Table 4.16: Placebo Theta Power Density Across ROI Electrodes

THETA BEFORE				THETA AFTER			
EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)	EEG1 (Fz)	EEG5 (Pz)	EEG6 (PO7)	EEG8 (PO8)
98.55	85.221	74.208	63.177	98.4	85.013	74.55	63.067
90.23	83.333	75.014	60.882	90.024	83.211	74.932	60.559
89.77	84.107	73.331	61.453	89.88	84.211	73.114	61.227
62.102	64.105	66.011	60.801	62.331	64.911	66.201	60.721
67.137	65.551	67.341	71.021	67.321	66.021	67.321	70.891
64.225	66.932	70.243	69.263	64.112	65.134	70.511	68.772

1. Paired t-test (Theta)

Table 4.17: Placebo Electrode-level paired t-test results (Theta)

Electrode	t-value	p-value	Interpretation
Fz	0.12	0.911	Not significant
Pz	−0.43	0.749	Not significant
PO7	0.92	0.412	Not significant
PO8	− 4.02	0.017	Significant

2. Combined ROI approach (average across 4 electrodes per subject)

- t (5) = -0.17

- $p = 0.592$ → Not statistically significant ($p > 0.05$)
- Cohen's d = 0.07, negligible effect size

3. Scientific Interpretation

At the ROI level, theta power did not show a statistically significant change following exposure to the placebo ($t(5) = -0.17$, $p = 0.592$, Cohen's d = 0.07), indicating the absence of a robust relaxation-related neural response. At the electrode level, none of the electrodes (Fz, Pz, PO7, PO8) demonstrated statistically significant changes (all $p > 0.05$). As the placebo contained no scent and served purely as a control condition, the absence of significant theta modulation supports the conclusion that any observed neural changes in the fragrance conditions are attributable to olfactory stimulation rather than experimental artifacts or repeated testing effects.

4.1.5 Discussion of EEG Power Density Findings

Table 4.18 presents the mean differences of the power density values (in $\mu V^2/Hz$) recorded before and after fragrance exposure for each fragrance group, including the placebo. The table also includes the calculated t-value, Cohen's d effect size, and corresponding p-values from paired-sample t-tests to determine the statistical significance of the changes. The symbol (*) indicates statistically significant results, which were determined by the p-value ($p < 0.05$), and the sign of the t-value indicates the direction of change, whether an increase or a decrease.

Table 4.18: Summary of Statistical Analysis of Power Density Before and After Fragrance Exposure Across Groups

Fragrance Type	Wave	Mean Difference (µV²/Hz)	t-value	Cohen's d value	Effect Size	p-value
Fragrance A (Floral & Fruity)	Alpha	4.152	2.77	1.13	Large	0.033*
	Theta	-4.067	-2.21	0.9	Large	0.079
Fragrance B (Spices & Wood)	Alpha	5.338	4.17	1.7	Large	0.008*
	Theta	-0.064	-0.04	0.02	Negligible	0.967
Fragrance C (Citrus-Floral)	Alpha	1.911	1.72	0.7	Medium	0.146
	Theta	-2.954	-1.02	0.42	Medium	0.353
Placebo	Alpha	0.001	0.02	0.01	Negligible	0.984
	Theta	-0.066	-0.17	0.07	Negligible	0.592

4.1.5.1 Discussion on Fragrance A

Fragrance A (a floral–fruit type) produced a statistically significant increase in alpha power with the p-value of 0.033 (<0.05), indicating a relaxation-related neural response and supporting a calming effect. However, theta power did not exhibit a statistically significant change with a p-value of 0.079 (>0.05), suggesting that the fragrance did not robustly engage deeper internal or meditative processing. The large effect size observed for theta, despite not being statistically significant, suggests a potentially meaningful effect that may not have reached statistical significance due to the small sample size. Taken together, these findings indicate a partial calming effect, predominantly mediated through alpha activity rather than consistent modulation across both EEG markers of calmness.

Focusing on alpha, exposure to Fragrance A (Fruity-Floral) was associated with a notable increase in alpha power across parietal (Pz) and right parietal-occipital (PO8). The enhancement of alpha activity has been linked to states of relaxed wakefulness and internalized attention (Risqiwati *et al*., 2024; Deshmukh,2023; Sander *et al*., 2016). The enhancement of alpha oscillations is widely recognized as a neural marker of relaxed but alert states, reflecting reduced cortical arousal and improved inhibitory control over distracting information (Bonnefond & Jensen, 2025; Schneider *et al*., 2022). This suggests that Fragrance A may facilitate a calm and focused mental state. Within this group, the increase in alpha may indicate that the olfactory profile of Fragrance A contributed to a sense of comfort or mood stabilization, although further research would be required to determine whether this differs meaningfully from other fragrance types.

Simultaneously, the reduction in theta activity supports the notion of lowered cognitive strain and physiological arousal, as theta is often linked to drowsiness, stress, or increased cognitive effort (Raufi & Longo, 2022; Newson & Thiagarajan, 2019). The combined pattern of increased alpha and decreased theta indicates that Fragrance A can induce a state of relaxation without compromising alertness, aligning with its proposed aromatherapeutic benefits.

These findings are consistent with prior studies reporting that floral and fruity fragrances can positively modulate brain oscillations to promote calmness (Sun *et al*., 2025; Sowndhararajan & Kim, 2016). While the EEG results suggest a calming neural effect, subjective measures of relaxation were not collected, representing a limitation and an opportunity for future research to correlate neural responses with self-reported calmness.

4.1.5.2 Discussion on Fragrance B

Fragrance B (a spice & wood type) produced a statistically significant increase in alpha power with the p-value of 0.008 (< 0.05), indicating a relaxation-related neural response and supporting a calming effect. However, theta power did not exhibit a statistically significant change with a p-value of 0.967 (> 0.05), suggesting that the fragrance did not robustly engage deeper internal or meditative processing. The negligible effect size observed for theta further indicates that this lack of significance reflects a genuinely minimal physiological effect rather than a power limitation. Taken together, these findings indicate a strong calming effect, predominantly mediated through alpha activity rather than consistent modulation across both EEG markers of calmness.

