CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

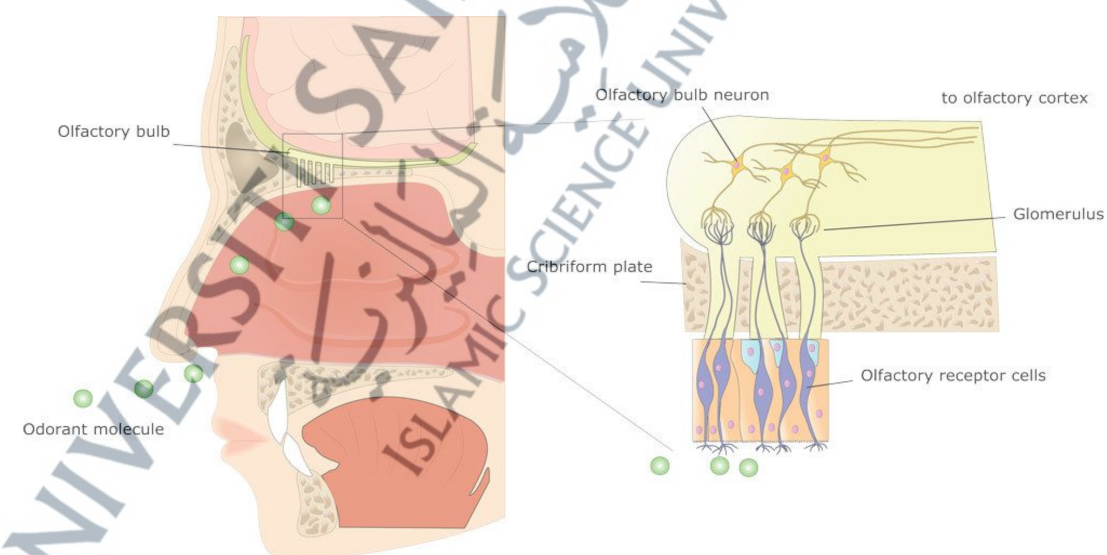
This section of the chapter critically examines current academic research concerning the impact of scents on human thought processes and emotional conditions, focusing specifically on EEG research and short-term memory. It explores earlier results on calmness triggered by fragrances, emphasizes the application of EEG for evaluating neurophysiological responses, and analyses the influence of fragrance exposure on working memory, particularly non-verbal and visual short-term memory. Moreover, it examines the use of gas chromatography-mass spectrometry (GC-MS) in studying fragrances to link particular chemical components with their noted impacts.

2.2 The Olfactory System: From Nose to Brain

2.2.1 Neural Mechanism

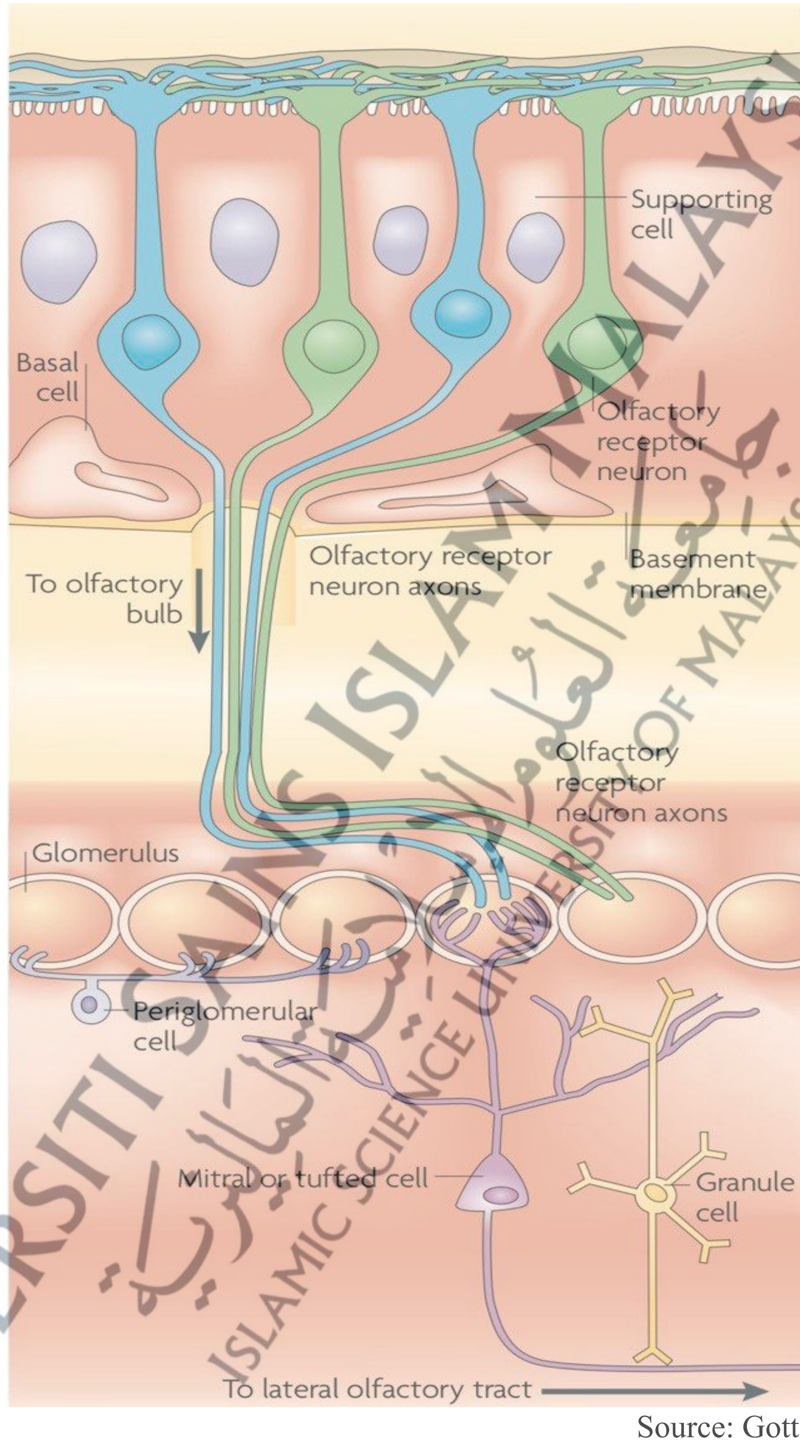
Olfaction, known as the sense of smell, is an intricate mechanism that allows individuals to identify scents (Barwich, 2020; Sharma *et al*., 2019). This process starts with specific receptors in the nasal space that detect fragrance molecules (Paluchova *et al*., 2017; Breer, 2024). These receptors produce signals that are conveyed to the olfactory bulb, which subsequently transmits them to different brain regions, such as the olfactory cortex and limbic system (Shiner, 2020). The olfactory cortex handles the perception and identification of smells, whereas the limbic system, associated with emotions and memory, affects the emotional responses and memories triggered by scents. Figure 2.1 depicts the main areas that play a role in the process of smelling. In addition to the olfactory cortex, the olfactory bulb transmits signals to the amygdala, hippocampus, and orbitofrontal cortex (Barwich, 2020). The amygdala handles emotion processing, the hippocampus is key for memory formation, and the orbitofrontal cortex participates in decision-making and reward processing, all of which shape the overall perception of smells.

