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Olfactory effects of *d*-Borneol on psychophysiological parameters among healthy participants

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Abstract

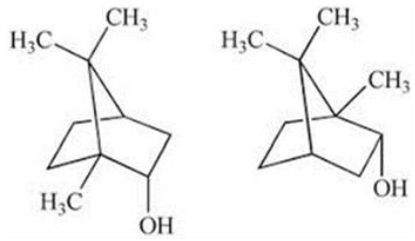
d-Borneol ($C_{10}H_{18}O$) is a highly lipid-soluble bicyclic monoterpene alcohol widely used in a variety of traditional remedies. However, current studies on the inhalation of *d*-borneol remain limited in terms of CNS, ANS and emotional states. This study aimed to investigate the effects of *d*-borneol inhalation on psychophysiological parameters among healthy participants. Twenty-four healthy participants were recruited for participation in trials. The current research determined the changes in the autonomic nervous system (ANS) through physiological parameters, central nervous system (CNS) through electroencephalography (EEG) recordings, and psychological parameters through emotional states. EEG recordings were conducted based on 10-20 systems, and EEG band power was calculated by Fast Fourier Transformation (FFT). For data analysis, *d*-borneol was inhaled and compared with sweet almond oil as base oil. Paired t-test was employed to measure the oil inhalation. The findings indicated that *d*-borneol inhalation could cause effects on (1) ANS physiological parameters by significantly increasing systolic blood pressure, diastolic blood pressure, and heart rate, (2) psychological parameters of emotional states by significantly increasing the mean scores for good, active, fresh, romantic feelings while considerably decreasing the mean scores for bad, stressed, frustrated, annoyed, and disgusted feelings, and (3) EEG parameters by significantly increasing the power of the beta waves in the left and right areas of the posterior brain. In summary, *d*-borneol caused significant changes in psychophysiological parameters, indicating the stimulating effects of *d*-borneol inhalation. The results in this study would be useful as scientific evidence for future research conducted on other groups of participants.

Keywords**:** *d-borneol; EEG; emotional states; psychophysiological parameters; stimulating effects.*

1. Introduction

Aromatic essences including volatile compounds are popular in the cosmetics, food, and pharmaceutical industries due to the use of their fragrances and various pharmaceutical properties. *d*-Borneol is a common volatile compound widely used in a variety of traditional remedies because it can stimulate the sense of smell as well as the emotional center of the human brain. *d*-Borneol can be obtained naturally from tropical plants known as

Dryobalanops aromatica C.F.Gaertn. Locally, it is known as Borneo Camphor, Camphor tree, or Sumatran Camphor. *D. aromatica* belongs to the Dipterocapaceae family, which grows in Peninsular Malaysia (Lim, Loh, & Ho, 2013).



(1a) *d*-borneol (1b) *l*-borneol

Figure 1 Chemical structure of *d*-borneol and *l*-borneol (Zhang, Fu, & Zhang, 2017)

d-Borneol ($C_{10}H_{18}O$) is bicyclic monoterpene alcohol with an odorous scent and pungent, bitter taste. Naturally, its appearance is colorless to white crystalline solid. It is divided into 2 enantiomers: *d*-(+)-borneol and *l*-(-)-borneol (Zhang, Fu, & Zhang, 2017). *d*-Borneol possesses numerous biological activities such as analgesic (Jiang et al., 2015), anti-hyperglycemic, anti-hyperlipidemic (Madhuri, & Naik, 2017), anti-oxidant, anti-inflammation and neuroprotection. *d*-Borneol also acts as an effective topical pain reliever in humans (Wang et al., 2017) and an interesting, effective agent for enhancing intranasal drug delivery to the brain (Zhang, Fu, & Zhang, 2017).

d-Borneol possesses the Blood-Brain Barrier permeability by inhibiting efflux protein function, active transport by ion channels, promoting vasodilatory neurotransmitters and emitting tight junction protein (Zheng et al., 2018). *d*-Borneol could alleviate Blood-Brain Barrier disruption, lower oxidative reactions, and inhibit inflammation as well as apoptosis. Thus, it could potentially be used as a neuroprotective agent for cerebral ischemic injury (Chen et al., 2019). In traditional Chinese medicine, borneol is a representative (life-saving) drug with orifice-opening agents used for the purposes of resuscitation or helping patients to regain consciousness in critical circumstances such as coma, stroke and traumatic brain injury (Wang, Feng, & Hu, 2014). As one of the medicines used in traditional Chinese medicine through nose insufflating therapy, *d*-borneol [Tianranbingpian] from *D. aromatica* is mobile and piercing. They work their way through the nose-to-brain delivery route (Erdő, Bors, Farkas, Bajza, & Gizurarson, 2018).

