Original Article

Analysis of Event-related Potential Dynamics Reveals Lavender Aroma Modulates Cognitive Flexibility: An Electroencephalography Investigation Based on Task Switching Paradigms

Reyhaneh Afghan[1], Hamid Soltani Zangbar[2], Soomaayeh Heysieattalab[3], Abbas Ebrahimi-Kalan[2], Amin Besharat[4], Nasser Samadzadehaghdam[4]

[1]Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy, [2]Department of Neurosciences and Cognition, Faculty of Advanced Medical Sciences, Tabriz University of Medical Sciences, Tabriz, Iran, [3]Department of Cognitive Neuroscience, University of Tabriz, Tabriz, Iran, [4]Department of Biomedical Engineering, Faculty of Advanced Medical Sciences, Tabriz University of Medical Sciences, Tabriz, Iran

Abstract

Background: The therapeutic potential of lavender aroma is well documented, with proven results in reducing stress and facilitating mental repose. However, its effects on specific domains of executive function, such as cognitive flexibility, have not been sufficiently studied. This gap is significant for understanding how nonpharmacological interventions can influence complex cognition. **Methods:** This study investigates these effects by employing task-switching paradigms to assess cognitive flexibility. The neural correlates were measured via electroencephalography (EEG), focusing on P300 event-related potentials (ERPs). P300 latency and amplitude, a key ERP component reflecting cognitive processing, were measured at EEG electrodes Cz and FCz. **Results:** The data revealed that lavender inhalation induced specific neural changes. Following lavender inhalation, the P300 peak amplitude at the Cz electrode increased during switch trials, which could indicate improved cognitive control in demanding situations. At the FCz electrode, the latency of P300 was significantly reduced during switch trials, which could suggest the importance of this area in processing speed. **Conclusion:** The findings of the current study verify the neuromodulatory effects of lavender aroma in improving processes related to cognitive flexibility. This provides a physiological basis for its benefits, suggesting it could be effectively applied in future clinical interventions for cognitive enhancement.

Keywords: *Cognitive flexibility, electroencephalography, event-related potential, lavender essential oil, task-switching paradigm*

Submitted: 04-Oct-2025 **Revised:** 28-Jan-2026 **Accepted:** 09-Feb-2026 **Published:** 01-Jul-2026

Introduction

In recent decades, there has been a growing interest in understanding the cognitive and neural mechanisms of executive functions. Among these, cognitive flexibility – the ability to shift between mental sets to adapt to changing environments[1] – represents a crucial component. Not only does enhanced cognitive flexibility support successful transitions into adulthood, career achievement, and academic performance, but it also mitigates age-related cognitive decline.[2,3] Given its broad implications, investigating methods to enhance this ability remains a priority in cognitive neuroscience.

Interestingly, olfactory perception has been linked to various complex mental functions, particularly through aromatherapy's demonstrated effects on cognition and neural activity. By definition, aromatherapy utilizes plant-derived essential oils via inhalation or topical application to address physical and psychological conditions.[4] Of these, lavender oil stands out as the most widely studied,[5] owing to its robust effects on brain function.[6] For instance, research shows lavender inhalation improves sleep quality by modulating electroencephalography (EEG) patterns to promote slow-wave sleep.[7] Moreover, a meta-analysis confirms its cognitive benefits, specifically through reduced arousal and enhanced sustained attention.[8] Together, these findings position lavender as a promising candidate for investigating cognitive flexibility, a combination of direct cognitive and indirect emotional pathways enhancement.

How to cite this article: Afghan R, Zangbar HS, Heysieattalab S, Ebrahimi-Kalan A, Besharat A, Samadzadehaghdam N. Analysis of event-related potential dynamics reveals lavender aroma modulates cognitive flexibility: An electroencephalography investigation based on task switching paradigms. J Med Sign Sens 2026;16:18.

Address for correspondence:
Dr. Nasser Samadzadehaghdam, Department of Biomedical Engineering, Faculty of Advanced Medical Sciences, Tabriz University of Medical Sciences, Tabriz, Iran.
E-mail: nsamadzadeh_a@yahoo.com

Access this article online

Website: www.jmssjournal.net

DOI: 10.4103/jmss.jmss_100_25

Quick Response Code:

Research outcomes have illustrated that both pleasant and unpleasant odors alter brain activity. A study has shown that focused attention significantly affects how olfactory stimuli, especially plant essential oils, are perceived, as indicated by noticeable changes in EEG features.[9] Beyond EEG, studies based on event-related potentials (ERPs) have provided additional evidence supporting the idea that aromas positively improve cognitive function. As an example, it has been discovered that the presence of three aromas – lavender, rose, and lemon – shortens the delay in P300 latency, suggesting that aroma may be useful in reducing mental fatigue and cognitive workload.[10] Complementing these findings, Invitto and Mazzatenta revealed that olfactory ERPs – particularly the N1 component, which reflects sensory processing – are faster in the right frontal region during odor exposure.[11] Similarly, odor-picture integration tasks elicit a late "slow wave" ERP effect, marked by prolonged latency and amplitude peaks, indicating higher cognitive demand during multisensory conflict resolution.[12]