To provide additional insight into the functional roles of these brain areas in the olfactory network, Gottfried (2015) offers a diagram of the neural circuitry that plays a role in fragrance perception (refer to Figure 2.2). This model demonstrates how signals travel from the olfactory receptor neurons in the nasal cavity to the olfactory bulb, subsequently reaching higher brain areas like the amygdala, hippocampus, and orbitofrontal cortex. These areas play roles in different aspects of olfactory processing, such as emotion regulation, memory creation, decision-making, and reward evaluation, respectively.



Source: Scottish Acquired Brain Injury Network Website (n.d)

Figure 2.1: The Important Parts of the Smell Mechanism



Source: Gottfried (2015)

Figure 2.2: Neurological Mechanism Behind the Effects of Scent on The Brain

Grasping these neural mechanisms is essential for analysing EEG data, since the careful positioning of EEG electrodes can assist in identifying brain activity linked to fragrance exposure. This focused strategy aims to provide important insights into the neurophysiological links of fragrance exposure and enhance understanding of how fragrances affect the human brain.

Within the scope of this research, a comprehensive grasp of these neural processes and their relationships is crucial for analysing the EEG data. By positioning EEG electrodes near important brain areas using this understanding, it will be feasible to identify and examine brain activity associated with fragrance-triggered calmness. This targeted method is expected to yield important insights into the neurophysiological links of calmness and furnish a more profound comprehension of how scents influence the human brain.

In addition, most existing studies on the olfactory system primarily emphasize its anatomical pathways and structural connectivity, focusing on regions such as the olfactory bulb, piriform cortex, amygdala, and orbitofrontal cortex. While these studies provide valuable insights into how fragrance information is processed in the brain, fewer investigations have examined the functional neurophysiological responses associated with emotional states such as calmness. Therefore, this study extends beyond anatomical descriptions by assessing functional brain activity using EEG, specifically through alpha and theta power modulation, to evaluate fragrance-induced calmness. This approach enables a more direct and objective measurement of neural responses to olfactory stimulation, addressing a critical gap in the literature and strengthening the scientific basis for fragrance-related emotional modulation.

2.2.2 The Role of Olfaction in Cognitive and Emotional Processing

The olfactory system maintains a unique link to the limbic system, which regulates emotions, memory, and involuntary functions (Jacobson *et al*., 2025; Kaushal *et al*., 2024). In contrast to other senses, olfactory signals bypass the thalamus and directly reach crucial brain areas, such as the amygdala and hippocampus (Mori & Sakano, 2021). This distinct neural route suggests that odors can greatly influence emotional and cognitive functions. This neurological framework supports the current research's examination of how soothing scents might influence emotional regulation and memory, evaluated through EEG measurements of brain activity.

Several studies have highlighted that olfactory triggers not only elicit emotional reactions but also stimulate autobiographical memories more efficiently than visual or auditory signals (Wyatt, 2025; De & Bender, 2018; Herz, 2016). This occurrence, commonly known as the "Proustian effect," emphasizes the powerful link between odors and the processes of memory encoding and retrieval. In terms of cognitive performance, fragrance can affect arousal, focus, and working memory by altering the brain areas responsible for these abilities (Fekri *et al*., 2023). Due to the significant anatomical and functional relationship between the olfactory system and memory-associated brain areas, this research leverages that link to investigate how soothing scents may affect brainwave patterns related to working memory, particularly emphasizing non-verbal and visual short-term memory capabilities. Building on this evidence, the present study integrates EEG alpha and theta power modulation with CogniFit app measures of non-verbal and visual short-term memory to assess the functional impact of calming fragrances on memory-related brain activity and performance.

2.2.3 Aromatherapy

The influence of scent on human thinking and wellness has become an increasingly intriguing topic. Fragrances, including both essential oils and synthetic compounds, engage with the olfactory system, initiating a series of neural activities that can affect multiple facets of brain function, such as mood, focus, and memory (Rawal *et al*., 2022; Rezaeyan *et al*., 2025). This connection is enabled by the robust anatomical and functional relationships between the olfactory system and essential brain areas involved in emotional and cognitive functions, such as the limbic system and prefrontal cortex (Jacobson *et al*., 2025; Bothwell *et al*., 2023).

