

Original Research

# Effects of Volatile Organic Compounds (VOCs) of *Cinnamomum burmannii* in Its Natural State on Physical and Mental Health

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## Abstract

Aromatic plant is an important element in the construction of landscape environment space. As an aromatic plant, *Cinnamomum burmannii* releases rich volatile organic compounds (VOCs), which can improve the quality of the environment, and have a health effect on the human body through smell. In order to determine the relationship between *Cinnamomum burmannii* VOCs and physical and mental health, the physiological and psychological indexes of volunteers were analyzed in indoor and outdoor environments with different concentrations of *Cinnamomum burmannii* VOCs. And the behavioral activities and physiological indexes of the animals were studied through experiments on the open field behavior of mice. Results of quantitative analysis of human physiological indicators indicated that the volunteers were in the most relaxed state at low concentration of *Cinnamomum burmannii* VOCs in indoor ( $0.10 \pm 0.04 \text{ m}^3/\text{m}^2$ ), and outdoor ( $0.10 \pm 0.05 \text{ m}^3/\text{m}^2$ ). Investigation of human psychological indicators demonstrated low concentration of *Cinnamomum burmannii* VOCs ( $0.10 \pm 0.05 \text{ m}^3/\text{m}^2$ ) could relieve the stress and improve the mental state on the human body to a large extent. In addition, the open-field behavioral experiment of mice revealed the low concentration of *Cinnamomum burmannii* VOCs ( $2.04 \times 10^{-3} \text{ g}/\text{cm}^3$ ) had the best effect on promoting motility and exploring cognitive ability of mice. These results can provide a basis for the application of aromatic plants in the landscape environment through their health benefits.

**Keywords:** *Cinnamomum burmannii*, tridimensional green biomass, open field test, symptom checklist

## Introduction

As the world's ecological environment is deteriorating, people's work and life have become

increasingly stressful; the demand for physical and mental health is increasing. A quality landscape environment promotes human physical and mental health [1, 2], and its effects on health care and healing are gradually attracting attention. Aromatic plants are an important landscape element in the creation of environmental spaces with green landscaping, and the volatile organic compounds (VOCs) that they release not

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only improve the eco-environmental quality, but also act on the human body through smell and thus have health effects [3, 4]. *Cinnamomum burmannii* is an evergreen tree of the *Camphor* family with a clear cinnamon odor from the bark and an odor similar to sandalwood from the young branch tips [5]. Both the nutritional and reproductive organs of *Cinnamomum burmannii* are rich in VOCs, and most of these volatile substances have health benefits [6]. In woods where 95% of the tree layer is *Cinnamomum burmannii*, the ambient physical comfort level is 'very comfortable' and the airborne particulate matter concentration is within the primary mass concentration limit, which is a good overall health function [7].

In 2021, Wang selected *Cupressus macrocarpa* 'Goldcrest', *Ternstroemia gymnanthera*, *Trachelospermum jasminoides* and *Perilla frutescens* as the research object, the results indicated that these four aromatic plants had different positive effects on human blood pressure, heart rate and radio waves [8]. In 2016, Song et al. found that the blood oxygen saturation of subjects increased, but the systolic blood pressure, diastolic blood pressure, and heart rate all decreased after sniffing *Cedrus deodara*, whereas there was no significant difference after sniffing *Acer truncatum* compared to the control group, and the smell of *Cedrus deodara* was more relaxing than that of *Acer truncatum* [9]. In 2019, He studied on the intervention effect of aromatic plant volatiles on human health. The results showed that smelling the four plants had no significant effect on human heart rate, but had a certain effect on human blood pressure, and had a very significant interference effect on human brain waves [10]. In 2017, Lee et al. made a blend of essential oils from *Citrus limon*, *Eucalyptus robusta* Smith, *Camellia sinensis*, and *Mentha canadensis* Linnaeus, and after inhaling this aromatic oil, the subjects felt less stressed and depressed and their sleep quality improved [11]. The 3-week forest rehabilitation could improve sleep quality and alleviate psychological stress reaction of diabetic patients and healthy volunteers in Yanminghu Town, which is rich in 87 kinds of forest volatiles [12]. In 1985, researchers of the University of Tokyo established that the concentration of terpene volatiles contained in the natural state of the forest had an effect on the living behavior of mice and proposed that it was related to the concentration threshold [13]. These studies suggest that aromatic plants have certain health benefits, but the relevance of the VOCs they release to human health is not yet clear.