The link between olfaction and cognition extends to clinical and behavioral domains. Cognitive abilities are directly affected by exposure to different inhalation conditions,[13] and there exists a significant correlation between the cognitive processing speed, as evaluated by the letter-digit substitution test, and the scores obtained from the Scandinavian odor-identification test for identifying odors.[14] In addition, olfactory impairment has been widely acknowledged as a prominent predictor of different neurodegenerative disorders.[15] Supporting this, Ward *et al*.[1] identified olfaction (assessed via UPSIT and OMT) as a predictor of memory recall and odor-evoked brain activity in Alzheimer's patients, proposing it as a functional biomarker for cognitive decline. Moreover, olfactory function correlates positively with cognitive flexibility.[16] In healthy populations, for example, odor proficiency ("Sniffin' Sticks Screening 12") predicts set-shifting ability (TMT-A/B).[17]

Despite these promising findings, the cognitive effects of aromatherapy remain debated. For example, while some evidence suggests stress reduction, systematic reviews highlight insufficient conclusive data.[18] Furthermore, prior research has primarily examined aromatherapy's effects during rest, leaving its task-dependent neural mechanisms underexplored. To address this gap, our study investigates lavender aroma's impact on cognitive flexibility and brain activity during task-switching paradigms, advancing understanding of its real-time neuromodulatory role.

Materials and Methods

Experimental procedure

Participants were 20 people between the ages of 22 and 42, with 8 females (Male = 27.625, standard deviation [SD] = 4.688) and 12 males (male = 29.5, SD = 6.557). All of them had normal (or corrected) vision and reported no odor allergies. They were instructed to maintain their usual daily routines and sleep patterns. Prior to providing their written consent, participants were verbally informed about the experimental protocol and the fact that their brain activity would be recorded. They then endorsed this agreement by signing a document sanctioned by the ethics committee.

The participants were positioned around 80 cm away from a computer monitor in a room that was electrically insulated. Following a brief experiment overview, an EEG cap was fitted on each participant. They then received instructions for optimizing task performance and minimizing artifacts during the EEG recording. To confirm their understanding of the instructions, participants first completed a practice block. Next, they engaged in a task-switching paradigm[19] run in MATLAB (version R2010b), during which their brain activity was recorded. Upon conclusion of this task, they were exposed to an olfactory stimulus in the form of inhaled lavender essential oil. Participants breathed in lavender essential oil as an olfactory stimulation. We provided a 4-gram bottle of lavender essential oil close to the subjects' noses and instructed them to take five deep breaths to inhale it before repeating the procedure.

Task-switching paradigm

Owing to its engagement of diverse cognitive functions – including stimulus perception, task-set updating, attentional control, and conflict detection – the task-switching paradigm is widely used in research on cognitive flexibility.[20-22] Two effects are included in this paradigm: the mixing effect (i.e., the difference in performance between single and mixed blocks) and the switch effect (i.e., the difference in performance between the switch and nonswitch trials in mixed block).[23] Consequently, this specific cognitive task was used in the current study.

This task presented visual stimuli consisting of a white digit on a black background, encircled by a solid or dashed square. In the less/more task, the square surrounding the digit was solid, and participants were asked to indicate whether the digit was less or more than 5 (excluding the digit 5). Responses were made using the left key for numbers <5 and the right key for numbers >5. The odd/even task involved a dashed square and required participants to indicate whether the digit was odd or even, with the left and right keys corresponding to odd and even numbers, respectively. The mixed block comprised 256 trials, divided into four blocks of 64 trials, and required participants to switch between the less/more and odd/even tasks. Participants were instructed to respond both quickly and accurately, using the index finger to press one of the left or right keys. Participants had 1500 ms to respond to the on-screen digit. A 500 ms interval separated consecutive trials, and a 2-min rest period was given between blocks.

Pictorial details of the task sequence in the mixed block are provided in Figure 1.

Electroencephalographic recording

Continuous EEG signals were recorded using a 64-channel Waveguard™ cap (ANT Neuro, Enschede, Netherlands) configured according to the international 10-10 system, at a sampling rate of 1000 Hz. All signals were referenced to the mean activity of two mastoids, and electrode impedance was kept below 10 KΩ throughout the recording. Participants completed the initial task-switching paradigm and were then instructed to inhale the lavender oil five times as deeply as possible. After this olfactory exposure, they performed the same paradigm again.

Electroencephalography data preprocessing

EEG data were processed using the EEGLAB open-source toolbox.[24] As a preliminary step, a bandpass filter was applied to EEG signals with a low and high cut-off frequency of 0.5 and 30 Hz, respectively, to remove artifacts including baseline drift and wandering. The data were resampled to 250 Hz to allow visual inspection in a shorter period of time in addition to high-frequency noise reduction. Then, data were visually inspected to remove heavily artifactual segments caused mainly by muscle noise. Independent component analysis was performed to remove eyeblink and eye movement artifacts from EEG signals. These components have usually high amplitudes and can destroy the ERP waveform drastically. Therefore, their removal is mandatory. Finally, EEG signals were segmented into epochs from −200 ms to +1000 ms with respect to the target stimulus onset. The epochs were baseline-corrected by removing the mean voltage calculated over the range of [−200, 0] related to the target onset. Common average referencing and linear trend removing were the last steps of preproccessing of trials. At last, EEG trials corresponding to correct responses were considered for the further analysis.

Event-related potentials analysis

Before averaging the trials and computing ERP signals, trials were categorized into nonswitch and switch groups, as well as before aroma inhalation and after aroma inhalation. Meanwhile, the subject's task responses were analyzed, and trials associated with incorrect responses were excluded. Then, the trials were averaged with respect to the visual stimulus onset. The data were processed in MATLAB (version R2022b).