The origins of aromatherapy can be linked to ancient cultures, and its recent revival is due to an increased fascination with holistic and alternative therapies (Farrar & Farrar, 2020). Aromatherapy's varied uses include inhalation and massage, showcasing its adaptability in tackling different physical and mental issues (Vora *et al*., 2024). The fragrant characteristics of plants, like Melissa Officinalis (lemon balm), are acknowledged for their important contribution to contemporary holistic mental wellness and mind-body practices. Although the use of scents in aromatherapy has historical origins and is frequently linked to relaxation and alleviation of stress, recent research has started to investigate the wider cognitive impacts of fragrance exposure (Farrar & Farrar, 2020). Research indicates that certain scents can affect brainwave patterns, which may impact cognitive functions such as attention, memory encoding, and retrieval (Cai *et al*., 2024; Sun *et al*., 2025; Ko *et al*., 2021). In line with this, the present study investigates how fragrance exposure modulates EEG alpha and theta power to reflect changes in calmness and working memory performance.

2.3 Psychological Effects of Fragrances

2.3.1 Fragrance-Induced Calmness and Relaxation

Studies have indicated that specific essential oils, including lavender and chamomile, possess anxiolytic properties and encourage relaxation (Sattayakhom *et al*., 2024; Ebrahimi *et al*., 2022). Research utilizing EEG has shown heightened alpha wave activity triggered by soothing scents, indicating improved relaxation and lowered stress levels (Santos *et al*., 2025). Additional research has emphasized the influence of various fragrance categories, such as citrus and floral scents, in adjusting stress reactions and emotional states. Certain scents might also affect neurotransmitter function, especially serotonin and dopamine, linked to mood control (Ahmad & Pratap, 2024). Consequently, this research aims to investigate how these mood-related pathways might affect EEG-assessed calmness and cognitive ability, especially regarding non-verbal and visual short-term memory.

2.3.2 EEG Studies on Fragrance Exposure

Several research studies have investigated the impact of scents on EEG activity. For example, being exposed to enjoyable scents has been linked to higher alpha and theta power, which reflects relaxation and improved cognitive function (Sun *et al*., 2025). EEG research has likewise indicated that unpleasant smells can trigger heightened beta and gamma wave activity, reflecting increased cognitive load and stress responses (Kwon *et al*., 2025). For instance, the scent of lavender has been associated with increased alpha wave activity, which correlates with relaxation and a tranquil state conducive to cognitive functioning (Ko *et al*., 2021). In contrast, the aroma of peppermint has been linked to increased beta wave activity, reflecting enhanced focus and attentional engagement (Thangaleela *et al*., 2022), which may support working memory performance. These results indicate that scents may trigger particular neurophysiological reactions that could affect different facets of cognitive abilities, such as working memory (Li *et al*., 2024; Cai *et al*., 2024; Lin *et al*., 2022).

Although beta activity is relevant to attention and cognitive effort, the present study does not analyse beta waves because its primary objective is to examine fragrance-induced calmness rather than task-driven cognitive arousal. Alpha and theta waves are more directly associated with relaxation, emotional regulation, and memory-related processes under low-arousal conditions, making them more appropriate indicators for the study's focus. The exclusion of beta wave analysis is therefore acknowledged as a methodological limitation.

Apart from their immediate effects on brainwaves, the chemical components of scents and their fragrance characteristics can affect the central nervous system, cognitive abilities, and psychophysiological processes (Sun *et al*., 2025; Masuo *et al*., 2021). The analysis of essential oils, specifically, requires additional research, since each element may have different psychoactive impacts (Bunse *et al*., 2022). EEG provides an effective method for charting the neural circuits engaged in handling olfactory data and the resulting influence on cognitive activities such as working memory. Research shows that the praecuneus, in conjunction with a network comprising the insula, amygdala, and medial orbital gyrus, is essential for the processing of pleasant scents (Carlson *et al*., 2020).

Furthermore, studies have reported gender differences in odor perception and associated EEG responses, with females often demonstrating more pronounced neural reactions to specific scents (Son *et al*., 2024). However, the present study focuses exclusively on male participants to control for biological variability related to hormonal fluctuations, menstrual cycle phases, and potential differences in olfactory sensitivity, which could confound EEG measurements and cognitive performance outcomes. By selecting male participants, this study aims to enhance internal validity and ensure greater consistency in neurophysiological responses, thereby allowing for a clearer interpretation of the effects of calming fragrances on brain activity and working memory. This design choice is acknowledged as a limitation, and future studies may extend this investigation to female populations for broader generalizability.

2.4 Neurophysiological Measurement (EEG)

2.4.1 Overview of EEG and Its Application in Neuroscience

EEG is a non-invasive method employed to observe the electrical activity of the brain, providing immediate information on cognitive and emotional conditions (Reaves *et al*., 2021). Various brainwave frequencies correspond to distinct mental states, where alpha waves are connected to relaxation and theta waves are associated with cognitive processing and memory consolidation (Hima *et al.*, 2020). EEG is extensively utilized in cognitive and affective neuroscience to evaluate variations in brain activity across diverse stimulus conditions. Research has additionally examined EEG power spectral density and connectivity assessments in evaluating emotional processing (Demuru *et al*., 2020). This research will employ EEG to identify alterations in alpha and theta wave activity after exposure to fragrance. It seeks to pinpoint neural indicators of calmness and their possible connection to working memory effectiveness.

2.4.2 Alpha, Theta, and Beta Waves

Alpha, theta, and beta waves represent distinct brain activity patterns that can be assessed and examined through EEG (Cho *et al*., 2024; Basharpoor *et al*., 2021). These brainwave patterns are linked to different cognitive and emotional processes, such as attention, relaxation, memory, and cognitive control, all of which are essential for working memory effectiveness and emotional regulation (Attar, 2022).