Focusing on alpha, the analysis showed a significant increase in alpha power across all electrodes, in frontal (Fz), parietal (Pz), and parietal-occipital (PO7/PO8) regions. This pattern suggests that Fragrance B may promote calmness through modulation of cortical alpha rhythms, since alpha oscillations are widely recognized as a neural marker of relaxation (Risqiwati *et al*., 2024; Deshmukh,2023; Phneah & Nisar, 2017). The olfactory profile of Fragrance B includes woody and resinous compounds such as Cedrol and Thujopsene, which have been reported to possess sedative or anxiolytic properties (Maduka *et al*., 2024; Pegard, 2022; Zhang & Yao, 2018). While these findings provide preliminary support for fragrance-induced modulation of EEG signals, a direct comparison with other fragrances using strong statistical correlation (e.g., ANOVA) would be needed to establish whether Fragrance B produces a stronger effect than alternative scent profiles, which was one of the limitations in this study.

On the theta, none of the electrodes (Fz, Pz, PO7, PO8) demonstrated statistically significant changes (all $p > 0.05$). The negligible effect size (Cohen's $d = 0.02$) indicates that Fragrance B did not meaningfully modulate theta activity on calmness, as theta is often linked to drowsiness, stress, or increased cognitive effort (Raufi & Longo, 2022; Newson & Thiagarajan, 2019). This suggests that the calming effect observed for this fragrance was primarily reflected in alpha modulation rather than theta-related neural processes.

4.1.5.3 Discussion on Fragrance C

Fragrance C (a citrus-floral type) did not produce a statistically significant increase in alpha power, indicating the absence of a robust relaxation-related neural response. None of the electrodes demonstrated statistically significant modulation (all $p > 0.05$), although the parietal region (Pz) showed a trend towards significance ($p = 0.099$). The medium effect size (Cohen's $d = 1.7$) observed at the ROI level suggests a modest change, but this did not reach statistical significance.

Theta power also did not exhibit a statistically significant change, indicating that the fragrance did not robustly engage deeper internal or meditative processing. Although a medium effect size was observed, the lack of statistical significance suggests that any theta modulation was weak and inconsistent. Taken together, these findings indicate that Fragrance C did not produce a meaningful calming effect, as neither alpha nor theta activity showed consistent or statistically reliable modulation.

This suggests that its effect on calmness may be more limited under the present conditions. The refreshing citrus notes may evoke alertness or invigoration rather than sustained relaxation (Chandra *et al*., 2025; Eissa, 2024), which could explain the smaller changes in EEG rhythms.

4.1.5.4 Discussion on Placebo

Placebo exposure did not produce a statistically significant change in alpha power with a p-value of 0.984 (> 0.05), indicating the absence of a relaxation-related neural response. None of the electrodes across the ROI demonstrated statistically significant modulation, and the negligible effect size confirms that the observed differences were physiologically minimal rather than masked by limited statistical power.

Theta power likewise did not exhibit a statistically significant change with a p-value of 0.592 (> 0.05), indicating that the placebo did not engage deeper internal or meditative neural processing. The near-zero effect size further supports the conclusion that the placebo condition did not meaningfully modulate calmness-related neural activity, indicating that the observed changes in the fragrance groups are likely attributable to olfactory stimulation rather than time-related or procedural factors.

Taken together, these findings confirm that the observed calming effects in Fragrances A and B are not attributable to expectancy or testing effects but reflect genuine fragrance-specific neural modulation.

4.1.6 Topographical Maps

Following the statistical analysis, topographical maps were generated to visually represent the spatial distribution of alpha and theta power across the scalp based on the mean changes. These maps help further illustrate the changes observed in the EEG data after fragrance exposure. Figure 4.5 shows the distribution of alpha activity across the scalp for each condition, both before and after fragrance exposure. An increase in alpha power is visually observable, especially following exposure to Fragrance B, indicating a calming effect. Fragrance A also led to increases, to a lesser extent, while Fragrance C and the placebo condition showed minimal to no meaningful changes.

Furthermore, Figure 4.6 illustrates the theta band distribution, where a general decrease in theta power is observed after fragrance exposure. The most notable decrease occurred for Fragrance A and C, suggesting reduced drowsiness or mental disengagement (Daneshgar *et al*., 2025). In contrast, Fragrance B showed minimal theta change, indicating a calming effect without inducing drowsiness (Bonakdarpour *et al*., 2023), but the effect size was negligible. The placebo condition again showed no meaningful differences.

In conclusion, the present findings suggest that alpha wave power may serve as a sensitive indicator of calmness in this study, with a significant increase observed for Spices & Wood (Fragrance B). These results provide preliminary support for the idea that fragrance exposure can influence emotional states, as reflected by EEG signal changes, particularly in the alpha band. However, further comparative analyses with larger samples and wider brain regions are needed to confirm whether these effects differ substantially across fragrance types.

