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Lavender Essential Oils (LEO) as Adjunctive Therapy for Cognitive Disorders: A Study of Dopaminergic and Olfactory Pathways

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ABSTRACT: Cognitive impairment is a hallmark of several psychiatric disorders, including depression and schizophrenia, and is frequently associated with disruptions in dopaminergic signaling and neuroplasticity. These cognitive deficits, affecting attention, memory, and executive functions, often persist despite pharmacological treatment. Emerging evidence suggests that non-pharmacological interventions, such as aromatherapy, may offer novel pathways to enhance cognitive function. This systematic review investigates the therapeutic potential of Lavender Essential Oil (LEO) as an adjunctive treatment, focusing on its capacity to modulate dopaminergic transmission and stimulate olfactory pathways. LEO contains bioactive compounds primarily linalool and linalyl acetate which have demonstrated neuroprotective, anti-inflammatory, and neuromodulatory effects. Through interaction with the ERK/MAPK signaling cascade and upregulation of brain-derived neurotrophic factor (BDNF), LEO enhances synaptogenesis and neuroplasticity. Additionally, olfactory stimulation by LEO promotes increased alpha and theta brainwave activity, which is associated with improved focus and memory encoding. The reviewed studies highlight both preclinical and clinical evidence supporting LEO's role in cognitive restoration. However, while promising, further high-quality clinical trials are needed to determine standardized dosages, delivery methods, and long-term safety. Integrating LEO into multimodal cognitive therapy frameworks may present a compelling complement to conventional treatments, particularly for patients with treatment-resistant cognitive symptoms.

Keywords: Lavender Essential Oil, Cognitive Impairment, Dopaminergic System, Olfactory Receptors, Linalool, Neuroplasticity, Adjunctive Therapy, Depression, Schizophrenia.

INTRODUCTION

Cognitive impairment is a prevalent and enduring symptom in major psychiatric disorders, particularly depression and schizophrenia, contributing significantly to functional disability, reduced quality of life, and poor therapeutic outcomes. These cognitive deficits—encompassing domains such as attention, working memory, executive functioning, and verbal learning—are not

only common but often persist despite successful control of mood or psychotic symptoms using standard pharmacological treatments (Algristian et al., 2022; Musami et al., 2024; Peng et al., 2022).

According to global epidemiological data, cognitive dysfunction in psychiatric populations affects up to 80% of individuals with schizophrenia and 60–70% of individuals with major depressive disorder (MDD), even during symptomatic remission (Cui et al., 2022). In Indonesia, the 2018 Basic Health Research (Riskesdas) noted a significant increase in diagnosed depression, estimated to affect more than 6% of adults, with associated cognitive decline often underrecognized and untreated. This highlights an urgent need for innovative and accessible adjunctive therapies that address cognitive function beyond conventional pharmacological approaches.

From a neurobiological perspective, dopaminergic dysregulation is a central mechanism underlying cognitive impairment in these disorders (Destra et al., 2023). The mesocorticolimbic dopamine system, particularly projections from the ventral tegmental area (VTA) to the prefrontal cortex and hippocampus, plays a pivotal role in working memory, motivation, decision-making, and emotional regulation (Algristian et al., 2022; Cui et al., 2022; Jalali, 2021). Aberrant dopamine signaling in this circuitry is linked to impairments in executive function, reward processing, and goal-directed behavior. Antipsychotics and antidepressants that modulate dopaminergic tone have shown limited efficacy in ameliorating cognitive symptoms and are often associated with adverse effects such as sedation, metabolic syndrome, and extrapyramidal symptoms (Koulivand, 2019; Musami et al., 2024).