d-Borneol has been used in traditional Chinese and Japanese medicine to treat analgesia, anesthesia, anxiety and depression. *d*-Borneol extracted from *D. aromatica* is used in traditional Thai medicine known as Phimsen as a tonic for the heart and brain. *d*-Borneol used as one of the crude drugs in Thai traditional medicine has been found to be one of the Thai medicinal recipes on the Wat Pho stone inscription (Ruangrungsi, 2010) and Wat Matchimawas Worawihan Songhla inscription (Sivaphongthongchai, 2013). It is an effective treatment for cold and other respiratory ailments by inhalation of the vapors. A previous study was conducted on the feasibility of an herbal steam bath on nasal allergic rhinitis symptoms. *D. aromatica* was used as one of the herbal medicines taken together as an herbal steam bath, which reduced the symptoms statistically. The researchers concluded that an herbal steam bath was an effective treatment for allergic rhinitis symptoms (Tungsukruthai, 2020).

Sweet almond oil has been used as a diluent control in previous studies to compare the effects of essential oil inhalation. For instance, Gulluni et al. (2018) conducted a study to examine the effects of cannabis essential oil inhalation. The findings revealed that sweet almond inhalation as a control group did not cause significant effects on the brain wave activity or ANS parameters (Gulluni et al., 2018). Another previous study also suggested that a carrier oil used to dilute essential oils is regarded to be inert and used only for dilution purposes (Care, 2003). As a non-olfactory stimulating carrier, sweet almond oil was used to dilute rose oil in previous clinical research to determine olfactory thresholds (Philpott, Goodenough, Passant, Robertson, & Murty G., 2003).

Currently, a large body of research studies have been carried out to examine the effects and therapeutic properties of *d*-borneol. However, studies focusing on the inhalation of *d*-borneol in terms of CNS, ANS and emotional states remain lacking.

2. Objectives

This study aims to investigate the effects of *d*-borneol inhalation on psychophysiological parameters among healthy participants.

3. Materials and methods

Participants

The sample size was calculated according to a previous study (Sayorwan et al., 2013). In this study, there were 24 participants in total (21 participants and 3 participants as 10% added to compensate for expected drop-outs). Twenty-four participants participated in the first session for ANS parameters and psychological parameters of emotional states. However, only 21 participants were left in the second session for EEG recordings because 3 participants were excluded from this study as artifact rejection was assigned at ±80 Hz for all EEG channels (Kaewcum, & Siripornpanich, 2018).

Regarding the inclusion criteria, 24 healthy participants based on WHO and Asian criteria values (Llido, & Mirasol, 2011) from both genders aged between 20 and 35 years were recruited for the current research. All participants were healthy volunteers with right-handedness measured by the Edinburgh Handedness Inventory scale (Oldfield, 1971) and were free of neurological diseases. The volunteers who chose the target scale between 2 to 4 on the "Odor familiarity five-point Likert scale" were recruited. Exclusion criteria included participants with a history of neurological and psychiatric illnesses such as substance abuse, traumatic brain injury with a history of loss of consciousness, and central nervous system (CNS) medication. Female participants who were pregnant and participants who were allergic to volatile compounds were also excluded.

Materials

d-Borneol was obtained from Ji'an Yufeng Co., Ltd., China. Sweet almond oil was obtained from Chemipan Corporation Co., Ltd., Thailand. As a carrier oil, sweet almond oil was used to dilute *d*-borneol prior to its use as an intervention. 10% (W/V) underwent preliminary investigation and was found to be the most acceptable concentration. Sweet almond oil inhalation was also studied as diluent or vehicle control. Both sweet almond oil and *d*-borneol diluted with sweet almond oil were delivered from an oxygen pump system via a plastic tube through a face mask at a constant rate of 2L/min.