In this study, the effects of different concentrations of VOCs of *Cinnamomum burmannii* on human physiological and psychological health indexes were quantitatively analyzed under the influence of a single factor of the human olfactory sense. The study was also combined with an open-field test to measure the behavior of mice, to provide ideas for establishing objective and quantitative evaluations of the creation of green landscaping environments and their recreational benefits in the future.

## Materials and Methods

### Research Materials and Subjects

The plant material used for the experiment, *Cinnamomum burmannii*, was grown in the practical teaching and science and technology innovation base of the biological garden of School of Life Sciences, Zhaoqing University, and the plants were in good health. Potted *Cinnamomum burmannii* with an average crown width of  $0.98 \pm 0.03$  m, an average crown height of  $1.46 \pm 0.05$  m, and consistent plant growth were selected for the study of human health indicators.

Sixty volunteers were randomly selected, among which 42 valid data were obtained, including 18 males and 24 females aged between 18 and 24 years old; all included volunteers were healthy college students with no history of disease (Note: the values of the systolic blood pressure, diastolic blood pressure, and heart rate of volunteers before the test were all within the normal range). The volunteers were informed 24 h before the test that they should clean their heads, avoid stimulating beverages such as alcohol, coffee, or other drugs [14], refrain from intense, frequent exercises, and maintain a good diet and rest.

Forty male Kunming mice (purchased from Guangdong Medical Laboratory Animal Center) of 4 to 5 weeks old and 18 to 25 g body mass were labeled and randomly divided into four groups of 10 mice each. The mice were kept in the experimental room at a constant temperature of  $24 \pm 1^\circ\text{C}$ , with light and dark cycles every 12 h. The mice were fed freely with standard mouse food and water. They were housed for 3-5 days to accustom them to the new environment prior to the open-field test.

### Measurement of Human Physiological and Psychological Indicators

Measurement of physiological indicators: physiological indicators including brain waves ( $\alpha$  and  $\beta$  waves) and surface electromyography (EMG) were measured using a hand-held Neurobit Optima 4 biofeedback tester, with electrodes placed according to the international 10-20 system method [15], and the reference electrode was placed on the forehead. The blood pressure [systolic blood pressure (SBP), diastolic blood pressure (DBP)], and heart rate (HR) of the volunteers were measured using an electronic wrist blood pressure monitor HEM-8611 [16].

Psychological indicators: the volunteers were tested for changes in their psychological indicators using the SCL-90 self-assessment scale before and after scenting.

### The Effects of *Cinnamomum burmannii* VOCs on Human Health in Indoor Environment

It has been shown that the concentration of plant VOCs and negative air ion concentration are

positively correlated with each other [17], and the negative air ion concentration in green areas increases with the increase of three-dimensional green biomass (TGB) [18]. Therefore, in this study, we set the TGB of *Cinnamomum burmannii* as quantitative indicators of its indoor and outdoor VOC emission gradients. The TGB of *Cinnamomum burmannii* was measured before the experiment using the method of Liu et al. as a reference [19].

Four quiet, clean, and odor-free enclosed experimental rooms were selected as the experimental sites, all with an indoor height of 3.5 m and an area of 10 m<sup>2</sup>, and the indoor temperature was controlled at 23–25°C. The experiment was conducted in four treatment groups, and the TGB of *Cinnamomum burmannii* per unit areas (TGB/m<sup>2</sup>) placed in each experimental room were 0.00 m<sup>3</sup>/m<sup>2</sup>, 0.10±0.04 m<sup>3</sup>/m<sup>2</sup>, 0.30±0.03 m<sup>3</sup>/m<sup>2</sup>, and 0.60±0.03 m<sup>3</sup>/m<sup>2</sup>, which were marked as blank control group CK<sub>1</sub> and experimental groups I<sub>1</sub>, I<sub>2</sub>, and I<sub>3</sub>, accordingly. Before the experiment, the potted *Cinnamomum burmannii* plants were moved to each experimental room with different TGB treatments and allowed to fully release VOCs in the enclosed space for 24 h. During the experiment, the volunteers sat in a rest area for 15 min to adjust their personal state and minimize the disturbing factors inside and outside the human body such as the movement