Our analysis focused specifically on the Cz and FCz electrode sites. Therefore, further analyses were conducted on these channels. The P300 component of the ERPs was examined in terms of both peak amplitude and latency. The super-grand average across the electrodes (combining both conditions and scenarios) was visually inspected to determine the appropriate time window for P300 peak and latency detection (270–400 ms).

Results

To determine the effect of aroma inhalation on the performance of subjects in nonswitch and switch tasks, we conducted a statistical analysis on the P300 peak amplitude [Figure 2] and latency [Figure 3] at the Cz and FCz electrodes, respectively, before and after inhalation. The rationale behind this selection was twofold: To avoid frontal electrodes due to their susceptibility to ocular artifacts (e.g. blinks) and to avoid occipital electrodes, as they are heavily driven by visual processing and were not central to our research question. The midline electrodes, Cz and FCz, minimize hemispheric laterality effects, and align with the typical topography of the components under study. We assessed the normality of the P300 amplitude and latency values extracted from these electrodes using the Shapiro–Wilk test. For normally distributed data, we performed paired t-tests; otherwise, we used Wilcoxon signed-rank tests. All statistical analyses were conducted in MATLAB, with $P < 0.05$ considered statistically significant.

The analysis of P300 ERP components at the Cz and FCz electrodes revealed differential effects of aroma inhalation under task-switch conditions. For P300 peak amplitude at Cz, according to Table 1, a significant increase was observed following aroma inhalation in the switch scenario (before: 1.23 ± 0.81 μV, after: 1.52 ± 0.74 μV; $P = 0.029$, Cohen's $d = 0.529$), whereas no significant change occurred in the nonswitch condition ($P = 0.292$).

Regarding P300 latency at FCz, according to Table 2, aroma inhalation significantly shortened latency in the nonswitch scenario (before: 0.355 ± 0.022s, after: 0.347 ± 0.029 s;

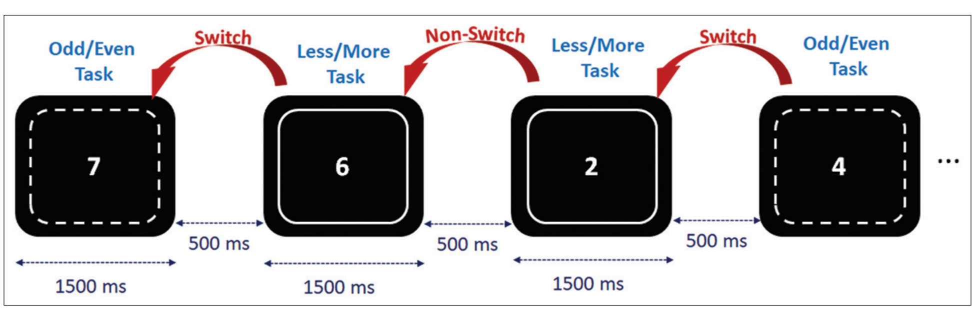

Figure 1: Task sequence in the mixed block

$P = 0.006$, $r = 0.610$). In the switch scenario, latency also decreased significantly (before: 0.353 ± 0.026 s, after: 0.350 ± 0.026 s; $P = 0.001$), albeit with a smaller effect size (Cohen's $d = 0.157$).

Grand average ERP waveforms at the Cz electrode across all subjects, along with their corresponding topographic maps, are shown in Figure 4 for the statistically significant switch scenario, both before and after inhalation.

Grand average ERP waveforms at FCz across all participants, along with their topographic maps, are displayed in Figure 5 (for nonswitch trials) and Figure 6 (for switch trials), showing pre- and postinhalation comparisons.

Discussion

In the present study, the mental sequel of lavender essential oil inhalation on cognitive flexibility via perusing the P300 latency and amplitude appearance during the execution of a

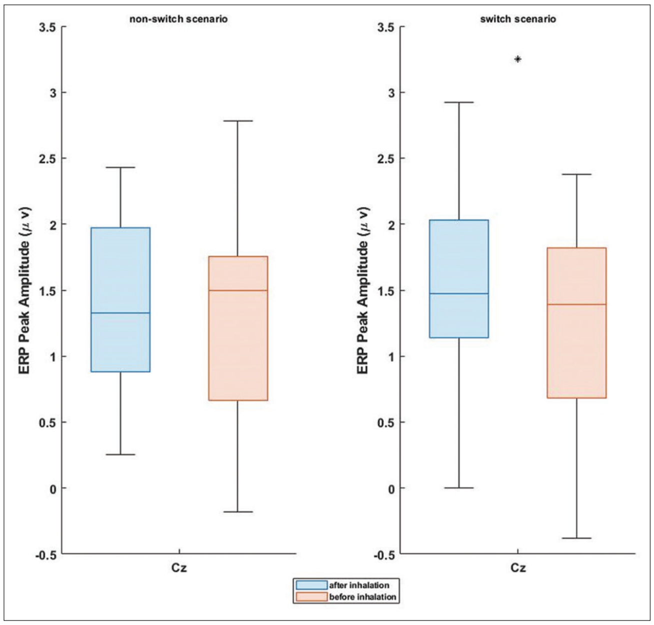

Figure 2: Boxplots of event-related potentials peak amplitudes at the Cz electrode for non-switch (left) and switch (right) scenarios. The central line in each box represents the median, the box edges mark the 25th and 75th percentiles (*P = 0.029)