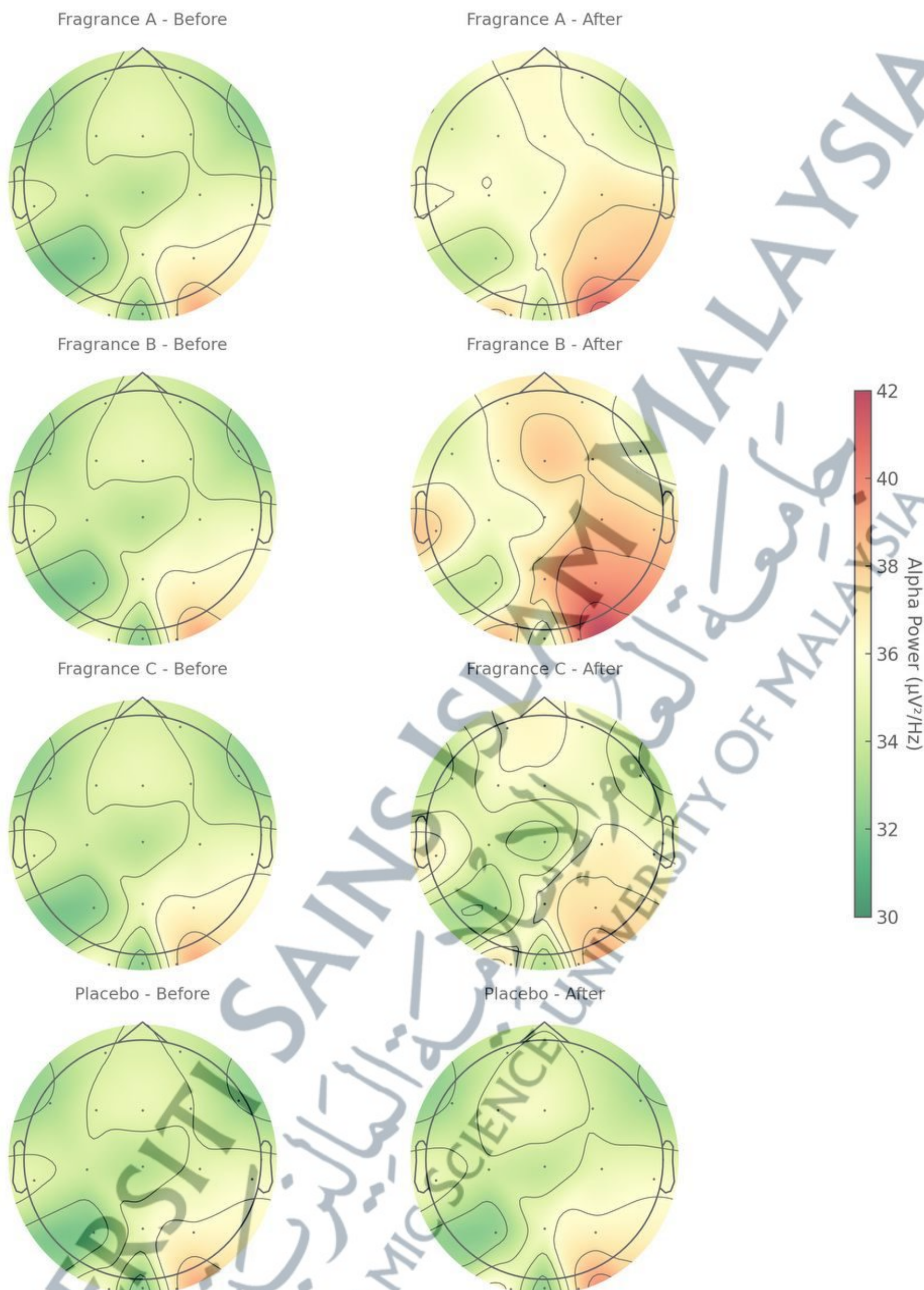


Figure 4.5: Topographical distribution of alpha band power before and after exposure to Fragrance A, B, C, and Placebo. Warm colors (e.g., red, yellow) represent higher alpha power, typically associated with increased relaxation or reduced cortical activation.