state and climatic environment before entering the experimental room from outside [14]. After the volunteers became calm, they were sequentially entered into the experimental rooms CK<sub>1</sub>, I<sub>1</sub>, I<sub>2</sub>, and I<sub>3</sub>. As shown in Fig. 1a), the blood pressure and heart rate were measured in the experimental room after 4 min of sitting still with an eye mask on, followed by the measurement of brain waves and surface EMG, and the EEG signals were collected for 4 min. After completing the test in one treatment group, the volunteers were required to return to the resting area and sit for 4 min before moving to the next experimental room to eliminate the effect of the inhaled aroma of *Cinnamomum burmannii* on the test of the next treatment group.

#### The Effects of *Cinnamomum burmannii* VOCs on Human Health in Outdoor Environment

In the “Suiyuan” wellness garden in the biological garden of Zhaoqing University, an open-air rectangular field with a perimeter height of 1.5 m and an area of 20 m<sup>2</sup> was formed using white rainproof cloth as the scenting area for the treatment group (Fig. 1b). No other aromatic plants were planted in the surrounding area, and an open space away from the scenting area was selected as the control group (CK<sub>2</sub>). The treatment groups O<sub>1</sub>, O<sub>2</sub>, and O<sub>3</sub> were placed with

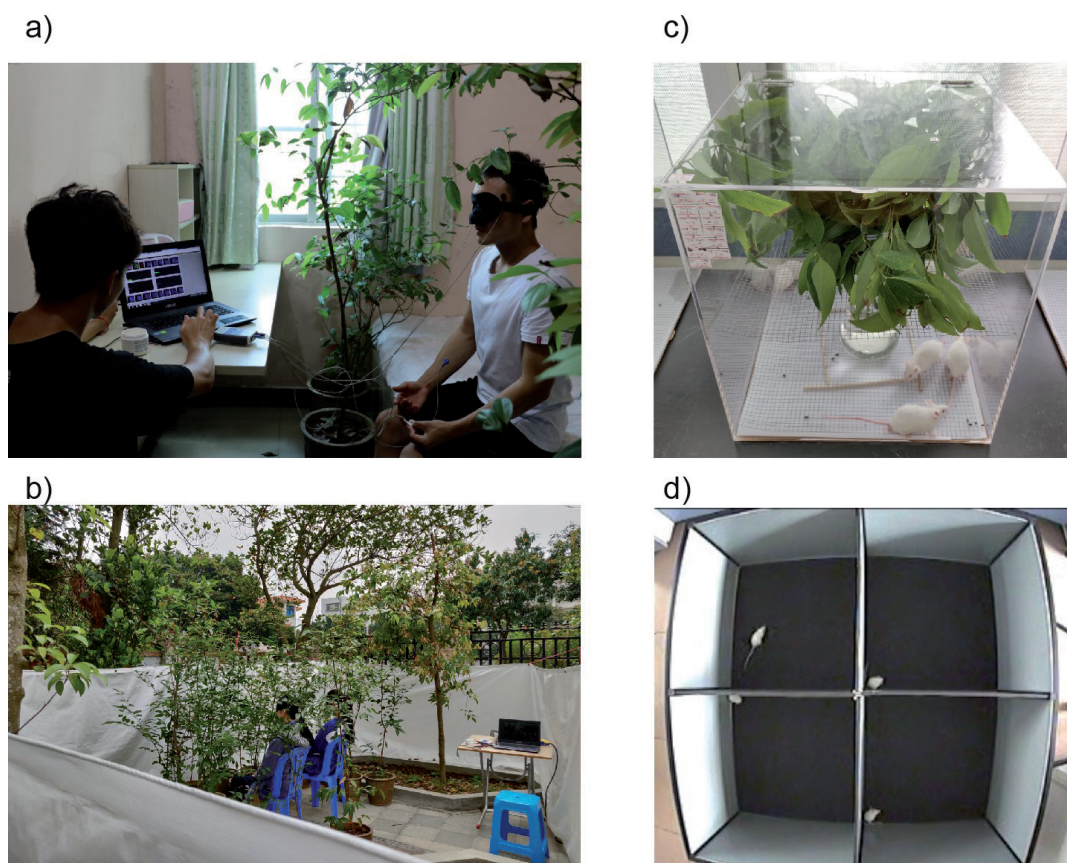


Fig. 1. a) Indoor test site. b) Outdoor test site. c) Open field test treatment box. d) BW-OF302 open-field experimental video analysis system.



the TGB of *Cinnamomum burmannii* per unit area of  $0.10 \pm 0.05 \text{ m}^3/\text{m}^2$ ,  $0.30 \pm 0.03 \text{ m}^3/\text{m}^2$ , and  $0.60 \pm 0.01 \text{ m}^3/\text{m}^2$ , respectively.

The test was conducted on a day with clear weather and no wind between 8:00-11:00 am and 2:30-5:30 pm, and relevant environmental factors were recorded using the HT-8500 5-in-1 multifunctional environmental tester. The steps for measuring the blood pressure, heart rate, brain waves, and EMG in the outdoor test were basically the same as those in the indoor test, with the difference that it was necessary to return to CK<sub>2</sub> for 10 min of meditation before completing the test in one treatment group and moving to the next one.