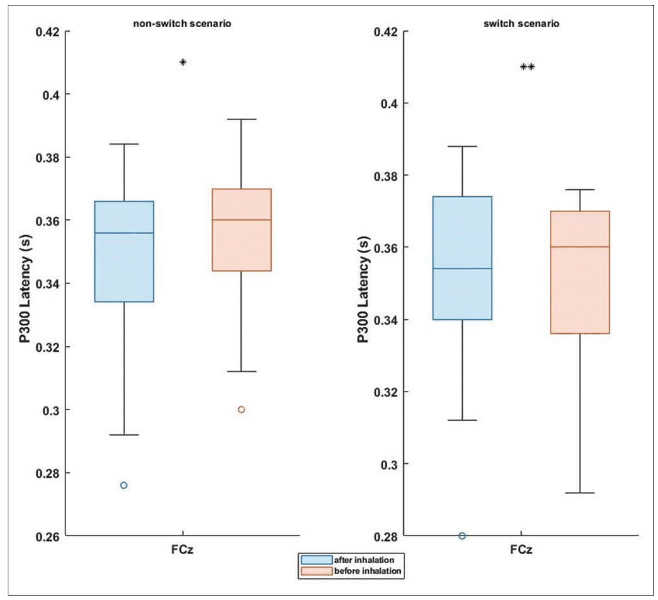

Figure 3: Boxplots of event-related potentials peak latency at the FCz electrode for non-switch (left) and switch (right) scenarios. The central line in each box represents the median, the box edges mark the 25th and 75th percentiles. (*P = 0.006, **P = 0.001)

Table 1: Descriptive statistics for the Cz electrode under nonswitch and switch scenarios, before and after aroma inhalation

	P300 peak amplitude before inhalation (μV)	P300 peak amplitude after inhalation (μV)	Test type	Test statistic	P	Effect size (Cohen's d)
Nonswitch	1.31±0.76	1.40±0.70	Paired t-test	t-statistic: −1.0849 df: 19 SD: 0.3735	0.292	0.2426
Switch	1.23±0.81	1.52±0.74	Paired t-test	t-statistic: −2.3660 df: 19 SD: 0.5427	0.029	0.5291

SD – Standard deviation

Table 2: Descriptive statistics for the FCz electrode under nonswitch and switch scenarios, before and after aroma inhalation

	P300 latency before inhalation (s)	P300 latency after inhalation (s)	Test type	Test statistic	P	Effect size
Nonswitch	0.355±0.022	0.347±0.029	Wilcoxon signed-rank test	z: −2.7286 Signedrank: 32	0.006	r=0.6101
Switch	0.353±0.026	0.350±0.026	Paired t-test	t-statistic: −3.9374 df: 19 SD: 0.0166	0.001	Cohen's d=0.1568

SD – Standard deviation

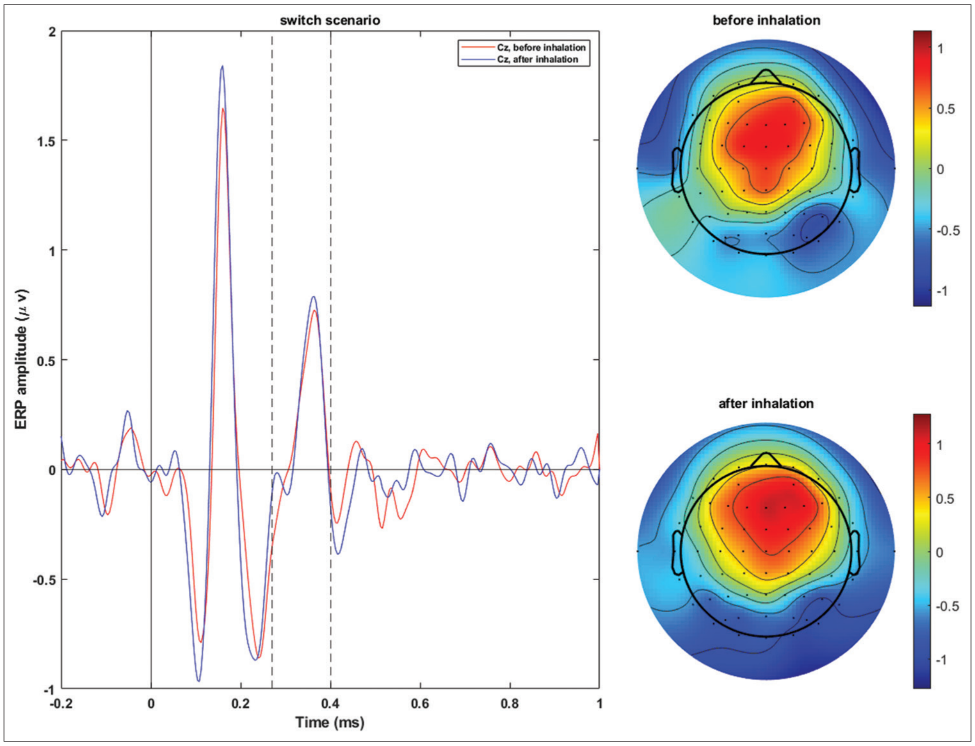

Figure 4: Left: Grand average event-related potentials waveforms at the Cz electrode before and after lavender inhalation for the switch scenario. Right: Topographic maps (topoplots) of voltage distribution across all electrodes at the P300 peak latency before and after lavender inhalation