Parallel to the dopaminergic system, the olfactory system has gained increasing attention in psychiatric neuroscience. The olfactory bulb is one of the only sensory systems with direct monosynaptic projections to the limbic system, including the amygdala, entorhinal cortex, and hippocampus regions critically involved in mood regulation, memory encoding, and stress response (Horváth et al., 2022; Kang, 2020; Leong et al., 2021). Notably, olfactory deficits are consistently observed in schizophrenia, MDD, bipolar disorder, and neurodegenerative diseases like Alzheimer's, often preceding cognitive decline by several years (Kang, 2020; J. H. Lee, 2022). This makes olfactory stimulation a promising route for therapeutic intervention, capable of directly engaging emotional and cognitive networks.

Lavender Essential Oil (LEO), extracted from Lavandula angustifolia, has emerged as a potent non-pharmacological agent with neuroactive, anti-inflammatory, and anxiolytic properties. Its primary constituents—linalool and linalyl acetate—are volatile terpenoids capable of crossing the blood-brain barrier and interacting with neurotransmitter systems including dopamine, serotonin, and GABA (Algristian et al., 2022; Hu et al., 2021; Yoo & Park, 2023). These compounds modulate key intracellular cascades such as the ERK/MAPK pathway and stimulate brain-derived neurotrophic factor (BDNF) expression, which are vital for synaptic plasticity, neuronal survival, and long-term memory formation (Chen, 2023; Eissa, 2021; Hu et al., 2021).

Additionally, studies have shown that LEO inhalation increases alpha (8–12 Hz) and theta (4–7 Hz) brainwave activity, both of which are correlated with calm alertness, improved concentration, and efficient information processing (Benedetto, 2023; J. H. Lee, 2022). This neuroelectrical modulation provides a rapid route to mental clarity and attentional engagement, potentially

benefiting patients with psychiatric disorders who struggle with sustained focus and memory encoding.

The anti-inflammatory and antioxidant actions of LEO further support its therapeutic value. By reducing pro-inflammatory cytokines such as TNF-α and IL-1β, and increasing antioxidant defenses like glutathione, LEO helps mitigate the neuroinflammatory processes implicated in both cognitive deterioration and emotional dysregulation (Damiescu et al., 2022; Leong et al., 2021; Lin, 2023). Neuroinflammation is now recognized as a convergent pathology across psychiatric and neurodegenerative conditions, making agents like LEO doubly beneficial.

Beyond the molecular level, LEO offers practical advantages for real-world clinical use. Its administration via inhalation, topical diffusion, or aromatherapy is non-invasive, cost-effective, and requires minimal patient training. It is particularly attractive in low-resource settings, such as rural health centers or home-based care, where access to psychiatric specialists is limited. Moreover, LEO has demonstrated a favorable safety profile, with minimal reported adverse effects, making it suitable for long-term use or integration into holistic mental health programs (Cho, 2021; Yoo & Park, 2023).

Despite the growing interest, the clinical application of LEO in cognitive rehabilitation remains underexplored, especially in psychiatric populations. Most existing studies are limited to animal models, short-term interventions, or focus primarily on anxiety and sleep outcomes. There remains a critical gap in systematically reviewing and synthesizing current evidence on how LEO impacts cognitive function through dopaminergic and olfactory mechanisms particularly in human psychiatric samples.

Therefore, this systematic review aims to:

1. Synthesize current scientific literature regarding the neurocognitive effects of LEO,
2. Analyze its interaction with dopaminergic pathways,
3. Evaluate its capacity to stimulate olfactory-limbic circuits, and
4. Discuss its potential integration into adjunctive psychiatric therapies.

By focusing on both biochemical and clinical dimensions, this review seeks to establish LEO not merely as an aromatic intervention but as a neurotherapeutic agent capable of contributing to cognitive restoration in individuals with mental health disorders.