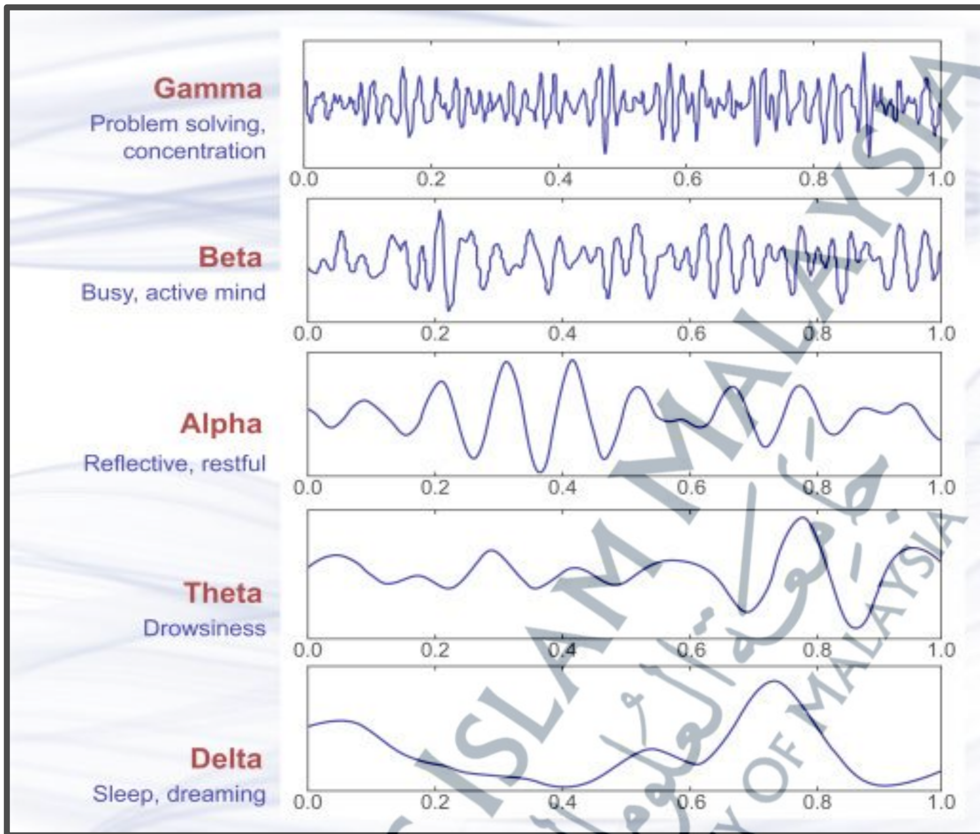
Alpha waves, usually fluctuating at frequencies ranging from 8 to 13 Hz, are frequently observed during calm alertness. An increase in alpha power, indicating the strength or intensity of alpha wave activity, has been consistently associated with sensations of calmness, reduced stress, and mental ease (Attar, 2022). In relaxed states, such as meditation or with closed eyes, alpha activity increases, reflecting reduced sensory processing and a shift toward internal mental activity. In this study, alpha power is examined as a neural indicator of calmness in response to fragrance exposure.

Theta waves, marked by slower frequencies between 4 and 7 Hz, are commonly linked to deep relaxation, meditation, and light sleep stages (Deshmukh, 2023). In addition, theta activity plays a critical role in memory encoding and retrieval, which are vital components of working memory. Increased theta power has been associated with enhanced cognitive processing and improved memory performance (Youvan, 2024; Deshmukh, 2023). In this study, theta power is analyzed to reflect fragrance-related changes in memory processing and cognitive relaxation.

Beta waves, typically ranging from 13 to 30 Hz, are associated with active thinking, focused attention, problem-solving, and heightened cognitive engagement (Diaz *et al*., 2019; Frikha *et al*., 2021). Elevated beta activity is often observed during task performance and alert mental states, and it has also been linked to anxiety and stress under certain conditions. Therefore, beta waves are relevant when examining cognitive effort and arousal levels during task-based activities. Although beta waves are relevant to active cognitive processing, they are not analyzed in this study as the primary focus is on calmness rather than heightened cognitive arousal.

Even though beta activity is theoretically relevant to cognitive processing and working memory, this study focuses specifically on alpha and theta waves due to their stronger association with relaxation, calmness, and memory-related processes in the context of fragrance exposure. Additionally, the present study aims to evaluate the calming effects of fragrances, making alpha and theta waves more appropriate indicators of the targeted emotional and cognitive states.

The exclusion of beta wave analysis is acknowledged as a limitation of the study, and future research may consider incorporating beta activity to provide a more comprehensive understanding of fragrance-related neural modulation. Figure 2.3 shows a visual depiction of the different brainwave types captured by EEG, emphasizing the link between alpha and theta waves and cognitive functions related to working memory, whereas Table 2.1 demonstrates the distribution of brain waves categorized by frequency bands.



Source: Abhang *et al* (2016)

Figure 2.3: Types of Waves and Their Patterns

Table 2.1: Brain wave distribution by frequency of band wave

Name of the Frequency	The frequency of Band Wave (Hz)
Delta	0.5-4
Theta	4-8
Alpha	8-13
Beta	13-30
Gamma	>30

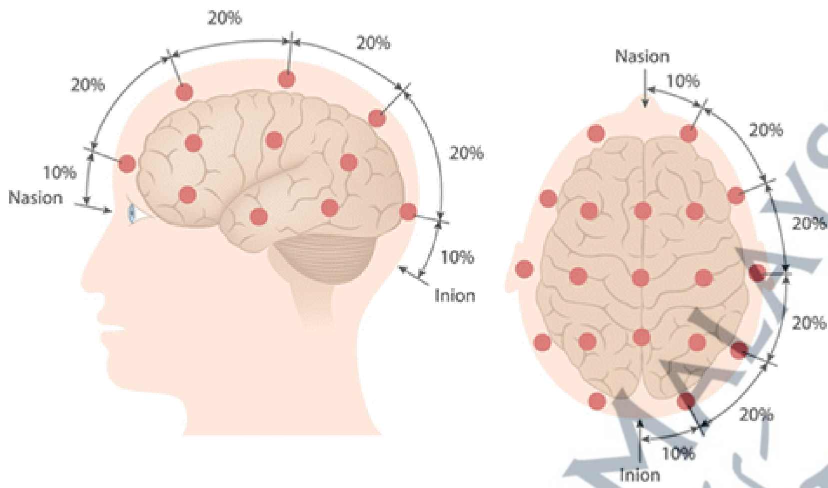
Source: Koudelkova *et al.* (2018)