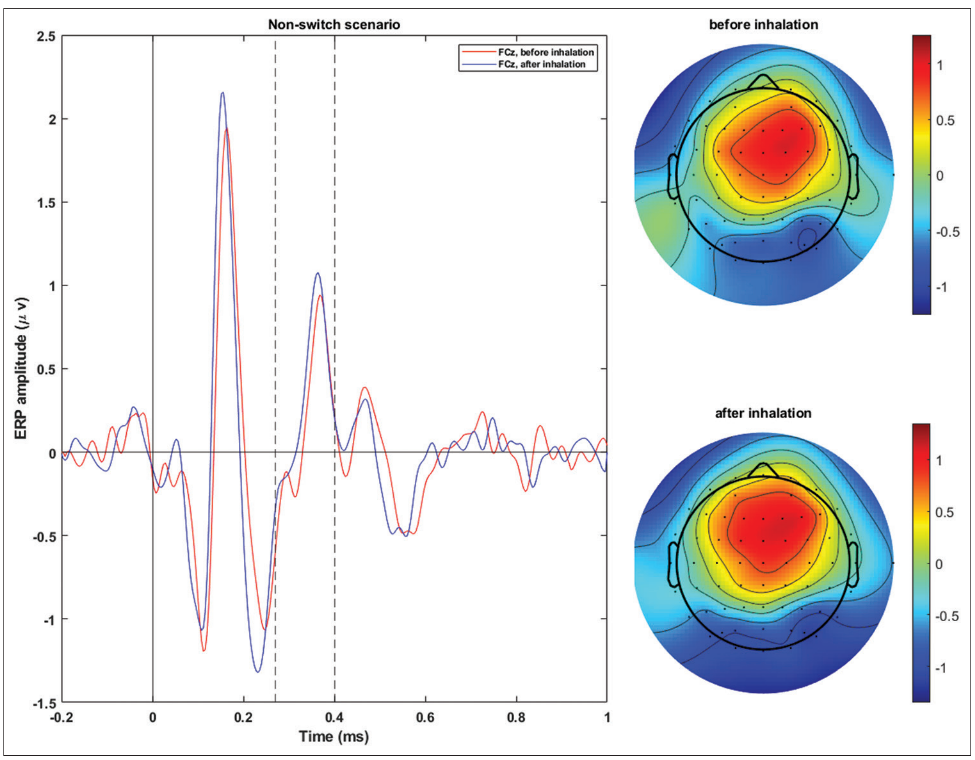

Figure 5: Left: Grand average event-related potential waveforms at the FCz electrode before and after lavender inhalation for the non-switch scenario. Right: Topographic maps (topoplots) of voltage distribution across all electrodes at the P300 peak latency before and after lavender inhalation

specific cognitive flexibility task, task-switching paradigm, was investigated. The findings verified a significant effect of inhalation on cognitive flexibility based on the P300-related indices, amplitude, and latency. Specifically, there was a substantial increase in the amplitude of P300 at the Cz location through switch trials, whereas no such

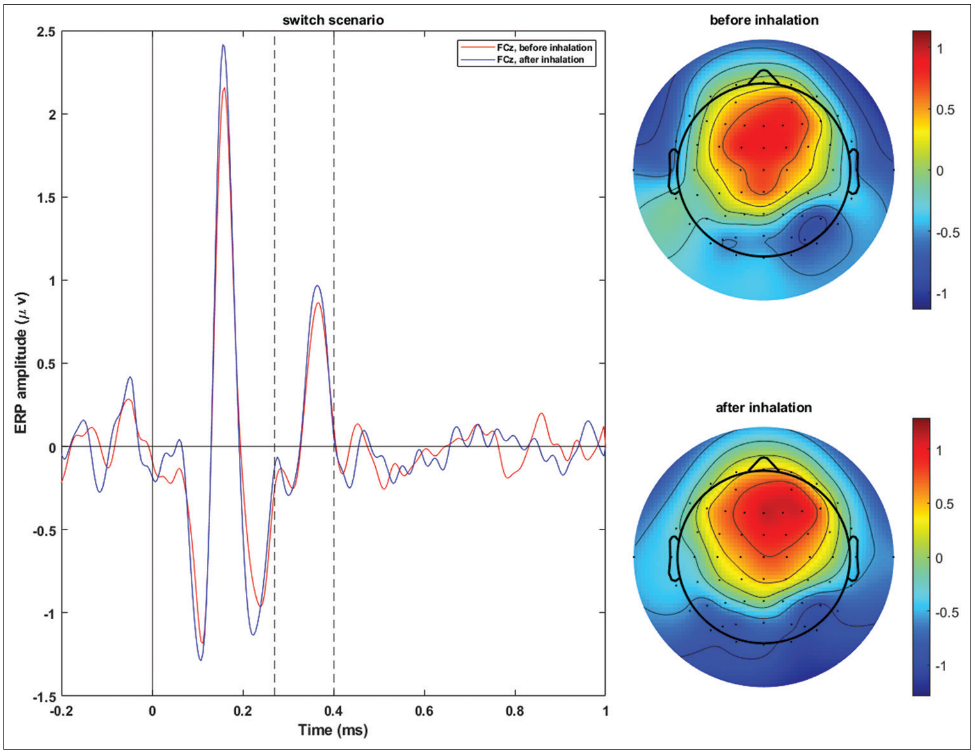

Figure 6: Left: Grand average event-related potential waveforms at the FCz electrode before and after lavender inhalation for the switch scenario. Right: Topographic maps (topoplots) of voltage distribution across all electrodes at the P300 peak latency before and after lavender inhalation

significance was found in nonswitch trials. On the other hand, at the FCz electrode, there was a significant alteration in P300 latency during task switching trials. Based on these findings, new perspectives can be reached on methods of improving cognitive flexibility through the induction of olfactory pathways.