Outcome measurements

ANS parameters

A Biolight M7000 Multi-Parameter Patient Monitor (BIOM7000) was utilized to record physiological parameters including heart rate, respiratory rate, skin temperature, and systolic as well as diastolic blood pressure.

Psychological parameters of emotional states

A set of scales on various types of emotional states was employed in the framework introduced by the Geneva Emotion and Odor Scale to evaluate the emotional states (Thanatuskitti, Siripornpanich, Sayorwan, Palanuvej & Ruangrungsi, 2020a). This scale was designed to measure their subjective personal feelings through a 100-mm visual analog scale on emotional states (good, bad, active, drowsy, fresh, relaxed, stressed, frustrated, romantic, annoyed, calm, and disgusted).

EEG parameters

EEG recordings were carried out according to the international 10-20 system by applying a set of 31 electrodes with one additional ground (Jasper, 1958). The researchers also used both mastoids as the recording reference with an average of both mastoids equal to A1+A2/2. The researchers monitored electrooculography (EOG) by placing four electrodes on both external acanthi (HEOL and HEOR), left supraorbital (VEOU) and infraorbital (VEOL) regions. Each participant was asked to put on an electro-cap made of elastic spandex-type fabric with recessed silver/silver chloride (Ag/AgC1) electrodes attached to the fabric. The researchers set electrode impedances below five kOhms (Lorig, 2000). The researchers utilized the recording system known as Acquire Neuroscan version 4.3 (Compumedics Neuroscan, Australia). The researchers set the online filter to a bandpass with a low pass equal to 60 Hz and a high pass equal to 0.1. A/D rate was 500 Hz. The gain was set at 19. Notch filter was open at 50 Hz (Ajjimaporn, Rachiwong, & Siripornpanich, 2018). During EEG analysis, the continuous EEG data was cut into 2,000 milliseconds-length EEG epoch. The post-recording filter was set as band-pass at 0.3-30 Hz and the artifact rejection was assigned at ±80 Hz for all EEG channels (Kaewcum, & Siripornpanich, 2018). The power spectrum of the respective frequency bands was analyzed based on the Fast Fourier Transform (FFT) ranging from delta (0.5-4 Hz), theta (4.5-8 Hz), alpha (8.5-13 Hz) and beta waves (13.5-30 Hz) (Siripornpanich, Sampoon, Chaithirayanon, Kotchabhakdi & Chutabhakdikul, 2018).

Data collection

The general characteristics of each participant were recorded, namely age, weight, height and BMI. Data for ANS physiological parameters were collected including systolic and diastolic blood pressure, heart rate, and skin temperature as well as respiratory rate. Each participant was asked to complete a set of scales on 12 types of emotional states based on the Geneva Emotion and Odor Scale to evaluate the psychological parameters. The absolute powers of EEG recordings on brain wave activities were calculated and interpreted into frequency bands divided into five areas including left anterior (Fp1, F3, F7), right anterior (Fp2, F4, F8), center (Fcz, Cz, Cpz), left posterior (P3, T5, O1) and right posterior (P4, T6, O2) (Sayorwan et al., 2013).

Study design and data analysis

Pre-test and post-test designs were performed in this study. SPSS statistical package version 22 was used for data analysis. Descriptive statistics, percentage, mean values and standard deviation (SD) were applied to report the general characteristics of all the participants. The physiological and emotional changes in heart rate, skin temperature, blood pressure and EEG parameters between resting and sweet almond oil inhalation as well as sweet almond oil and 10% *d*-borneol inhalation were analyzed by paired *t*-test. A p-value less than 0.05 was considered statistically significant. In addition, the Shapiro-Wilk test was used for normality.

Ethical Considerations

The current research was approved by the Ethical Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University, Permissions No. COA No. 074/2020. The research experiments were conducted in an EEG laboratory at the Research Center for Neuroscience, Institute of Molecular Biosciences, Mahidol University on Salaya campus in Nakhon Pathom province, Thailand. Research was conducted from the 1st of April 2020 to the 1st of December, 2020. All participants provided informed consent before participating in this study. The researchers who conducted the experiments were well-trained in the use of all measurement tools.