2.4.3 Brain Signal Detection

EEG provides a non-invasive approach for identifying and examining the electrical activity produced by the brain, allowing for the assessment and analysis of neural signals linked to different cognitive and emotional conditions. This method captures the slight voltage changes resulting from the coordinated actions of countless neurons, offering insight into the ever-changing nature of brain activity (Toutant, 2023; Dube, 2024).

The process of EEG recording entails the careful positioning of electrodes on the scalp, usually adhering to standardized layouts like the commonly employed 10-20 system or the more detailed 10-10 system (Schuele, 2020). The selection of the electrode placement system is determined by the particular research aims and the intended degree of spatial precision in recording brain activity. The 10-20 system is a recognized approach for positioning electrodes on the scalp during EEG recording (Macorig *et al*., 2021). In this setup, electrodes are positioned at 10% or 20% intervals among significant landmarks on the head, including the nose, ears, and occipital region.

This setup offers broad monitoring of the brain's electrical activity and is commonly employed in both clinical and research environments because of its ease of use and efficiency, as can be seen in Figure 2.4. This standardized electrode placement enables accurate detection of electrical signals generated by neuronal activity across different cortical regions. As a result, it facilitates reliable measurement of brainwave patterns, such as alpha and theta activity, allowing for consistent assessment of functional brain responses during sensory and cognitive tasks.

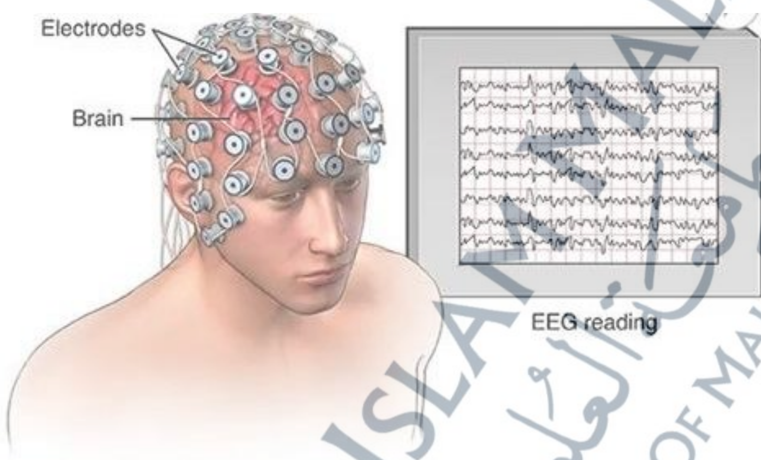


Source: Alotaiby *et al*. (2015)

Figure 2.4: EEG Electrode Placement

To achieve more detailed or specific brain activity mapping, the 10-10 system provides greater resolution by positioning the electrodes closer at intervals of 10% (Niso *et al*., 2023). This permits the usage of additional electrodes, offering greater spatial resolution regarding brain activity and enabling researchers to identify slight variations in brain waves among various areas. Both systems guarantee uniformity in electrode positioning, enhancing the reliability and comparability of EEG data among various subjects and research (Rojas *et al*., 2018; Jeon *et al*., 2018).

The electrodes (refer to Figure 2.5) identify the electrical signals generated by the brain, which are subsequently amplified and filtered through an EEG amplifier to improve signal quality and eliminate undesired noise (Devi *et al*., 2022). The EEG signals obtained reflect the combined electrical activity of the brain regions beneath, providing insight into the neural processes linked to different cognitive and emotional states. The EEG signals possess a range of frequency elements, typically known as brainwaves. These brainwaves, such as alpha, beta, delta, theta, and gamma waves, oscillate at unique frequency ranges and correspond to various brain states and cognitive functions (Roy *et al*., 2022; Attar, 2022).



Source: Koudelkova *et al*. (2018)

Figure 2.5: Electrode of EEG for Brain Signal Detection

EEG data analysis requires employing different signal processing techniques to derive meaningful information from intricate signals. A prevalent method, power spectral analysis, deconstructs the EEG signal into its frequency elements and evaluates the power or amplitude across each frequency range (Pahuja & Veer, 2022). This approach allows researchers to examine the roles of various brainwaves and recognize activity patterns associated with particular cognitive states or activities. Correct positioning of EEG electrodes is crucial for capturing electrical activity from pertinent brain regions and guaranteeing precise identification and understanding of neural signals (Qin *et al*., 2023).

2.4.4 EEG Perspective on Brain Regions Involved in Calmness and Memory

The assessment of calmness and cognitive capacity of working memory via EEG signals is intricately connected to the distinct roles of different brain areas. The frontal lobe, particularly the medial prefrontal cortex, is closely associated with emotional regulation, decision-making, and attentional control (Prodhan *et al*., 2024). The prefrontal cortex plays a central role in executive functions, including working memory, inhibitory control, cognitive flexibility, and goal-directed behaviour, making it a key region for evaluating higher-order cognitive processing. In addition, the temporal lobe, especially the medial temporal structures such as the hippocampus and entorhinal cortex, is critical for memory formation, storage, and retrieval, as well as for processing sensory inputs, including olfactory stimuli (Casillo *et al*., 2020).