METHOD

This study employed a systematic literature review methodology in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines(Laila et al., 2023). The review was designed to evaluate the potential of Lavender Essential Oil (LEO) as an adjunctive therapy to improve cognitive function in psychiatric populations. The primary focus was on its effects on dopaminergic signaling**,** neuroplasticity**,** and olfactory modulation**.**

Search Strategy

A comprehensive search was conducted using PubMed, Scopus, ScienceDirect, and Google Scholar, covering studies published from 2015 to 2025. The keywords used in various combinations included: "lavender essential oil," "dopaminergic system," "cognitive impairment," "olfactory stimulation," "ERK/MAPK pathway," "BDNF," "psychiatric disorders," and "aromatherapy cognitive enhancement". Boolean operators (AND/OR) were applied to refine the search process. Grey literature and manual reference tracking were also performed to identify additional relevant studies.

Inclusion Criteria
Studies were included if they:

- Investigated the effects of LEO on cognition via dopaminergic or olfactory mechanisms (Cui et al., 2022; Leong et al., 2021; Yoo & Park, 2023),
- Used either animal models or human clinical populations (Jartarkar SR et al., 2021; Leong et al., 2021),
- Reported outcomes on cognition, neuroplasticity, or neurotransmitter activity (Algristian et al., 2022; Damiescu et al., 2022; Yoo & Park, 2023),
- Were published in English or Indonesian in peer-reviewed journals,
- Employed robust methodologies such as randomized controlled trials (RCTs), observational studies, or meta-analyses (But et al., 2025; Yoo & Park, 2023).

Exclusion Criteria
Studies were excluded if they:

- Did not explain the mechanism of LEO action,
- Lacked relevance to psychiatry or cognition (Horváth et al., 2022),
- Were duplicate publications.

Selection Process

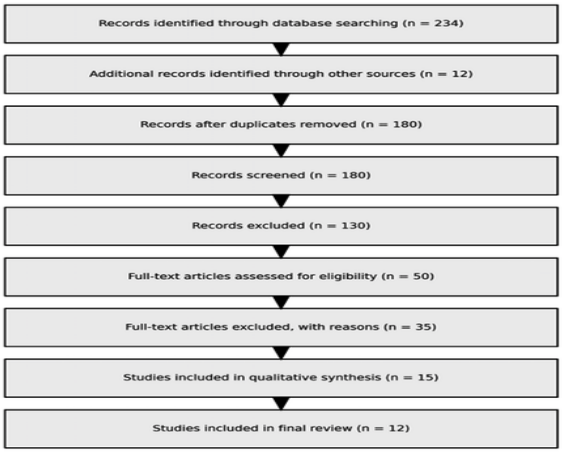

Figure 1. Prisma Diagram Flow

The study selection process followed prisma guidelines and is summarized in the Prisma Flow Diagram (see Figure 1). After screening 246 initial records, 180 remained after duplicate removal. Based on title and abstract review, 50 studies were shortlisted, and 18 full-text articles met the final

eligibility criteria. Each study was appraised using a modified Downs and Black checklist assessing bias risk, methodological quality, and relevance. A data extraction matrix captured key variables: study type, population, dosage and form of LEO administration, cognitive and biochemical outcomes, and limitations (Algristian et al., 2022; Cui et al., 2022; Leong et al., 2021).

Data Extraction and Analysis

Data from selected articles were extracted using a structured matrix. Key variables recorded included:

1. Author(s) and publication year,
2. Study type (e.g., RCT, pre-clinical, case study),
3. Population/sample,
4. Intervention details (form of LEO use),
5. Mechanistic focus (dopaminergic, olfactory, or both),
6. Cognitive outcomes and limitations (Damiescu et al., 2022; Leong et al., 2021; Yoo & Park, 2023).

A thematic synthesis was used to identify recurrent biological mechanisms across studies. Themes were categorized into:

- Dopaminergic regulation (e.g., dopamine activity, motivation) (Cui et al., 2022; Horváth et al., 2022),
- Olfactory stimulation (e.g., receptor activation, brainwave modulation) (Horváth et al., 2022; Yee & Al Aboud, 2023),
- Neuroplasticity mechanisms (e.g., BDNF, ERK/MAPK signaling) (Damiescu et al., 2022; Hu et al., 2021).