Procedures

The experiments were conducted in a quiet, air-conditioned room with the temperature set to 24±1 °C and relative humidity between 50-65%. The experiments were carried out in the morning between 8.00 a.m.-12.00 p.m. to reduce the impact of the circadian rhythm. The experiments were divided into two sessions: the first session for ANS parameters, emotional states, and the second session for EEG recordings. In the first session, the cuff of BIOM7000 functioned automatically by inflating itself to measure the systolic blood pressure and then slowly deflating itself to measure the diastolic blood pressure while each participant remained still. In the second session, each participant was wearing an electro-cap with recessed silver/sliver chloride (Ag/AgC1) electrodes attached to the fabric. The participant needed to sit still without physical movement to avoid interfering with the brain wave activities during EEG recordings.

The first session was conducted to measure ANS and emotional state parameters. Each participant sat in a comfortable armchair far from the ANS acquisition unit in a quiet, air-conditioned room. After a 10-minute rest, the ANS parameters were recorded according to the instruction manual. Each participant filled out the emotional state questionnaire for baseline (resting period). The participant inhaled sweet almond oil for 10 minutes. After that, there was a 5-minute interval during which each participant filled out the questionnaire on emotions (SO period). Finally, each participant inhaled 10% w/v *d*-borneol for 10 minutes and then filled out the questionnaire on emotions (BO period).

There was a 7-day interval as a wash-out period between the two experiments. The second session for EEG recordings was carried out. Firstly, each participant's EEG was recorded as a baseline while eyes were opened and closed (5 minutes each). Then, sweet almond oil was inhaled for 8 minutes with eyes closed. Finally, 10% w/v *d*-borneol was inhaled for 8 minutes with eyes closed. The absolute powers of brain activities were analyzed during three experimental periods: Resting (eye closing), sweet almond oil inhalation (SO), and *d*-borneol inhalation (BO). The procedures are summarized in the flowchart below. In this study, all the participants followed the same protocol.

Regarding safety concerns, the participants who had symptoms or risks after

inhalation could consult with the doctor in the research team. If there was any emergency such as severe allergy, the participants would be hospitalized for diagnosis and provided proper suitable treatment. This study informed the safety precautions in the consent form.

Figure 2 The procedures are sequenced in this flow chart

4. Results

General characteristics of the participants

In the first session (ANS and Emotional parameters) for this study, twenty-four participants (12 males and 12 females) aged between 20 and 35 years old with normal body mass index were asked to inhale *d*-borneol. The mean and SD values of participants' age, height, weight and BMI were 21.92 (±2.47) years old, 167.58 (±6.40) cm, 58.29 (±4.89) kg, 20.66 (±1.00) kg/m^2 respectively. In the second session (brainwave parameters) after artifact rejection based on EEG analysis, there were twenty-one participants (10 males and 11 females) aged 21.90 (±2.41) years old, 167.52 (±6.72) cm, 58.33 (±5.21) kg, 20.68 (±1.07) kg/m^2 (Table 1). In this study, no complaints or complications arose. There were also no dropouts due to side effects.

Table 1 General characteristics of participants

Parameter	ANS and Emotional parameters (First session) (n= 24)		Brainwave parameters (Second session) (n= 21)	
	Mean	**SD**	**Mean**	**SD**
Age (years)	21.92	2.47	21.90	2.41
Height (cm)	167.58	6.40	167.52	6.72
Weight (kg)	58.29	4.89	58.33	5.21
Body Mass Index (kg/m^2)	20.66	1.00	20.68	1.07

ANS physiological parameters

The ANS parameters were recorded in the mean and SD values during the three periods of the experiment: Resting (R), sweet almond oil inhalation (SO) and *d*-borneol inhalation (BO). *d*-Borneol inhalation caused significant changes in most ANS parameters (Table 2). *d*-Borneol inhalation significantly increased ANS physiological parameters, namely systolic blood pressure, diastolic blood pressure, and heart rate ($p<0.05$)

Table 2 Mean and SD values of the ANS parameters during the three periods of the experiment: Resting (R), sweet almond oil inhalation (SO), and *d*-borneol inhalation (BO)