Considering the increase in P300 amplitude in the Cz area during switching trials, it can be concluded that whenever the cognitive load of the task is high, the transfer of cognitive concepts to the Cz area increases to appropriately control the complex situation and select the best available option, consistent with the similar finding that ascertains P300 amplitude represents cognitive engagement and the re-equipping of dynamic mental interpretation.[25-27] The enhanced amplitude of P300 in task switching trials, which is concerned with increased cognitive flexibility and mental reorientation demand, indicates that inhalation may support the CF-linked executive function. This viewpoint is further reinforced by the obvious anxiolytic implications of lavender, which have been proven to improve calming and confront physiological anxiety.[28,29] Following the modulation of the arousal state of humankind by lavender inhalation, it provides an ideal situation for mobilizing cognitive resources based on switching platforms, which meet the mental demands of the task.[30] The absence of significant Cz P300 amplitude changes in non-switch trials may indicate that this consequence is context-sensitive and related to the challenge of cognitive processes.

The significant change of P300 latency at FCz across both switch and nonswitch conditions, without substantial modulation of amplitude, may verify an overall consequence of lavender inhalation on the temporal dynamics of CF-related mental processing in prefrontal regions. The FCz location interacts with frontal executive functions, including intention purposing, conflict analysis, and sequential or parallel top-down process and control.[31,32] A considerable reduction in P300 latency in this region could mirror the quick decision-making processes following stimulus evaluation, independent of switching paradigms.

The current study findings concern evidence that acknowledges the successful modulatory outcome of the olfactory stimuli through direct cognitive procedures[8,33] or indirect emotional pathways. Studies report a promising improvement in memory following exposure to lavender aroma that aligned with alertness enhancement.[34] However, few outcomes have inferred the underlying temporal and spatial brain dynamics involved in these manifestations from the related electrophysiological data. By extracting ERP components, the current study adds an eventual feature to existing literature, verifying that lavender aroma impresses the intention and timing of cortical fluctuations linked to cognitive flexibility.

Furthermore, the particular and scattered spatial pattern of aroma effects – amplitude increase at the Cz and latency modulation at the FCz – suggests that the aromatic representation of lavender stimulation on olfaction is variable across the cerebral cortex. This diverse effect concerns the selective and purposeful consequence of aroma on the functionally relevant neural circuits, depending on the nature of the stimulation and the cognitive demands of the task.[35,36] This finding is supported by a shred of growing evidence that sensory inputs specifically modulate neural processes in brain locations.[37,38] These results confirm an emerging comprehension of the reliable outcome of noninvasive sensory interventions on executive functions and higher-order cognitive processes. Aromatherapy is a potential cognitive enhancer in clinical and nonclinical contexts for the modulation of stress or performance of cognitive demands in environments.[39,40]

Another key feature of the current study is the specific effects of the presented aroma on task indicators. The increase in P300 amplitude during the switch trials compared to the nonswitch trials indicates that the lavender aroma may primarily affect cognitive control, which is one of the main indicators of cognitive flexibility.[41] This finding confirms previous data that the P300 plays a role in processing salient and complex aspects of cognitive functions.[42,43] In the process of cognitive tasks, reconfiguration of the task steps may be necessary, which requires inhibiting previous responses and re-adjusting attention,[44,45] and the presence of a pleasant and relaxing aroma can play a pivotal role in this resetting.

This type of finding mirrors the embodied cognition models, which state that the cognitive interpretation of all phenomena in the brain is a resonance of inputs from the contextual cues and the physical structure of the body.[46] Considering this framework, the olfactory inputs stimulate limbic structures, including the amygdala and hippocampus, that manage the modulation of attentional reactions and memory formation.[47] This mutual and dynamic interaction between the olfactory system and cognitive parts of the brain rapidly modulates cortical processing through cognitive contexts and stressful conditions.[48]

From a practical perspective, the integration of olfactory stimulation like lavender aromas with switching tasks holds potential and natural cognitive flexibility facilitators for environments with rapid switching response load, such as traffic control and educational settings. Furthermore, the contribution of noninvasive and cost-effective sensory modalities to clinical and natural cognitive paradigms can be helpful in meeting the complex cognitive needs of today's world. On the other hand, consistent with our previous research,[30] behavioral data analysis showed that subjects responded more accurately and with shorter reaction times following lavender essential oil inhalation.

Study limitations

Several experimental aspects of this study should be acknowledged. The primary limitation is the pre-post design without a separate control condition, which limits causal inference regarding lavender's specific effect. To reduce confounding from practice and fatigue, we employed a task with fully randomized sequences and incorporated rest periods between recordings. Furthermore, the manual delivery of the aroma, while a pragmatic choice, meant we could not precisely control intensity or timing across participants – a constraint common in initial exploratory studies of this kind. Although we did not formally assess olfactory sensitivity or emotional state, participants were screened to be healthy and were tested in a controlled, calm environment to minimize undue stress. Our electrode selection was intentionally restricted to midline sites (FCz, Cz) to align with the established topography of the target P300 components and to avoid artifacts from frontal and occipital regions; while this focused approach is standard, it does not capture the full parietal distribution, suggesting broader mapping in future work could be beneficial. Taken together, these considerations temper strong causal claims but do not diminish the core observation of a significant neurophysiological association. Future studies employing olfactometers, active sham controls, and assessments of olfactory and emotional baseline states will be essential to isolate the precise neuromodulatory mechanisms of lavender inhalation.