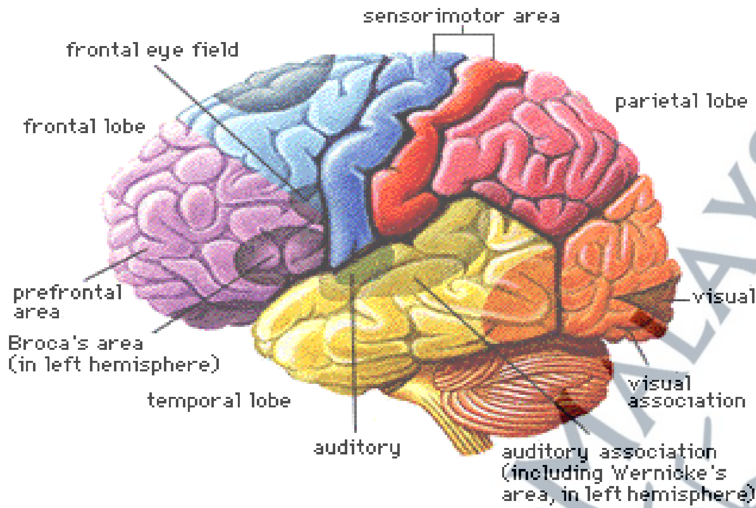
Moreover, studies show that heightened alpha activity in the frontal region frequently correlates with relaxation, whereas frontal theta activity is tied to focused attention and internal cognitive control (Basharpoor *et al*., 2021; Casillo *et al*., 2020). Consequently, the frontal cortex is essential in examining both calmness and executive functioning, particularly in response to sensory inputs such as scent. Figure 2.6 illustrates the main brain areas or lobes, whereas Figure 2.7 displays the placement of EEG electrodes.

Along with the frontal areas, the parietal and occipital regions, such as Pz, PO7, and PO8, are crucial for memory, sensory integration, and visual-spatial processing. These areas are recognized for producing alpha oscillations, essential for both relaxed alertness and activities that require memory retrieval (Chen & Rau, 2022). Pz (parietal midline) contributes to internal focus and calmness states, frequently exhibiting heightened alpha and theta activity in relaxed or meditative conditions (Lieberman *et al*., 2025).

Additionally, alpha activity in the parietal-occipital region is typically heightened during periods of mental relaxation, indicating its significance in assessing calmness. The PO7 and PO8 parietal-occipital electrodes play a role in sensory and emotional processing, showing sensitivity to rises in alpha power that generally indicate relaxed wakefulness and reduced cognitive effort (Ling *et al*., 2025). Additionally, the temporo-parietal junction plays a role in attention switching and episodic memory, which is crucial for examining alterations in working memory before and following cognitive or sensory interventions (Lago, 2024). Therefore, the frontal and parietal-occipital regions collectively provide a significant basis for examining both calmness and memory functions in EEG-based research.

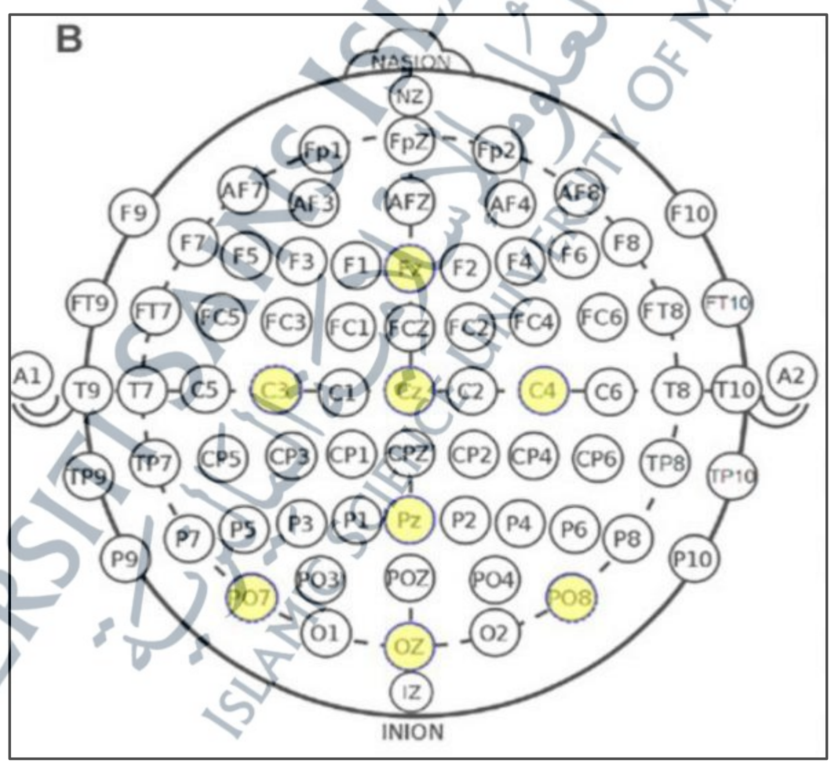
In this study, EEG recordings from the frontal (Fz), parietal (Pz), and parieto-occipital (PO7 and PO8) regions were used to examine fragrance-induced changes in alpha and theta power, providing insights into neural correlates of calmness and memory-related processing across these key brain areas.

Although the prefrontal and temporal lobes are known to play important roles in executive function and memory processing, this study focuses on Fz, Pz, and PO7/PO8 because these regions offer reliable indicators of calmness in response to fragrance exposure. The exclusion of direct prefrontal and temporal recordings is acknowledged as a limitation, and future studies may include these areas to provide a more comprehensive neural profile.



Source: Dixon (2010)

Figure 2.6: Lobes of the Brain



Source: G. tec Medical Engineering Website (n.d.)