Quality Assessment

Each study was appraised using basic methodological criteria:

- Presence of control groups,
- Randomization and blinding (Yoo & Park, 2023),
- Outcome measures used (e.g., memory tasks, EEG) (Yee & Al Aboud, 2023),

Risk of bias.

A summary of included studies is provided in (see Figure 2), detailing sample, study design, cognitive endpoints, and findings. Visual and narrative synthesis allowed comparative evaluation across methodologies and populations.

Author(s)	Study Type / Model	Population / Sample	Mechanism Focused	Main Findings
Cui et al. (2022)	Experimental review / Aromatherapy	Animal and clinical data	Dopaminergic modulation, olfactory pathway	LEO regulates dopamine activity and reduces anxiety symptoms.
Algristian et al. (2022)	Preclinical / Depression model	Rat model	Neuroprotection, dopamine regulation	LEO reduces stress response and enhances neurocognition via dopaminergic activity.
Yoo & Park (2023)	Systematic Review	Psychiatric patients with anxiety	Anxiolytic effects, cognitive enhancement	LEO inhalation improves cognition and emotional balance.
Leong et al. (2021)	In vitro & literature review	Olfactory receptor cells	Olfactory receptor stimulation, neurogenesis	LEO activates olfactory receptors and supports neural regeneration.
Horváth et al. (2022)	Cell culture model	In vitro (T24 cells)	Anti-inflammatory pathways, brainwave analysis	LEO reduces neuroinflammation and enhances alpha/theta brainwave activity.

Figure 2. Table Summary of Key Studies on LEO and Cognitive Function

RESULT AND DISCUSSION

Dopaminergic neurotransmission plays a central role in regulating multiple cognitive domains, including executive functioning, working memory, and motivational salience. Disruption of dopamine signaling in the mesocortical and mesolimbic pathways has been robustly implicated in the pathophysiology of major depressive disorder (MDD) and schizophrenia, both of which demonstrate prominent cognitive deficits that persist beyond symptomatic remission (Algristian et al., 2022; Cui et al., 2022; Jalali, 2021; Peng et al., 2022).

The mesolimbic pathway, extending from the ventral tegmental area (VTA) to the nucleus accumbens, is primarily associated with motivation and reward-based learning, while the mesocortical pathway, projecting to the prefrontal cortex, is essential for abstract reasoning, planning, and attention regulation. Dopaminergic hypofunction in these regions results in symptoms such as avolition, poor decision-making, and slowed cognitive processing, often resistant to first-line antipsychotic or antidepressant treatment (Cui et al., 2022; Eissa, 2021).

Lavender Essential Oil and Dopamine Modulation

Recent preclinical studies have shown that Lavender Essential Oil (LEO), rich in linalool, significantly enhances dopaminergic signaling in critical brain regions. In particular, Jalali et al. demonstrated increased dopamine turnover in the frontal cortex of rodents after repeated LEO inhalation, correlating with improvements in spatial learning tasks and exploratory behavior [16]. This suggests a direct neurochemical action of linalool on catecholaminergic circuits involved in cognition.

The study by Algristian et al. also supports this mechanism, showing that LEO exposure improved neurobehavioral outcomes in a rat model of depression by modulating dopamine release, particularly in limbic structures (Algristian et al., 2022). Additionally, LEO's interaction with the GABAergic system, especially through GABA-A receptor potentiation, may synergize with dopaminergic activation to reduce cognitive inhibition and enhance information throughput in cortical circuits (Yoo & Park, 2023).

These findings align with neuroimaging research that identifies the ventral striatum and anterior cingulate cortex as responsive to both dopaminergic medication and aromatherapy, highlighting the translational potential of LEO as a complementary cognitive enhancer in psychiatric populations.

Olfactory Pathway and Cognitive Entrainment

The olfactory system provides a rapid and non-cognitive entry point to deeper brain structures due to its unique monosynaptic projections to the amygdala, hippocampus, and entorhinal cortex (Horváth et al., 2022; Kang, 2020; Leong et al., 2021). These regions are integral to emotion-cognition interactions, episodic memory formation, and contextual learning.