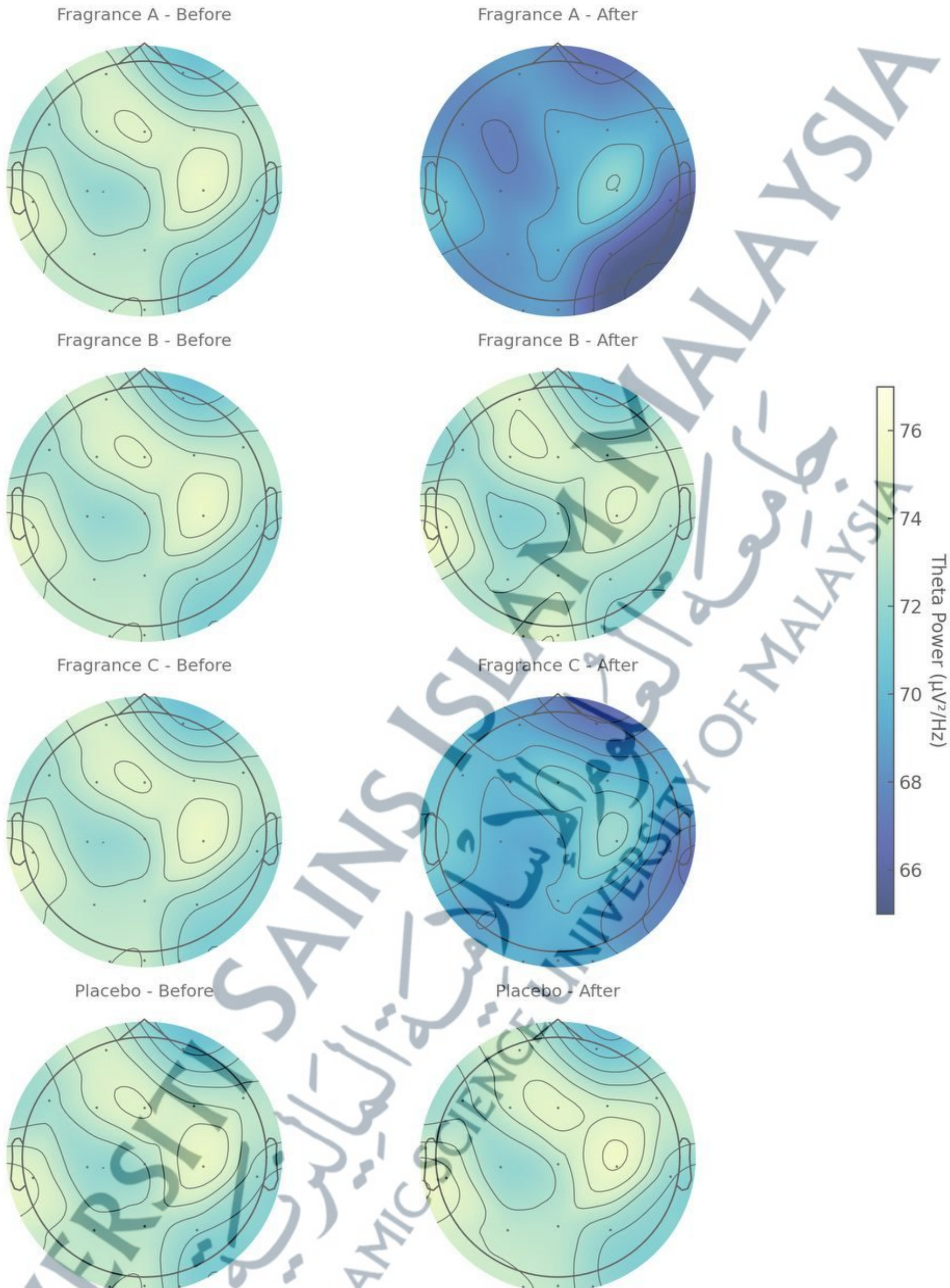


Figure 4.6: Topographical distribution of theta band power before and after exposure to Fragrance A, B, C, and Placebo. Cooler tones (e.g., blue) reflect higher theta activity, often linked to drowsiness or emotional processing.

4.2 Composition of The Fragrances and Their Potential Influence on EEG

This section describes the chemical composition of the fragrances analysed using Gas Chromatography–Mass Spectrometry (GC-MS), followed by scientific interpretations regarding their potential to modulate EEG alpha and theta power density. The focus is on understanding how specific volatile compounds, identified in each fragrance, may influence brain activity related to calmness and cognitive processes.

4.2.1 GC-MS Results

The chemical compositions of the three fragrances (Fragrance A – *Floral & Fruity*, Fragrance B – *Spices & Wood*, and Fragrance C – *Citrus-Floral*) were analysed using GC-MS and the Agilent Mass Hunter Software. The analysis provided both the relative abundance and the compound percentage for each identified compound in the respective fragrance formulations. Relative abundance represents the proportional contribution of each compound to the overall chemical composition of the fragrance sample based on the peak areas on the chromatogram. The compound percentage was calculated by dividing each compound's relative abundance by the total relative abundance of the sample and then multiplying by 100 to obtain the proportion within the mixture. The tables 4.19 to 4.21 below summarize the GC-MS profiling results for each fragrance:

Table 4.19: GC-MS Results for Fragrance A (Floral and Fruity)

CHEMICAL COMPOUND	RELATIVE ABUNDANCE	COMPOUND PERCENTAGE
Octanal, 2-(phenylmethylene)-	95.5	15.70

Ethylene Brassylate	92.9	15.27
Cyclopentaneacetic acid, 3-oxo-2-pentyl-, methyl ester	81.2	13.35
Lilial	76.8	12.63
Butylated Hydroxytoluene	75.7	12.45
1-Propanol, 2-(2-hydroxypropoxy)-	52.1	8.57
1,2-Dihydropyridine, 1-(1-oxobutyl)	39	6.41
Limonene	29.2	4.80
Azulene, 1,2,3,4,5,6,7,8-octahydro-1,4- dimethyl-7-(1-methylethenyl)-	26.6	4.37
Cyclopenta[g]-2-benzopyran, 1,3,4,6,7,8- hexahydro-4,6,6,7,8,8-hexamethyl	19.7	3.24
1,5-Dimethyl-1-vinyl-4-hexenyl butyrate	19.5	3.21

Table 4.20: GC-MS Results for Fragrance B (Spices and Wood)

CHEMICAL COMPOUND	RELATIVE ABUNDANCE	COMPOUND PERCENTAGE
2-Propanol, 1,1'-oxybis	94.1	11.50
Ethyl Citrate	92.4	11.29
Piperonal	89.2	10.90
2H-1-Benzopyran-2-one	85.7	10.47
Cyclopentaneacetic acid, 3-oxo-2-pentyl-, methyl ester	77.1	9.42
Ethyl Vanillin	77	9.41
Vanillin	66.4	8.11
Thujopsene	46.5	5.68
Cedrol	41.1	5.02
1,2-Dihydropyridine, 1-(1-oxobutyl)-	34.6	4.23
Oxacycloheptadec-8-en-2-one	31.8	3.89
1-Propanol, 2-(2-hydroxypropoxy)-	28.6	3.49
Limonene	26.4	3.23
2-Octanol, 2-methyl-6-methylene	15.3	1.87
1,5-Dimethyl-1-vinyl-4-hexenyl butyrate	12.2	1.49

Table 4.21: GC-MS Results for Fragrance C (Citrus-Floral)

CHEMICAL COMPOUND	RELATIVE ABUNDANCE	COMPOUND PERCENTAGE
Octanal, 2-(phenylmethylene)-	96.4	15.91
2(3H)-Furanone, 5-heptyldihydro	79.3	13.09
Cyclopentaneacetic acid, 3-oxo-2-pentyl-, methyl ester	75.8	12.51
Benzeneethanol, alpha.,.alpha.-dimethyl-, acetate	71.8	11.85
3-Cyclohexene-1-methanol, alpha,.alpha.4- trimethyl-propanoate	70.6	11.65
Cyclopenta[g]-2-benzopyran, 1,3,4,6,7,8- hexahydro-4,6,6,7,8,8-hexamethyl	49.5	8.17
1,6-Octadien-3-ol, 3,7-dimethyl-, formate	42.6	7.03
Acetic acid, phenylmethyl ester	32.7	5.40
1,2-Dihydropyridine, 1-(1-oxobutyl)-	32.2	5.32
Cyclohexene, 1-methyl-5-(1-methylethenyl)-, (R)-	26.9	4.44
Bicyclo[3.1.0]hex-2-ene, 4-methyl-1-(1- methylethyl)-	20.4	3.37
1R-. alpha. -Pinene	7.59	1.25

4.2.2 Interpretation for Fragrance A

Fragrance A, a floral-fruity formulation, is dominated by key volatile compounds: Octanal, 2-(phenylmethylene)– (15.70%), Ethylene Brassylate (15.27%), Cyclopentaneacetic acid, methyl ester (13.35%), and Lilial (12.63%), according to GC-MS analysis. In the EEG data, Fragrance A induced a significant increase in alpha power (mean +4.152 μV²/Hz) coupled with a decrease in theta power (mean −4.067 μV²/Hz), reflecting a neurophysiological state characterized by relaxed alertness (Malipeddi *et al*., 2024).