Conclusions

The present study provides convincing neurophysiological evidence supporting the beneficial effects of lavender aroma on cognitive flexibility, as indexed by P300 ERP during a task-switching paradigm. The observed increase in P300 amplitude at the Cz electrode during switch trials suggests enhanced cognitive control under demanding conditions, while the reduced P300 latency at the FCz electrode indicates faster processing speed in prefrontal regions. These findings highlight the neuromodulatory role of lavender inhalation in optimizing executive functions, particularly in contexts requiring rapid mental reconfiguration. The selective modulation of P300 components – amplitude changes in posterior regions (Cz) and latency shifts in frontal areas (FCz) – underscores the spatially distributed influence of olfactory stimuli on cognitive processing. This aligns with embodied cognition theories, wherein sensory inputs dynamically shape neural responses to meet task demands. From an applied perspective, these results advocate for the potential integration of lavender aromatherapy in settings requiring frequent cognitive shifts, such as high-stress work environments, educational contexts, and clinical interventions targeting executive dysfunction. Future research should explore dose–response relationships, long-term effects, and individual differences in responsiveness to olfactory stimuli. Overall, this study advances our understanding of sensory-mediated cognitive enhancement and underscores the therapeutic promise of non-invasive aromatherapy in bolstering mental agility.

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of Tabriz University of Medical Sciences (ethical code: IR. TBZMED. REC.1400.649) and was conducted in accordance with their ethical guidelines. All participants provided written informed consent.

Availability of data and materials

The datasets from this study are not publicly available. However, they can be made available upon reasonable request.

Financial support and sponsorship

This research was funded by Tabriz University of Medical Sciences (grant number 67517).

Conflicts of interest

There are no conflicts of interest.

References

1. Ward AM, Calamia M, Thiemann E, Dunlap J, Tranel D. Association between olfaction and higher cortical functions in Alzheimer's disease, mild cognitive impairment, and healthy older adults. J Clin Exp Neuropsychol 2017;39:646-58.
2. Burke SN, Mormino EC, Rogalski EJ, Kawas CH, Willis RJ, Park DC. What are the later life contributions to reserve, resilience, and compensation? Neurobiol Aging 2019;83:140-4.
3. Burt KB, Paysnick AA. Resilience in the transition to adulthood. Dev Psychopathol 2012;24:493-505.
4. Segen C. Dictionary of Alternative Medicine. Stamford, CT: Appleton and Lange; 1998.
5. Sattayakhom A, Wichit S, Koomhin P. The effects of essential oils on the nervous system: A scoping review. Molecules 2023;28:3771.
6. Thangaleela S, Sivamaruthi BS, Kesika P, Bharathi M, Kunaviktikul W, Klunklin A, *et al*. Essential oils, phytoncides, aromachology, and aromatherapy-a review. Appl Sci 2022;12:4495.
7. Ko LW, Su CH, Yang MH, Liu SY, Su TP. A pilot study on essential oil aroma stimulation for enhancing slow-wave EEG in sleeping brain. Sci Rep 2021;11:1078.
8. Malloggi E, Menicucci D, Cesari V, Frumento S, Gemignani A, Bertoli A. Lavender aromatherapy: A systematic review from essential oil quality and administration methods to cognitive enhancing effects. Appl Psychol Health Well Being 2022;14:663-90.
9. Cherninskii AA, Zima IG, Makarchouk NY, Piskorskaya NG, Kryzhanovskii SA. Modifications of EEG related to directed perception and analysis of olfactory information in humans. Neurophysiology 2009;41:63-70.
10. Kaneki N, Kurosaka T, Yamada H, Mitsubayashi H, Shimada K, Kamimura H. Effect of aroma on event-related potential in cognitive workload. Kansei Eng Int 2005;5:51-6.
11. Invitto S, Mazzatenta A. Olfactory event-related potentials and exhaled organic volatile compounds: The slow link between olfactory perception and breath metabolic response. A pilot study on phenylethyl alcohol and Vaseline oil. Brain Sci 2019;9:84.
12. Hörberg T, Larsson M, Ekström I, Sandöy C, Lundén P, Olofsson JK. Olfactory influences on visual categorization: Behavioral and ERP evidence. Cereb Cortex 2020;30:4220-37.
13. Midorikawa M, Suzuki H, Suzuki Y, Yamauchi K, Sato H, Nemoto K, *et al.* Relationships between cognitive function and odor identification, balance capability, and muscle strength in middle-aged persons with and without type 2 diabetes. J Diabetes Res 2021;2021:9961612.
14. Larsson M, Nilsson LG, Olofsson JK, Nordin S. Demographic and cognitive predictors of cued odor identification: Evidence from a population-based study. Chem Senses 2004;29:547-54.
15. Doty RL. Olfactory dysfunction in neurodegenerative diseases: Is there a common pathological substrate? Lancet Neurol 2017;16:478-88.
16. Challakere Ramaswamy VM, Schofield PW. Olfaction and executive cognitive performance: A systematic review. Front Psychol 2022;13:871391.
17. Yahiaoui-Doktor M, Luck T, Riedel-Heller SG, Loeffler M, Wirkner K, Engel C. Olfactory function is associated with cognitive performance: Results from the population-based LIFE-Adult-Study. Alzheimers Res Ther 2019;11:43.
18. Hur MH, Song JA, Lee J, Lee MS. Aromatherapy for stress reduction in healthy adults: A systematic review and meta-analysis of randomized clinical trials. Maturitas 2014;79:362-9.
19. Bae S, Masaki H. Effects of acute aerobic exercise on cognitive flexibility required during task-switching paradigm. Front Hum Neurosci 2019;13:260.
20. Uddin LQ. Cognitive and behavioural flexibility: Neural mechanisms and clinical considerations. Nat Rev Neurosci 2021;22:167-79.
21. Grange JA, Houghton G. Task Switching and Cognitive Control. New York, NY, US: Oxford University Press; 2014. p. viii, 392.
22. Tsai CL, Wang WL. Exercise-mode-related changes in task-switching performance in the elderly. Front Behav Neurosci 2015;9:56.
23. Karbach J, Kray J. How useful is executive control training? Age differences in near and far transfer of task-switching training. Dev Sci 2009;12:978-90.
24. Delorme A, Makeig S. EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J Neurosci Methods 2004;134:9-21.
25. Dickson DS, Wicha NY. P300 amplitude and latency reflect arithmetic skill: An ERP study of the problem size effect. Biol Psychol 2019;148:107745.
26. Fields EC. The P300, the LPP, context updating, and memory: What is the functional significance of the emotion-related late positive potential? Int J Psychophysiol 2023;192:43-52.
27. Scharinger C, Soutschek A, Schubert T, Gerjets P. Comparison of the working memory load in N-back and working memory span tasks by means of EEG frequency band power and P300 amplitude. Front Hum Neurosci 2017;11:6.
28. Donelli D, Antonelli M, Bellinazzi C, Gensini GF, Firenzuoli F. Effects of lavender on anxiety: A systematic review and meta-analysis. Phytomedicine 2019;65:153099.
29. Kim M, Nam ES, Lee Y, Kang HJ. Effects of lavender on anxiety, depression, and physiological parameters: Systematic review and meta-analysis. Asian Nurs Res (Korean Soc Nurs Sci) 2021;15:279-90.
30. Afghan R, Heysieattalab S, Zangbar HS, Ebrahimi-Kalan A, Jafari-Koshki T, Samadzadehaghdam N. Lavender essential oil inhalation improves attentional shifting and accuracy: Evidence from dynamic changes of cognitive flexibility and power spectral density of electroencephalogram signals. J Med Signals Sens 2024;14:12.
31. Friedman NP, Robbins TW. The role of prefrontal