Parameter	n	R		SO		BO		p-value R and SO	p-value SO and BO
		Mean	SD	Mean	SD	Mean	SD		
SBP (mmHg)	24	107.67	5.78	107.00	6.01	111.96	7.48	0.084	**<0.001***
DBP (mmHg)	24	65.67	4.83	65.29	3.70	66.58	3.46	0.515	**0.028***
HR (bpm)	24	68.21	6.13	67.67	6.15	70.04	5.50	0.173	**0.026***
ST (°C)	24	31.12	0.82	31.51	1.10	31.79	1.16	**0.009***	0.057
RR (bpm)	24	15.96	2.03	15.46	1.98	16.33	2.16	0.097	0.090

* Significant difference p-value < 0.05, Systolic (SBP) and diastolic (DBP) blood pressure, Heart rate (HR), Skin temperature (ST), Respiratory rate (RR)

Psychological parameters of emotional states

The psychological parameters of emotional states were recorded as mean and SD values during the three periods of the experiment. SO inhalation caused some significant changes in psychological parameters of emotional states. After SO inhalation, the scores for good feelings increased significantly while the scores for drowsy and stressed feelings decreased significantly (Table 3). BO inhalation significantly increased the scores for good, active, fresh, and romantic feelings while significantly decreasing the scores for bad, stressed, frustrated, annoyed, and disgusted feelings.

Table 3 Mean and SD values of the psychological parameters of emotional states during the three periods of the experiment: Resting (R), sweet almond oil inhalation (SO) and *d*-borneol inhalation (BO)

Parameter	n	R		SO		BO		p-value R and SO	p-value SO and BO
		Mean	SD	Mean	SD	Mean	SD		
1. good	24	5.88	0.98	6.06	0.91	6.59	1.32	**<0.001***	**0.032***
2. bad	24	1.18	0.94	1.11	0.84	0.46	0.34	0.439	**<0.001***
3. active	24	3.63	1.59	3.50	1.42	5.42	1.42	0.181	**<0.001***
4. drowsy	24	3.39	1.35	3.08	1.25	2.62	1.49	**0.015***	0.088
5. fresh	24	3.60	1.40	3.55	1.45	5.72	1.63	0.415	**<0.001***
6. relaxed	24	3.96	1.51	4.20	0.95	4.50	1.34	0.149	0.185
7. stressed	24	1.81	1.70	1.26	1.09	0.61	0.60	**0.008***	**<0.001***
8. frustrated	24	1.47	1.18	1.32	1.05	0.66	0.52	0.213	**<0.001***
9. romantic	24	1.68	1.26	1.80	1.10	2.78	0.94	0.408	**<0.001***
10. annoyed	24	1.00	1.22	0.91	0.90	0.57	0.56	0.463	**0.028***
11. calm	24	4.07	0.92	4.28	0.94	4.74	1.32	0.097	0.079
12. disgusted	24	0.34	0.30	0.39	0.30	0.24	0.21	0.388	**0.036***

* Significant difference p-value < 0.05

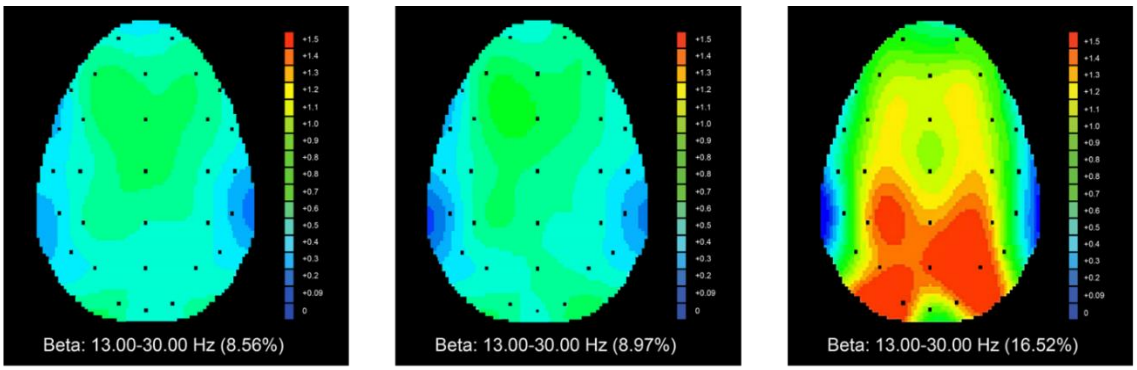
Data from EEG recordings

After BO inhalation, the power of the beta wave over the left and right posterior brain areas increased significantly ($p<0.05$) (Table 4). BO inhalation caused marginal changes without significance in delta, theta and alpha waves. The results of these three waves are shown in the Appendix I (section). The significant changes in the brain waves are illustrated in the topographical map of the brain (Figure 3).