Notably, Ethylene Brassylate, a widely used musky aroma in perfumery, has been shown in controlled EEG studies to elevate alpha wave activity and promote calm, supported by improved subjective mood ratings (Zennifa *et al.*, 2025). Lilial, a synthetic floral aldehyde, triggers neural pathways linked to olfactory-limbic processing, influencing mood and attentional networks, consistent with elevated alpha rhythms (Chen *et al*., 2025; Ramachanderan & Schaefer, 2019). Octanal derivatives, contributing citrus-green notes, have been reported to enhance mental clarity and alpha activity when used in inhalation studies (Li *et al*, 2022; Elterlein *et al*., 2024).

Though Cyclopentaneacetic acid, methyl ester has less direct EEG evidence, it contributes to the substance's smooth texture, likely enhancing the longevity of the sensory effect, which may support sustained EEG changes. Collectively, the musky-floral and citrus aldehyde blend in Fragrance A aligns with known mechanisms of alpha wave enhancement and theta regulation, suggesting a plausible pathway for fragrance-induced calm focus.

4.2.3 Interpretation for Fragrance B

Fragrance B is chemically characterized by a blend of woody, sweet, citrus, and slightly balsamic notes, composed of multiple volatile compounds. Among the most prominent constituents identified via GC-MS analysis are Cedrol, Piperonal, Vanillin, Ethyl Vanillin, and Limonene, along with 2-Propanol, 1,1'-oxybis, Ethyl Citrate, and several other esters and terpenes. These compounds contribute both to the olfactory identity of the fragrance and its potential neurophysiological effects.

According to the EEG findings, exposure to Fragrance B led to an increase in alpha power density and a reduction in theta power density among male participants, suggesting a shift toward a relaxed yet alert state, but the alpha was the best indicator of calmness in this study since the effect size on theta was negligible. This EEG pattern is often interpreted as indicative of calmness with attentional readiness, particularly when occurring in the frontal and parietal regions (Smetzer, 2025).

Several of the identified compounds have been linked in past studies to neurological or emotional modulation. Cedrol, a well-known sesquiterpene found in cedarwood, has been associated with reduced sympathetic activity and sedation, and is thought to help lower stress-related responses via parasympathetic activation alongside Thujopsene (Pegard, 2022; Maduka *et al*., 2024). Piperonal, a sweet balsamic compound structurally related to vanillin, has been shown to influence mood and potentially modulate neurotransmitter systems involved in emotional regulation (Akash *et al*., 2020 Pei *et al*., 2024).

Vanillin and Ethyl Vanillin, classic components with vanilla-like scents, are known for their soothing and comforting properties and are frequently included in aromatherapy formulations targeting stress relief (Choi *et al*., 2022; Bunschoten, 2023). Limonene, a citrus monoterpene, has also been noted for its anxiolytic and cognitive-enhancing effects in animal studies, especially when inhaled (Cui *et al*., 2022). In this formulation, the coexistence of both warm, woody notes (e.g., Cedrol) and bright, sweet compounds (e.g., Limonene, Piperonal) may synergistically influence the olfactory-limbic system to induce calming EEG effects.

These observed EEG changes are likely not due to a single compound but rather the combined presence and interaction of multiple constituents. The overall fragrance profile of Fragrance B, which is composed of woody, sweet, and citrus-aromatic molecules, supports its calming and focusing potential, especially in male subjects, as reflected by the enhancement of alpha activity and the attenuation of theta wave patterns post-exposure.

4.2.4 Interpretation for Fragrance C

Fragrance C is composed of a diverse blend of citrus and floral-oriented compounds, many of which are recognized for their refreshing, uplifting, and mood-enhancing properties. The major constituents of this fragrance include Octanal, 2-(phenylmethylene)-, 2(3H)-Furanone, 5-heptyldihydro, Cyclopentaneacetic acid, 3-oxo-2-pentyl-, methyl ester, and Benzeneethanol, α,α-dimethyl-, acetate, among others. Among these, Octanal derivatives are citrusy aldehydes known for their bright, clean aroma and have been shown to promote mental clarity and emotional freshness. This class of compounds often plays a role in enhancing cognitive alertness and may modestly increase alpha brainwave activity, which is associated with a calm yet alert state (Sukaew, 2024; Catalano *et al*., 2024).

In addition, 2(3H)-Furanone, 5-heptyldihydro, a sweet and fruity compound, and benzeneethanol derivatives such as Benzeneethanol, α,α-dimethyl-, acetate, contribute to the floral-fruity character, which can elicit pleasantness and reduce stress, potentially impacting theta and alpha power (Zhou *et al*., 2024; Schwab, 2013; Scognamiglio, 2012). 1R-α-Pinene, a terpene also found in essential oils like pine and rosemary, has been associated with improved attention and decreased anxiety in aromatherapy studies (Thangaleela *et al*., 2022). These compounds, through their olfactory stimulation of the limbic and frontal systems, may contribute to the modulation of EEG activity linked to calmness and focus.