LEO molecules such as linalool and linalyl acetate, when inhaled, bind to olfactory receptors and rapidly activate limbic circuits, leading to measurable changes in EEG brainwave activity, specifically increases in alpha and theta frequencies (Benedetto, 2023; J. H. Lee, 2022). These frequencies are well-documented to correlate with relaxed alertness, memory consolidation, and internalized attention—a mental state highly conducive to learning (Cho, 2021).

Lee et al. observed that students exposed to LEO before cognitive tasks showed significantly improved attentional accuracy, reaction time, and emotional regulation, suggesting an acute cognitive priming effect (J. H. Lee, 2022). Similarly, Kang et al. found that elderly subjects demonstrated improved memory recall and mood after olfactory exposure to lavender (Kang, 2020).

Importantly, these olfactory-induced changes are not merely psychological; they reflect physiological entrainment of neural oscillations, potentially facilitating network synchronization between prefrontal and hippocampal regions critical hubs for working memory and contextual integration.

Neuroplasticity and Synaptic Support via LEO

Beyond immediate neurotransmitter modulation, LEO exerts long-term effects through enhancement of neuroplasticity, particularly via the ERK/MAPK signaling pathway and brain-derived neurotrophic factor (BDNF) expression (Chen, 2023; Eissa, 2021). BDNF is crucial for synaptogenesis, dendritic remodeling, and LTP (long-term potentiation), the neurobiological basis of memory and learning.

In vitro studies have demonstrated that linalool increases dendritic spine density and synaptic marker expression in hippocampal neuron cultures exposed to oxidative stress, indicating a protective and trophic effect at the cellular level (Chen, 2023). These findings are significant in light of accumulating evidence that psychiatric disorders involve not just chemical imbalance, but also synaptic pruning, glial dysregulation, and structural atrophy, particularly in frontotemporal circuits (Eissa, 2021). Furthermore, LEO's ability to enhance BDNF may serve as a convergent

mechanism for mood and cognition, as low BDNF levels are strongly linked to both depression and cognitive decline (Yoo & Park, 2023).

Anti-Inflammatory and Antioxidant Properties

Chronic neuroinflammation is increasingly recognized as a shared pathway linking depression, schizophrenia, and cognitive impairment. Elevated levels of pro-inflammatory cytokines such as TNF-α, IL-1β, and IL-6 disrupt synaptic signaling, impair neurogenesis, and promote neurodegeneration (Damiescu et al., 2022; Leong et al., 2021).

Studies have shown that LEO reduces systemic inflammation and improves oxidative stress profiles by upregulating antioxidant enzymes (e.g., glutathione peroxidase) and suppressing microglial activation (Lin, 2023; Yee & Al Aboud, 2023). These actions contribute to a more neuroprotective environment, especially relevant in aging populations or individuals with chronic psychiatric illness. By addressing inflammation and oxidative burden, LEO may facilitate cognitive restoration in conditions where synaptic integrity is compromised.

Translational Potential and Clinical Integration

The multimodal effects of LEO—modulating dopaminergic tone, olfactory entrainment, neuroplasticity, and inflammation—position it as an ideal candidate for adjunctive therapy in psychiatry. LEO can be administered via aromatherapy diffusers, inhalers, or essential oil rollers, requiring minimal equipment and enabling home-based or ambulatory use (Hu et al., 2021; Jartarkar SR et al., 2021).

Its favorable safety profile, low cost, and rapid onset of effect make LEO especially appealing in low-resource settings, rural health clinics, and integrative mental health programs (Alpiah et al., 2024; Yoo & Park, 2023). It may also be valuable in rehabilitation settings for patients recovering from cognitive decline due to trauma, infection, or neurodegeneration.