Table 4 Mean and SD values of brain activities (beta powers) during the three periods of the experiment: resting (R), sweet almond oil inhalation (SO) and *d*-borneol inhalation (BO)

Brain Area	n	Beta Power (μV^2)						p-value R and SO	p-value SO and BO
		R		SO		BO			
		Mean	SD	Mean	SD	Mean	SD		
Left anterior	21	0.87	0.31	0.92	0.29	0.95	0.34	0.154	0.364
Right anterior	21	0.89	0.32	0.94	0.35	0.96	0.40	0.222	0.707
Center	21	0.91	0.30	0.99	0.33	1.03	0.36	0.204	0.582
Left posterior	21	0.95	0.46	0.93	0.44	1.19	0.39	0.727	**0.008***
Right posterior	21	0.96	0.41	0.98	0.50	1.30	0.41	0.704	**0.003***

* Significant difference p-value < 0.05



(3a) Resting **(3b) SO inhalation** **(3c) BO inhalation**

Figure 3 Topographical map of the changing beta brainwave activity in the brain. The red areas indicate a significant increase of beta power in the left posterior and right posterior areas during *d*-borneol inhalation.

5. Discussion

The psychophysiological parameters in this study, including ANS parameters, emotional states and brain wave activities through EEG recordings, were recorded to measure three levels of arousal. Hongratanaworakit (2004) proposed that the effects of aromas on the nervous system consisted of two levels of arousal including autonomic arousal, namely heart rate and cortical arousal such as brain wave activity (Hongratanaworakit, 2004). Sayorwan et al. (2012) reported that various emotional states such as good, bad, active and drowsy could be considered subjective behavioral arousal caused by odors (Sayorwan et al., 2012). Therefore, the three levels of arousal in this study comprised ANS parameters as autonomic arousal, emotional states as subjective behavioral arousal, and brain wave activities through EEG recordings as cortical arousal.

d-Borneol was diluted in sweet almond oil (SO). This carrier oil does not cause any significant changes in brain wave activities like in previous studies (Nuiden et al., 2021; Thanatuskitti, Siripornpanich, Sayorwan, Palanuvej & Ruangrungsi, 2020a). Sweet almond oil is commonly used as a carrier oil for diluting essential oils and helps the essential oil to be absorbed more evenly. Essential oil should be used after dilution in carrier oils (Garg, 2005) to avoid skin irritation and nasal epithetical cells. The results on ANS parameters in this study found that SO inhalation caused a significant increase in skin temperature, which was consistent with a previous study on the effects of inhaled rice paddy herb oil on the autonomic nervous system (Thanatuskitti,

Siripornpanich, Sayorwan, Palanuvej & Ruangrungsi, 2020b). The results for emotional states in this study reported that SO inhalation significantly increased good feelings while significantly decreasing drowsy and stressed feelings. On the contrary, Nuiden (2019) found that SO inhalation decreased heart rate in ANS parameters and decreased good feelings while increasing romantic feelings in emotional states (Nuiden et al., 2019). Another study by Thanatuskitti et al. (2020a) on the effects of inhaled rice paddy herb oil on brain wave activities and emotional states also reported that SO decreased stressed feelings in emotional states (Thanatuskitti, Siripornpanich, Sayorwan, Palanuvej, & Ruangrungsi, 2020a). The effects of sweet almond oil on ANS parameters and emotional states were revealed. This might be due to its mild odor not being completely comparable with room air, meaning it could trigger autonomic responses including skin temperature and emotional states. This study design could be beneficial for the further selection of carrier oil used in olfactory-brain research.

In comparison with SO, the results from this study reported that BO inhalation could significantly increase systolic blood pressure, diastolic blood pressure and heart rate. Blood pressure and heart rate are used to measure physiological changes affected by aroma substances. An increase in both ANS parameters might indicate stimulating effects (Hongratanaworakit, 2004). BO inhalation affected ANS parameters through significant increases in autonomic arousal.