Figure 2.7: Electrode Placement of the Unicorn Hybrid Black EEG System (EEG1–EEG8) on the Scalp

2.5 Cognitive Aspects (Working Memory)

2.5.1 Understanding Working Memory

Working memory refers to the ability to hold and manipulate information temporarily for cognitive tasks (Hartley & Hitch, 2022). It is crucial for learning, making decisions, and solving problems. This research centres on two primary aspects of working memory: visual short-term memory and non-verbal memory, as they are the core components of working memory. Models such as Baddeley's working memory framework emphasize the visuospatial sketchpad's function in managing visual and spatial data, whereas the phonological loop processes auditory input (Baddeley, 2021). Recent advancements in neuroscience have explored the neurobiological underpinnings of working memory, focusing on the role of the prefrontal cortex and hippocampus in short-term information storage (Sridhar *et al*., 2023). These brain areas are particularly significant in this research, as the effects of soothing scents on EEG activity could indicate neural adjustments linked to non-verbal and visual short-term memory processes.

2.5.2 Influence of External Factors on Working Memory

Studies indicate that external factors, such as exposure to fragrances, may influence working memory performance (Cai *et al*., 2024; Ambrosch *et al*., 2018). Certain research has indicated that exposure to particular scents improves memory retention, likely by affecting attention and arousal levels (Cai *et al*., 2024; Pizzoli *et al*., 2022). Moreover, olfactory cues have been associated with enhanced cognitive function in older adults, indicating possible uses for memory improvement in neurodegenerative conditions (Fatuzzo *et al*., 2023). Nonetheless, opposing results are present, as certain studies indicate no notable impact of fragrance exposure on working memory performance, suggesting the necessity for additional investigation. This research fills that void by utilizing EEG measurements and standardized memory tests to objectively assess how calming scents affect particular areas of working memory. In addition, non-verbal and visual short-term memory were independently assessed in this study using the CogniFit app, providing reliable behavioural measures of working memory performance.

2.5.3 Smell and Memory

The connection between fragrance and memory is deep, as odors frequently act as strong catalysts for detailed memories (Greco *et al*., 2025). The occurrence of aromas triggering memories is a widespread human phenomenon, and its foundational processes have been thoroughly examined in neuroscience and psychology (Ahmad & Pratap, 2024; Greco *et al*., 2025). The olfactory system, which detects and processes smells, has a distinct anatomical link to the limbic system, specifically the amygdala and hippocampus, which are essential brain areas related to emotion and memory, respectively (Freiherr, 2017). This direct route enables scents to trigger intense emotional reactions and aids in recalling memories tied to particular events or experiences. This relationship stems from the tight connection between the olfactory system and the limbic system, leading to enduring memory traces associated with olfactory signals.

Research has examined how smells can serve as strong triggers for memory recall in different situations, including a study on the effects of fragrance exposure during encoding and later memory retrieval (Dalal *et al*., 2020). Moreover, research has shown that being exposed to particular scents while learning or encoding can improve memory recall when that scent is experienced again during retrieval, a phenomenon referred to as fragrance-dependent memory (White *et al*., 2015). This implies that the contextual details offered by smells during encoding become a crucial component of the memory trace, aiding retrieval when the olfactory signal is presented again. In contrast, the present study evaluates memory performance before and after fragrance exposure rather than examining scent-dependent memory, focusing on the immediate effects of calming scents on working memory capacity.

2.6 Chemical Analysis (GC-MS)

2.6.1 Chemical Composition and Neurophysiological Effects

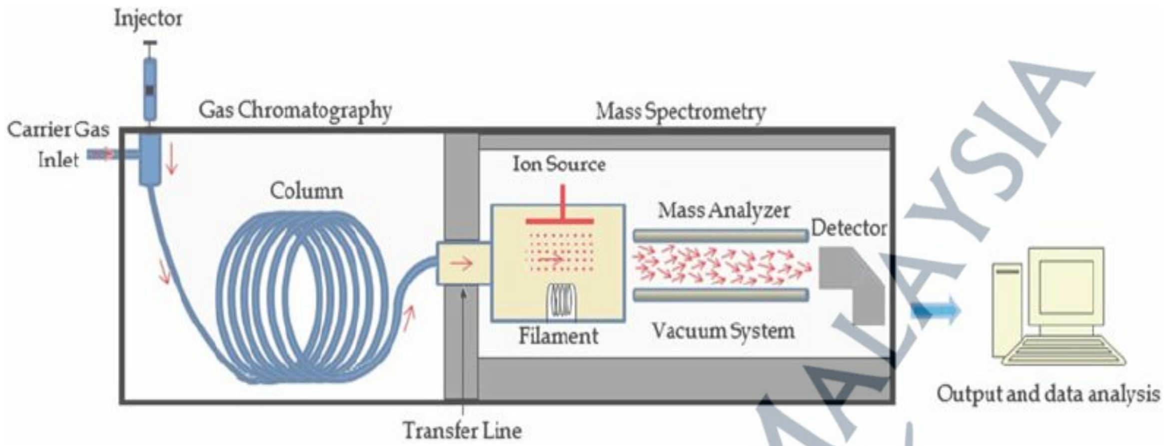
The chemical composition of fragrance is essential to its impact on the brain. Various fragrance elements engage with different receptors in the olfactory system, resulting in unique neural activation patterns as well as cognitive and emotional responses (Spence, 2020). Examining the chemical makeup of scents through methods such as GC-MS provides a clearer insight into their possible impacts on the brain. This information can guide the choice and development of scents for particular aims, like boosting working memory or encouraging relaxation.

2.6.2 Introduction to GC-MS

Gas Chromatography-Mass Spectrometry (GC-MS) is a method for analysing and identifying chemical substances within complex mixtures (Hubschmann, 2025). It is commonly used in fragrance studies to analyse the makeup of essential oils and synthetic scents. Improvements in GC-MS methods enable precise identification of volatile organic compounds, which are essential for fragrance perception and physiological reactions (Mahmoud *et al*., 2024).