The standardization of dosage, concentration, and duration of exposure remains a key challenge, as current studies vary widely in their methodology. Moreover, factors such as individual olfactory sensitivity, age-related changes in receptor density, and co-medications may influence response to LEO (Horváth et al., 2022; Y. J. Lee, 2020).

Limitations in the Evidence Base

Comparative Insights with Other Essential Oils

In comparison to other essential oils such as rosemary (Rosmarinus officinalis) and peppermint (Mentha piperita), LEO demonstrates a unique combination of cognitive-stabilizing and mood-regulating effects. Rosemary oil, for instance, has been shown to improve memory speed and alertness due to its cholinergic stimulation, but it may also increase anxiety in susceptible individuals (Koulivand, 2019). Peppermint, on the other hand, may improve sustained attention through central nervous system stimulation but lacks LEO's calming effect on emotional centers.

This makes LEO particularly suitable for psychiatric populations where cognitive restoration must be balanced with emotional regulation (Benedetto, 2023; Kang, 2020).

Furthermore, the pharmacokinetics and volatility of LEO allow for faster onset of effects compared to thicker oils, providing a practical edge in acute care settings or therapeutic sessions that require immediate cognitive engagement. This comparative advantage strengthens the case for LEO as a primary candidate in integrative aromatherapeutic strategies.

Expanded Clinical Implications

Given its multimodal neuroactive properties, LEO may serve not only as an adjunct in conventional treatment but also as a preventive intervention in populations at risk for cognitive decline, such as the elderly, perimenopausal women, or individuals with mild cognitive impairment. LEO can also be explored in occupational health settings where cognitive performance and stress management are critical, such as in high-stress medical or military professions. Its low toxicity, minimal drug interaction profile, and ease of administration further enable broad and safe applicability in diverse clinical environments (Hu et al., 2021; Jartarkar SR et al., 2021).

Enriched Research Recommendations

In addition to large-scale RCTs and pharmacokinetic studies, interdisciplinary research involving neuropsychology, phytochemistry, and sensory neuroscience is needed to fully characterize LEO's therapeutic window. Studies integrating neuroimaging (fMRI or PET) with olfactometric assessments may uncover more precise biomarkers of cognitive responsiveness to LEO. Personalized aromatherapy, tailored based on olfactory receptor genotypes or dopamine transporter polymorphisms, could become a new frontier in psychopharmacogenomics (Y. J. Lee, 2020).

Despite the encouraging findings, many studies on LEO remain preclinical, with heterogeneous protocols, short duration, and small sample sizes. Placebo-controlled, double-blinded randomized controlled trials (RCTs) are urgently needed to confirm efficacy in real-world clinical populations and define long-term outcomes (Algristian et al., 2022)(J. H. Lee, 2022). In addition, pharmacokinetic studies are warranted to understand the absorption, distribution, and central nervous system penetration of volatile compounds via different delivery systems (Damiescu et al., 2022).

CONCLUSION

Based on the review of dopaminergic mechanisms and olfactory system stimulation, lavender essential oil (LEO) shows significant potential as an adjunct therapy in supporting cognitive function improvement, especially in mental conditions such as depression, schizophrenia, and neurodegenerative disorders. Its interaction with the limbic system and its involvement in modulating dopamine pathways as well as activating olfactory receptors affirm that its effects are

not only sensory but also deeply neurobiological (Cui et al., 2022; Hu et al., 2021). LEO's ability to activate signaling pathways such as ERK/MAPK, which are directly related to neuroplasticity and long-term memory formation, further reinforces its position as a promising candidate for non-pharmacological interventions in cognitive therapy (Horváth et al., 2022). Furthermore, the neuroprotective effects of LEO are also evident from its anti-inflammatory properties and its role in reducing oxidative stress, which collectively create a more stable neural environment conducive to recovery and cognitive function enhancement (Damiescu et al., 2022). Activation of olfactory receptors by volatile LEO molecules can enhance alpha and theta brain wave activity, which has been shown to correlate with states of relaxation, focus, and improved memory. This indicates that LEO not only modulates neurotransmitter systems such as dopamine and serotonin but also has a tangible influence on the dynamics of brain activity and the limbic system, which regulates emotions and memory consolidation (Algristian et al., 2022).