BO inhalation caused significant changes in the absolute powers of brain wave activities, particularly beta waves. Beta waves, which have the highest frequency around 13 and 30 Hz, are related to an alert state of mind, motor preparation, focused attention or attention-carrier (Nueper, & Pfurtscheller, 2001). A study on driving drowsiness found that beta activity decreased when the driver fatigue level increased and the driver vigilance level decreased (Lee, Lee, & Chung, 2014). A previous study also reported that beta waves from the posterior parietal cortex increased to enable better upper limb movement during visually-guided movement (Chung, Ofori, Misra, Hess, & Vaillancourt, 2017). Neurofeedback, i.e. beta training, is beneficial for attention and cognitive function improvement as well as the enhancement of creative potential (Agnoli, Zanon, Mastria, Avenanti, & Corazza, 2018).

BO inhalation caused significant enhancement for specific emotional states. After *d*-borneol inhalation, the participants felt better, fresher, more active and romantic. At the same time, they had minimal bad, annoyed, stressed, frustrated and disgusted feelings. A previous study was conducted in 2006 on the effects of aroma air supplementation on active safety during car driving using a driving simulator. The findings revealed the awakening and alertness effects of *d*-borneol. The feeling of exhaustion was reduced. There was also a higher success rate for lane departure avoidance, which improved the straight-line stability of driving (Suzuki, Yasuda, Sassa & Harada, 2006).

d-Borneol was inhaled through the olfactory system, which is directly associated with brain structures, particularly the hippocampus, thalamus and frontal cortex responsible for managing memory and emotions. Olfactory information was transmitted from the olfactory bulbs to the primary olfactory cortex and then transmitted further to other brain regions (Sowndhararajan, 2016). Finally, the brain regions related to olfactory perception, autonomic homeostasis and other higher brain functions received the olfactory information for processing (Courtiol, & Wilson, 2015).

Brain wave activity through EEG recordings demonstrated the arousal effects of jasmine essential oil inhalation on the CNS and also the emotional states (Sayorwan, Siripornpanich, Hongratanaworakit, Kotchabhakdi & Ruangrungsi, 2013). Beta waves are activated in focused mental activity, problem-solving and decision-making (Das, 2019). Beta waves are dominant when people are engaged in reading, concentrated thought, and highly emotional or other tense mental states (Hongratanaworakit, 2004). In this study, *d*-borneol could induce a significant increase in the beta waves related to active attention during the waking rhythm of the brain (Idris et al., 2014), causing autonomic arousal through a significant increase in blood pressure and heart rate, thus making the participants feel better, more active, fresher and more romantic. A significant increase in systolic blood pressure and diastolic blood pressure caused by BO inhalation indicated an increase in autonomic arousal since

blood pressure is one of the activities under the sympathetic branch of the autonomic nervous system (ANS) (Hongratanaworakit, & Buchbauer, 2007).

Interestingly, *d*-borneol inhalation caused a significant increase in autonomic arousal through ANS parameters including systolic blood pressure, diastolic blood pressure, and heart rate. The results on the emotional states as subjective behavioral arousal found that the participants felt better, fresher, and more active after *d*-borneol inhalation, while it increased the beta waves through EEG recordings, considered changes in cortical arousal. The results of the psychophysiological parameters induced by *d*-borneol inhalation in healthy participants were consistent with previous studies (Sayorwan, Siripornpanich, Hongratanaworakit, Kotchabhakdi & Ruangrungsi, 2013; Nuiden et al., 2019). A previous study on the effects of jasmine essential oil inhalation on brain wave activities and the emotional states in healthy participants revealed that jasmine essential oil inhalation could increase beta waves and increase positive emotions including well-being, active, fresh and romantic feelings (Sayorwan, Siripornpanich, Hongratanaworakit, Kotchabhakdi, & Ruangrungsi, 2013). In another study on the effects of *Cinnamomum porrectum* essential oil inhalation on ANS parameters, emotional states in healthy participants reported that *Cinnamomum porrectum* essential oil inhalation increased ANS parameters including systolic blood pressure, diastolic blood pressure, heart rate, respiratory rate while inducing positive emotional states including active and fresh feelings (Nuiden et al., 2019). These results from previous studies in terms of active and fresh feelings induced by jasmine essential oil and *Cinnamomum porrectum* essential oil seemed to have stimulating effects similar to those of *d*-borneol inhalation in this study. Stern, Ray, and Quigley (2001) also suggested that increases in cortical arousal and/or autonomic arousal could be interpreted as a stimulating effect of aromas (Stern, Ray, & Quigley, 2001). Thus, *d*-borneol inhalation causing the increases in cortical arousal and autonomic arousal could contribute to its stimulating effects.