In terms of EEG data, Fragrance C was associated with a mild increase in alpha power density and a slight or negligible reduction in theta waves, suggesting a limited calming effect overall. Unlike Fragrance A and B, which showed more consistent enhancement of calm-related brain activity, Fragrance C demonstrated less pronounced changes across subjects. This variation could be partially explained by the olfactory nature of the compounds present. For instance, Octanal and α-Pinene are known to induce freshness and mild alertness, while 2(3H)-Furanone and Benzene ethanol esters are sweet and floral, potentially enhancing comfort but not necessarily deep calmness.

Given that all participants in this study were male, the chemical nature of Fragrance C may have played a role in the limited EEG response. Existing literature indicates that men tend to prefer woody, spicy, and citrus-based scents over sweet or floral aromas (Kapadia *et al*., 2023). Therefore, the sweet-dominant profile of Fragrance C might not have aligned with typical male olfactory preferences, which could explain the reduced emotional resonance and weaker neurophysiological effects. This gender-specific preference might have influenced both perception and subsequent EEG responses, resulting in minimal calming modulation.

4.2.5 Discussion of Chemical Compounds and EEG Response

The analysis of GC-MS data provided insight into the chemical profiles of each fragrance. Fragrance A contained dominant compounds such as Ethylene Brassylate and Lilial, both of which are known for their musky and floral olfactory character. These compounds are often linked with emotional modulation and comfort, which may explain the alpha enhancement.

Fragrance B, rich in Vanillin, Cedrol, and Piperonal, may provide the most robust calming effect on the EEG. Literature supports that Cedrol can decrease sympathetic activity and increase parasympathetic tone (Al-Harassi *et al*., 2022), which aligns with the observed elevation in alpha waves. The presence of vanillic and resinous elements further supports the fragrance's ability to induce calmness via olfactory-limbic mechanisms.

Fragrance C's profile included citrusy and floral esters such as Octanal derivatives and Cyclopenta-benzopyran. Although such compounds are often associated with freshness and mild stimulation, they may not be as effective in producing calming EEG signatures in males. This suggests that chemical composition interacts with olfactory preferences, potentially influenced by gender, and plays a key role in neuromodulation.

4.3 Effects of Fragrance on Working Memory Performance

4.3.1 Overview of Cognitive Performance Metrics

This section reports the participants' working memory performance, measured using the CogniFit digital platform, specifically focusing on non-verbal memory and visual short-term memory, which were measured before and after exposure to the three fragrance types and the placebo. The CogniFit test provides three primary metrics, which are 1) Score (%) – a quantitative performance index, 2) Accuracy Level – a qualitative label (e.g., Average, Great, High), and 3) Reaction Time (seconds) – the average time taken to respond, indicating processing speed.

Data was collected for 6 male participants per group. A paired sample t-test was conducted to compare the values before and after exposure for each metric in each fragrance condition. Results with a p-value of less than 0.05 were considered statistically significant, indicating that the observed changes were unlikely due to random variation and were likely caused by fragrance exposure. The results are interpreted in the following subsections.

4.3.2 Results of Working Memory Performance

Table 4.22: Working Memory Performance for Fragrance A

BEFORE					AFTER			
Sub	Score (%)	Speed	Accuracy	Reaction Time (s)	Score (%)	Speed	Accuracy	Reaction Time (s)
1	98	Average	Great	0.703	96	Average	Average	0.768
2	98	Average	Great	0.722	92	Average	Average	0.849
3	88	Average	Average	0.618	92	Average	Average	0.62
4	94	High	Great	0.673	98	High	Great	0.604
5	92	Average	Average	0.718	96	High	Average	0.623
6	94	Average	Average	0.702	96	High	Average	0.633

Table 4.23: Working Memory Performance for Fragrance B

BEFORE					AFTER			
Sub	Score (%)	Speed	Accuracy	Reaction Time (s)	Score (%)	Speed	Accuracy	Reaction Time (s)
1	98	Average	Great	0.733	98	Average	Great	0.729
2	98	Average	Great	0.614	100	High	Great	0.587
3	96	Average	Average	0.622	98	High	Great	0.603
4	92	High	Average	0.535	97	High	High	0.49
5	90	Average	Average	0.62	95	Average	High	0.601
6	94	High	Average	0.599	96	High	High	0.408

Table 4.24: Working Memory Performance for Fragrance C

	BEFORE				AFTER			
Sub	Score (%)	Speed	Accuracy	Reaction Time (s)	Score (%)	Speed	Accuracy	Reaction Time (s)
1	94	High	Average	0.67	98	High	Great	0.486
2	96	High	Average	0.67	94	Average	Average	0.586
3	97	Average	Average	0.731	96	Average	Average	0.645
4	92	Average	Average	0.765	97	Average	High	0.699
5	96	Average	Average	0.79	96	Average	Average	0.782
6	94	High	Average	0.651	96	High	High	0.504

Table 4.25: Working Memory Performance for Placebo

	BEFORE				AFTER			
Sub	Score (%)	Speed	Accuracy	Reaction Time (s)	Score (%)	Speed	Accuracy	Reaction Time (s)
1	91	Average	Average	0.891	92	Average	Average	0.887
2	96	Average	High	0.776	96	Average	High	0.677
3	90	Average	Average	0.982	91	Average	Average	0.98
4	94	High	Average	0.534	96	High	High	0.507
5	92	Average	Average	0.698	90	Average	Average	0.672
6	92	Average	Average	0.822	94	High	Average	0.502

4.3.3 Statistical Results & Interpretation

4.3.3.1 Fragrance A Effects on Working Memory

1. Accuracy Score (%)

- Before: Mean = 94.00%
- After: Mean = 95.00%
- Mean change = +1.00%

2. Reaction Time (s)

- Before: Mean = 0.689 s
- After: Mean = 0.683 s
- Mean change = −0.006 s

3. Paired t-test Results:

Accuracy Score

- t (5) = 0.591
- p = 0.580, Not statistically significant
- Cohen's d value = 0.24, Small effect