Lavender Essential Oil (LEO) demonstrates considerable promise as an adjunctive intervention in the management of cognitive impairments associated with psychiatric disorders, particularly depression and schizophrenia. Through its multifaceted actions modulating dopamine pathways, stimulating olfactory receptors, and enhancing neuroplasticity LEO contributes to improved attention, emotional regulation, and memory consolidation.

Its ability to activate the ERK/MAPK signaling pathway and elevate BDNF expression supports structural brain adaptation, offering benefits beyond temporary symptom relief. The use of LEO as a non-pharmacological strategy aligns with the growing demand for integrative mental health approaches, especially those that prioritize safety and minimal side effects.

While current findings highlight LEO's potential to complement conventional treatments, particularly in cognitive rehabilitation, future research should explore standardized dosages, long-term effects, and optimal delivery methods. Clinical implementation requires stronger evidence from well-powered randomized controlled trials and neuroimaging studies to fully define its therapeutic scope.

To ensure that the utilization of LEO can be widely and evidence-based, more systematic and standardized follow-up research steps are needed. Large-scale randomized controlled trials (RCTs) are crucial for objectively evaluating the efficacy of LEO in enhancing cognitive function (Peng et al., 2022). Neuroimaging studies are also highly recommended to directly visualize the impact of LEO on brain activity, particularly in terms of modulating dopaminergic pathways, ERK/MAPK, and connectivity between limbic locations (Cui et al., 2022). Additionally, research on the pharmacokinetics and distribution pathways of bioactive LEO in the body, whether through inhalation or other routes, needs to be further developed to optimize therapeutic effectiveness (Leong et al., 2021). Exploratory research examining the synergistic effects between LEO and conventional pharmacological therapy should also be prioritized, particularly regarding interactions with dopamine or serotonin reuptake inhibitors. The combination of these strategies has the potential to create a more effective and sustainable multimodal approach in the management of complex psychiatric disorders (Leong et al., 2021). Although the reviewed studies offer promising evidence for the cognitive benefits of Lavender Essential Oil (LEO), several limitations should be acknowledged to guide future research.

1. Internal Limitations (Study-Specific)

   First, there is considerable heterogeneity in study designs and methodologies across the included literature. Some studies employed pre-clinical models, while others utilized clinical or observational designs, making it challenging to compare results directly or perform quantitative synthesis (Algristian et al., 2022; Cui et al., 2022; Leong et al., 2021). Second, the forms of LEO administration varied significantly ranging from inhalation and topical application to oral formulations without consistent dosage reporting or duration (Horváth et al., 2022; Yoo & Park, 2023). This inconsistency may affect both outcomes and replicability. Third, many studies lacked rigorous control conditions, such as placebo groups, randomization, or blinding. These methodological gaps raise the risk of bias and reduce the internal validity of the findings (Jartarkar SR et al., 2021)(Hu et al., 2021).

2. External Limitations (Generalizability and Scope)

   In terms of external validity, individual variability in olfactory sensitivity and metabolic processing may influence the effects of LEO. For example, some individuals may have reduced olfactory receptor expression or genetic differences in monoamine metabolism, potentially altering responsivfeness to essential oils (Cui et al., 2022; Damiescu et al., 2022). Additionally, environmental factors, such as background odors, room lighting, or participant expectations, can influence outcomes during aromatherapy sessions but are rarely reported or controlled in published studies (Yoo & Park, 2023)(Yee & Al Aboud, 2023).

Finally, the long-term effects of LEO on cognition remain poorly understood, as most available studies are short-term. There is a lack of longitudinal studies tracking sustained neurocognitive outcomes, safety, and dosage optimization over time (Damiescu et al., 2022; Leong et al., 2021).

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