6. Limitations

The participants in this study inhaled *d*-borneol twice (sessions 1 and 2). Olfactory memory might be affected by repeated exposure to the odor since ANS parameters and EEG recordings could not be conducted simultaneously in the same experiment and ANS parameters were not measured continuously. In this study, *d*-borneol was administered as a single compound. If other essential oils contained *d*-borneol as a compound or *d*-borneol was mixed with other substances, the effects would be different. The stimulating effects of *d*-borneol in this study were initiated in healthy participants who chose the target scale between 2 to 4 on the "Odor familiarity five-point Likert scale".

7. Conclusion

The inhalation of *d*-Borneol caused significant changes in the three levels of arousal among healthy participants. The effects of BO inhalation may be classified as stimulating effects by causing autonomic arousal through the ANS parameters, subjective behavioral arousal through the psychological parameters of emotional states, and cortical arousal through changing brain wave activities. Increasing ANS parameters were shown, including systolic blood pressure, diastolic blood pressure and heart rate. The Geneva Emotion and Odor Scale was used to measure the emotional effect of *d*-borneol. Not only was a significant increase in positive emotional states found, but also a significant decrease in negative emotional states simultaneously. EEG recordings exhibited an increase in the absolute powers of beta activities in the left and right posterior regions.

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Conflicts of Interest

The researchers declare no conflicts of interest.

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10. Appendix I (section)

The results of sweet almond oil inhalation (SO) and *d*-borneol inhalation (BO) on the powers of delta, theta and alpha waves are summarized in the following supplementary tables**.**

Table 5 Delta powers of the brain activities during resting (R), sweet almond oil inhalation (SO) and *d*-borneol inhalation (BO)

Brain Area (n=21)	**Delta Power (μV^2)**							
	Resting		**SO**		**BO**		**p-value resting and SO**	**p-value SO and BO**
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**		
Left anterior	15.82	4.62	14.93	3.30	14.26	4.21	0.339	0.199
Right anterior	15.71	3.54	14.62	4.29	15.16	4.45	0.226	0.583
Center	12.66	4.28	12.24	4.37	11.90	4.46	0.556	0.619
Left posterior	10.13	2.98	10.09	2.94	9.97	3.81	0.939	0.871
Right posterior	10.34	3.80	9.88	3.05	9.19	3.00	0.424	0.230

Table 6 Theta powers of the brain activities during resting (R), sweet almond oil inhalation (SO) *d*-borneol inhalation (BO)

Brain Area (n=21)	Theta Power (μV^2)							
	Resting		SO		BO		p-value resting and SO	p-value SO and BO
	Mean	SD	Mean	SD	Mean	SD		
Left anterior	3.94	1.49	3.70	1.31	3.53	1.35	0.526	0.520
Right anterior	3.78	2.09	3.81	1.77	3.35	1.30	0.922	0.079
Center	4.90	2.02	4.51	1.82	3.94	1.41	0.469	0.286
Left posterior	2.11	0.95	2.27	0.90	2.08	0.71	0.437	0.171
Right posterior	2.57	1.67	2.12	1.03	1.97	0.92	0.078	0.462

Table 7 Alpha powers of the brain activities during the resting (R), sweet almond oil inhalation (SO) and d-borneol inhalation (BO)

Brain Area (n=21)	Alpha Power (μV^2)							
	Resting		SO		BO		p-value resting and SO	p-value SO and BO
	Mean	SD	Mean	SD	Mean	SD		
Left anterior	4.01	2.02	3.83	1.92	3.75	1.62	0.754	0.832
Right anterior	3.98	1.58	3.90	1.49	3.73	1.56	0.856	0.632
Center	4.37	1.79	3.94	1.46	3.85	1.93	0.234	0.847
Left posterior	4.14	1.85	3.89	1.38	3.60	1.44	0.731	0.387
Right posterior	3.94	1.36	3.66	1.53	3.45	1.18	0.478	0.803