Reaction Time

- t (5) = −0.181
- p = 0.863, Not statistically significant
- Cohen's d value = 0.07, Negligible effect

4. Interpretation:

A paired-samples t-test in working memory accuracy scores showed a slight increase from pre-exposure (M = 94.00%, SD = 3.74) to post-exposure (M = 95.00%, SD = 2.31); however, this difference was not statistically significant, t (5) = 0.59, p = 0.580. Reaction time demonstrated a marginal decrease from pre-exposure (M = 0.689 s, SD

= 0.040) to post-exposure (M = 0.683 s, SD = 0.099), which was also not statistically significant, t (5) = −0.18, p = 0.863. These findings indicate that fragrance exposure did not result in a statistically meaningful change in working memory performance. Effect size analysis indicated a small effect of fragrance exposure on accuracy (Cohen's d = 0.24) and a negligible effect on reaction time (Cohen's d = 0.07), suggesting that the observed changes in working memory performance were minimal and likely not practically meaningful.

4.3.3.2 Fragrance B Effects on Working Memory

1. Accuracy Score (%)

- Before: Mean = 94.67%
- After: Mean = 97.33%
- Mean change = +2.67%

2. Reaction Time (s)

- Before: Mean = 0.620 s
- After: Mean = 0.570 s
- Mean change = −0.050 s

3. Paired t-test Results:

Accuracy Score

- t (5) = 3.32
- p = 0.021, Statistically significant
- Cohen's d value = 1.36, Large effect

Reaction Time

- t (5) = −1.78
- p = 0.135, Not statistically significant
- Cohen's d value = 0.73, Moderate effect

4. Interpretation:

A paired-samples t-test revealed a significant improvement in working memory accuracy (t (5) = 3.32, p = 0.021), accompanied by a large effect size (Cohen's d = 1.36) following exposure to Fragrance B, with scores increasing from pre-exposure (M = 94.67%, SD = 3.39) to post-exposure (M = 97.33%, SD = 1.97). Reaction time decreased from pre-exposure (M = 0.620 s, SD = 0.070) to post-exposure (M = 0.570 s, SD = 0.111); however, this difference was not statistically significant, t (5) = −1.78, p = .135, and a moderate effect size, Cohen's d = −0.73. These findings indicate that Fragrance B significantly enhanced working memory accuracy but did not produce a statistically reliable improvement in response speed.

4.3.3.3 Fragrance C Effects on Working Memory

1. Accuracy Score (%)

- Before: Mean = 94.83%
- After: Mean = 96.17%
- Mean change = +1.34%

2. Reaction Time (s)

- Before: Mean = 0.713 s
- After: Mean = 0.617 s

- Mean change = −0.096 s

3. Paired t-test Results:

Accuracy Score

- t (5) = 1.16
- p = 0.297, Not statistically significant
- Cohen's d value = 0.48, Moderate effect

Reaction Time

- t (5) = −3.78
- p = 0.013, Statistically significant
- Cohen's d value = 1.15, Large effect

4. Interpretation:

A paired-samples t-test in working memory accuracy scores showed no statistically significant difference before (M = 94.83%, SD = 1.83) and after (M = 96.17%, SD = 1.33) exposure to Fragrance C, with a p-value of 0.297 (*t* (5) = 1.16). However, the moderate effect size (Cohen's d = 0.48) suggests a trend towards improved accuracy. Otherwise, a significant improvement in reaction time was observed (p=0.013), accompanied by a large effect size (Cohen's d = 1.55) before exposure (M = 0.713 s, SD = 0.057) and after exposure (M = 0.617 s, SD = 0.115), indicating a substantial improvement in processing speed and response efficiency following fragrance exposure.

4.3.3.4 Placebo Effects on Working Memory

1. Accuracy Score (%)

- Before: Mean = 92.5%

- After: Mean = 93.17%
- Mean change = +0.67%

2. Reaction Time (s)

- Before: Mean = 0.784 s
- After: Mean = 0.704 s
- Mean change = −0.080 s

3. Paired t-test Results:

Accuracy Score

- t (5) = 1.08
- p = 0.328, Not statistically significant
- Cohen's d value = 0.44, Moderate effect

Reaction Time

- t (5) = −1.59
- p = 0.173, Not statistically significant
- Cohen's d value = 0.65, Moderate effect

4. Interpretation:

No statistically significant change in working memory score was observed before (M = 92.50%, SD = 2.17) and after (M = 93.17%, SD = 2.56) placebo exposure, with a p-value of 0.328 (*t* (5) = 1.08). The moderate effect size (Cohen's d = 0.44) suggests a minimal improvement, likely due to practice or familiarity effects rather than a true intervention effect. Moreover, although reaction time showed an increase in reaction before (M = 0.784 s, SD = 0.156) and after (M = 0.704 s, SD = 0.195) fragrance exposure, with a moderate effect size (Cohen's d = 0.65), the change was not statistically significant (p = 0.173, *t* (5) = -1.59), supporting the interpretation that the observed effects under Fragrance B and C are unlikely to be attributable to practice or expectancy effects alone.

4.3.4 Discussion about Working Memory Performance Results

The summary results for the Working Memory Performance for all types of fragrance, including placebo, can be seen in Table 4.26. It presents the mean differences of the accuracy score and reaction of working memory performance recorded before and after fragrance exposure for each fragrance group, including the placebo. The table also includes the values of Cohen's d, effect size, and corresponding p-values from paired-sample t-tests to determine the statistical significance of the changes. The symbol (*) indicates statistically significant results, which were determined by the p-value ($p < 0.05$).