cortex in cognitive control and executive function. Neuropsychopharmacology 2022;47:72-89.

32. Ardila A, Bernal B, Rosselli M. Executive functions brain system: An activation likelihood estimation meta-analytic study. Arch Clin Neuropsychol 2018;33:379-405.
33. Chamine I, Oken BS. Aroma effects on physiologic and cognitive function following acute stress: A mechanism investigation. J Altern Complement Med 2016;22:713-21.
34. Filiptsova O, Gazzavi-Rogozina L, Timoshyna I, Naboka O, Dyomina YV, Ochkur A. The effect of the essential oils of lavender and rosemary on the human short-term memory. Alexandria J Med 2018;54:41-4.
35. Yamaguchi M. Functional sub-circuits of the olfactory system viewed from the olfactory bulb and the olfactory tubercle. Front Neuroanat 2017;11:33.
36. Kehl MS, Mackay S, Ohla K, Schneider M, Borger V, Surges R, *et al.* Single-neuron representations of odours in the human brain. Nature 2024;634:626-34.
37. Williamson RS, Ahrens MB, Linden JF, Sahani M. Input-specific gain modulation by local sensory context shapes cortical and thalamic responses to complex sounds. Neuron 2016;91:467-81.
38. Olcese U, Oude Lohuis MN, Pennartz CM. Sensory processing across conscious and nonconscious brain States: From single neurons to distributed networks for inferential representation. Front Syst Neurosci 2018;12:49.
39. Chamine I, Oken BS. Expectancy of stress-reducing aromatherapy effect and performance on a stress-sensitive cognitive task. Evid Based Complement Alternat Med 2015;2015:419812.
40. Xing D, Chen X, Ma Y, Chen M, Ho MF, Lam KK, *et al*. Application of aromatherapy in patients with cognitive impairment: An integrative review. J Integr Nurs 2025;7:95-111.
41. Gabrys RL, Tabri N, Anisman H, Matheson K. Cognitive control and flexibility in the context of stress and depressive symptoms: The cognitive control and flexibility questionnaire. Front Psychol 2018;9:2219.
42. Wilson GF, Swain CR, Ullsperger P. ERP components elicited in response to warning stimuli: The influence of task difficulty. Biol Psychol 1998;47:137-58.
43. Polich J. Task difficulty, probability, and inter-stimulus interval as determinants of P300 from auditory stimuli. Electroencephalogr Clin Neurophysiol 1987;68:311-20.
44. Gunduz Can R, Schack T, Koester D. Manual action re-planning interferes with the maintenance process of working memory: An ERP investigation. Psychol Res 2023;87:1784-805.
45. Xie L, Cao B, Li Z, Li F. Neural dynamics of cognitive control in various types of incongruence. Front Hum Neurosci 2020;14:214.
46. Buzsáki G, Tingley D. Cognition from the body-brain partnership: Exaptation of memory. Annu Rev Neurosci 2023;46:191-210.
47. Kostka JK, Bitzenhofer SH. How the sense of smell influences cognition throughout life. Neuroforum 2022;28:177-85.
48. Silvas-Baltazar M, López-Oropeza G, Durán P, Martínez-Canabal A. Olfactory neurogenesis and its role in fear memory modulation. Front Behav Neurosci 2023;17:1278324.