GC-MS functions by isolating volatile elements in a fragrance blend using gas chromatography, then identifying them through mass spectrometry according to their mass-to-charge ratios. This dual-purpose feature permits both qualitative and quantitative assessments of fragrance compounds, enabling scientists to identify even minute components that could influence psychological or neurophysiological effects (Ranjan *et al*., 2023). The process of gas chromatography functions by vaporizing the fragrance sample and moving it through a capillary column using an inert gas. In this process, the substances are isolated based on their volatility and their interaction with the column's stationary phase (Falaki, 2019). When each compound leaves the column at unique times (retention times), it is channelled into the mass spectrometer, where the molecules are ionized and identified according to their specific mass-to-charge (m/z) ratios. The generated chromatogram features peaks that illustrate the chemical composition of the fragrance sample. This method offers not just a chemical "fingerprint" of the scent but also facilitates the recognition of compounds that might possess psychoactive or soothing effects (McNair *et al*., 2019). Figure 2.8 depicts the elements of the GC-MS system along with its analytical process.

In the framework of this research, GC-MS is vital for pinpointing the primary bioactive compounds that may contribute to promoting calmness and influencing brain function. These chemical profiles might be linked with EEG data, providing a biochemical rationale for the changes in brainwave patterns and memory performance seen after exposure to fragrance.



Source: Emwas *et al*. (2015)

Figure 2.8: Main Components of GC-MS

2.6.3 Linking Chemical Components to Neurophysiological Effects

Research has sought to link particular chemical substances in scents to their psychological and cognitive impacts (Masuo *et al*., 2021). For instance, linalool, a key ingredient in lavender oil, is linked to calming and anti-anxiety effects. Likewise, limonene, present in citrus-scented products, has been associated with heightened alertness and enhanced mood (Agarwal *et al*., 2022). Apart from that, substances such as eucalyptol and alpha-pinene have demonstrated the ability to influence neurotransmitter activity, possibly improving calmness or concentration based on their concentration and combination (Weston *et al*., 2021).

Additionally, these results reinforce the idea that specific fragrance elements can have focused influences on brain activity, based on their molecular characteristics and concentration. The intricate nature of fragrance blends, typically made up of many volatile compounds, complicates the task of separating the influence of an individual element

(Louw, 2021). Consequently, connecting particular compounds to brain activity measured by EEG necessitates a multidisciplinary strategy that integrates analytical chemistry and neuroscience. More studies are required to confirm clear links between fragrance compounds and their effects on neurophysiology, especially in EEG-focused research. In this research, the chemical profiles acquired from GC-MS will act as the basis for investigating how these compounds could aid in fragrance-related calmness and enhancements in working memory, as indicated by variations in alpha and theta wave activity during EEG recording.

2.7 Gender Differences in Olfaction

Research has consistently reported that males and females differ in olfactory sensitivity and perception. Females often exhibit heightened sensitivity to odors, faster identification, and more pronounced neural responses in olfactory-related brain regions compared to males (Sorokowski *et al*., 2019; Son *et al*., 2024). These differences are thought to be influenced by biological factors such as hormonal fluctuations and structural variations in olfactory pathways.

Related to this study, only male participants were recruited to reduce variability in EEG responses and behavioural performance due to gender-related differences in olfactory sensitivity. This approach allows for a more controlled assessment of fragrance-induced calmness and working memory performance. However, this design choice limits generalizability, and future research is encouraged to include female participants or conduct comparative analyses to better understand gender-specific neural and cognitive responses to fragrance exposure.

2.8 Conceptual Framework

The conceptual framework of this study illustrated the relationships among fragrance exposure, brainwave modulation, and working memory performance. Calming fragrances were proposed to influence neural activity, particularly alpha and theta power, in the frontal, parietal, and parieto-occipital regions, reflecting changes in calmness and relaxation. Independently, working memory performance was assessed via the CogniFit app, focusing on non-verbal and visual short-term memory.

Additionally, the fragrance samples used in this study were analysed using GC-MS to identify their chemical composition, and qualitative interpretations of these compounds were made to explore their potential contributions to the observed neurophysiological and cognitive effects. This framework highlighted the pathway whereby fragrance exposure could induce physiological changes in the brain and corresponding effects on cognitive outcomes, providing a structured approach for investigating the neurocognitive effects of fragrance.

2.9 Summary of Literature Gaps

Although current studies offer valuable insights into how fragrances affect brain activity and cognitive performance, several significant gaps remain. First, most research has focused on subjective reports of mood or relaxation (Sabiniewicz *et al*., 2022; Baccarani *et al*., 2021), with limited objective assessment of neurophysiological mechanisms. Few studies have directly examined how specific fragrance compounds modulate brain activity using techniques such as EEG, ERP, or fMRI, particularly in male participants. While some fMRI studies have explored olfactory processing in relation to emotional responses (Martial *et al*., 2023; Wu *et al*., 2018), these investigations rarely link specific fragrances to measurable changes in cognitive functions like working memory. Similarly, ERP research has examined fragrance perception and attentional processes (Li *et al*., 2022; Abbasi *et al*., 2020); however, there is limited evidence connecting these findings to sustained changes in memory-related neural activity.

Other than that, validated behavioural assessment tools for working memory, such as the CogniFit app, are rarely incorporated in fragrance research. Most studies rely on simple recall tasks or subjective cognitive ratings (Healey *et al*, 2019; Srivastava & Vul., 2017), which may not capture subtle changes in non-verbal or visual short-term memory performance. This limitation highlights the need for standardized, technology-based cognitive assessments to provide more precise and objective measurements of working memory performance following fragrance exposure.

Overall, these gaps highlight the need for studies that integrate chemical profiling of fragrances (e.g., via GC-MS), objective neurophysiological measurements (EEG alpha and theta activity), and validated cognitive assessments (CogniFit) to comprehensively evaluate the effects of fragrance on calmness and working memory. The present study addresses these gaps by combining these methodologies to provide both physiological and behavioural evidence of fragrance-related modulation of brain function and cognitive performance.