Table 4.26: Summary of Working Memory Performance

Frag	Metric	Mean Differences	Cohen's d value	Effect Size	p-value
A	Score (%)	1	0.24	Small	0.580
	Reaction Time	-0.0065	0.07	Negligible	0.863
B	Score (%)	2.66	1.36	Large	0.021*
	Reaction Time	-0.051	0.73	Moderate	0.135
C	Score (%)	1.34	0.48	Moderate	0.297
	Reaction Time	-0.096	1.55	Large	0.013*
Placebo	Score (%)	0.67	0.44	Moderate	0.328
	Reaction Time	-0.08	0.65	Moderate	0.173

4.3.4.1 Discussion on Fragrance A

Exposure to Fragrance A (Fruity-Floral) resulted in only a modest numerical increase in accuracy and a minimal reduction in reaction time. However, these changes were not statistically significant ($p > 0.05$), and the effect sizes were small to negligible, indicating that Fragrance A did not meaningfully influence working memory performance. This suggests that although Fragrance A may have induced mild relaxation based on EEG indices, this physiological change did not translate into a measurable cognitive benefit.

From a cognitive neuroscience perspective, relaxation alone does not guarantee improved working memory performance. Working memory depends critically on prefrontal cortex engagement and sustained attentional control, and excessive relaxation may even reduce task engagement rather than enhance it (Sridhar *et al*., 2023; Bahmani *et al*., 2019; Funahashi, 2017). Thus, the lack of significant improvement following Fragrance A exposure is consistent with evidence that calming stimuli do not necessarily enhance executive cognitive performance unless accompanied by increased alertness or task-oriented arousal (De Luca & Botelho, 2021; Stevenson *et al*., 2018).

4.3.4.2 Discussion on Fragrance B

Fragrance B (Spices & Wood) produced a statistically significant improvement in working memory accuracy with a p-value of 0.021 ($p < 0.05$), accompanied by a large effect size (Cohen's $d = 1.36$), indicating a meaningful enhancement in cognitive performance. Although reaction time showed a moderate numerical decrease, this change did not reach statistical significance ($p > 0.05$), suggesting that Fragrance B primarily improved response accuracy rather than processing speed.

This pattern is consistent with the concept of optimal arousal, where moderate emotional stimulation enhances cognitive control and memory encoding without inducing stress or distraction (Zhang *et al*., 2023; Baccarani *et al*., 2023). Fragrance B may have activated neural circuits associated with attentional focus and working memory maintenance, potentially involving the dorsolateral prefrontal cortex and anterior cingulate cortex, regions known to support executive function and error monitoring (Sridhar *et al*., 2023; Alexander & Brown, 2015). The selective improvement in accuracy suggests enhanced cognitive stability rather than faster responding, which is a desirable outcome in tasks requiring precision.

4.3.4.3 Discussion on Fragrance C

Exposure to Fragrance C (Citrus-Floral) resulted in no statistically significant change in working memory accuracy ($p > 0.05$), although the effect size was moderate, suggesting a trend-level improvement that did not reach statistical significance. In contrast, reaction time showed a statistically significant reduction with a large effect size ($p = 0.013$, Cohen's $d = 1.55$), indicating a robust enhancement in processing speed following exposure. This may be due to the mildly stimulating nature of citrus-like components (Aprianti, 2025).

This dissociation between speed and accuracy suggests that Fragrance C primarily facilitated cognitive efficiency rather than memory precision. From a neurocognitive standpoint, faster reaction times reflect improved attentional readiness and neural processing speed, potentially mediated by increased alertness or sensory-driven arousal rather than enhanced working memory storage or manipulation (Florio, 2025; Pandey, 2025). Such effects are consistent with evidence that olfactory stimulation can modulate attentional networks and motor preparation pathways without necessarily improving mnemonic accuracy (Wallace, 2021).

Importantly, the absence of statistical significance in accuracy, despite a moderate effect size, indicates that Fragrance C may exert a meaningful but variable influence on memory performance, which could become detectable with a larger sample. However, the large and statistically significant improvement in reaction time supports a genuine physiological effect on cognitive processing speed rather than random fluctuation.

4.3.4.4 Discussion on Placebo

The placebo condition demonstrated no statistically significant changes in either working memory accuracy or reaction time ($p > 0.05$), with both outcomes exhibiting moderate effect sizes but failing to reach statistical reliability. This pattern suggests that any observed numerical changes were likely due to practice effects, expectancy, or random variation, rather than a true cognitive effect of fragrance exposure.

From a methodological perspective, the placebo condition serves as a critical control, confirming that repeated task exposure alone did not produce consistent or robust improvements in working memory performance. The absence of statistically significant changes under placebo strengthens the internal validity of the findings observed in the fragrance conditions, particularly for Fragrance B and Fragrance C, where specific performance enhancements were detected.

4.3.4.5 Overall Discussion on Working Memory Results

Taken together, the EEG results suggest that exposure to the fragrances induced varying degrees of calmness, as reflected in changes in alpha and theta power. However, these changes in calmness did not consistently translate to improvements in working memory performance across all fragrances. For example, while Fragrance A increased EEG markers of calmness, its effect on memory accuracy and reaction time was minimal and non-significant. Fragrance B, on the other hand, showed both enhanced EEG calmness and a significant improvement in accuracy, suggesting that certain aroma profiles may simultaneously support relaxation and cognitive facilitation. Fragrance C improved reaction time significantly, indicating that specific citrus–floral compounds may enhance processing speed, even if memory accuracy remains unaffected. Overall, these findings suggest that fragrance may contribute to subtle cognitive benefits, but the relationship is not uniform and likely depends on the specific chemical composition of the fragrance.

Critically, these effects cannot be explained solely by relaxation or calmness. While EEG indices suggested changes in emotional or arousal states, only certain fragrances translated these physiological shifts into measurable cognitive benefits, supporting the concept of optimal arousal rather than generalized relaxation as a driver of cognitive enhancement. This dissociation underscores the importance of examining both neurophysiological and behavioural outcomes when evaluating the cognitive effects of olfactory stimuli because the observed calmness measured via EEG did not consistently translate into measurable improvements in working memory, suggesting that the relationship between relaxation and cognitive performance requires further investigation.