The outdoor experimental groups CK<sub>2</sub> and O<sub>1</sub> were selected as the test sites for measuring the psychological effects on humans before and after scenting. The volunteers arrived at the test site, sat in CK<sub>2</sub> for 15 min waiting to return to calm, and were tested on the SCL-90 self-rating scale. Subsequently, after entering the O<sub>1</sub> scenting area, they sat quietly with the eye mask on for 30 min [20] and returned to CK<sub>2</sub> to be retested on the SCL-90 self-rating scale.

#### Indicators to Determine the Effect of *Cinnamomum burmannii* VOCs on the Spontaneous Behavior of Mice

The spontaneous behavioral indices of mice were observed and recorded using the BW-OF302 open-field experimental video analysis system. 0 g, 100 g, 200 g, and 300 g of fresh *Cinnamomum burmannii* branches and leaves were inserted into 500 ml bottles and placed in homemade plexiglass treatment boxes (35 cm × 35 cm × 40 cm), using the method of hydroponics (Fig. 1c), labeled as the control group CK<sub>3</sub> and experimental groups R<sub>1</sub>, R<sub>2</sub>, and R<sub>3</sub>, respectively, with gradients of *Cinnamomum burmannii* varying from  $0.00 \text{ g}/\text{m}^3$ ,  $2.04 \times 10^{-3} \text{ g}/\text{cm}^3$ ,  $4.08 \times 10^{-3} \text{ g}/\text{cm}^3$ , and  $6.12 \times 10^{-3} \text{ g}/\text{cm}^3$ . To ensure normal breathing of the mice while reducing the diffusion of the aroma of the *Cinnamomum burmannii*, four ventilation holes of 1 cm in diameter were drilled in the lid above the treatment box.

After weighing and recording the body mass of mice by 9:50 am, the four groups of mice were placed in the corresponding treatment boxes and treated continuously for 4 h each day from 10:00-14:00. The treated mice were then put into the BW-OF302 open-field experimental video analysis system (Fig. 1d) to observe the activities of each batch of animals within 5 min, which was performed once a day for 6 days of continuous treatment trials. The mice were tested for the total exercise distance of mice, distance of central regional activities, weight of mice, number of fecal particles, standing times.

#### Data Analysis

BioExplorer and BioReview software were used to collect, transform, and analyze human bioelectric signal

data. The autonomous activity behavior and physiological responses of the mice were recorded and analyzed using the BW-IOF301 Locomotor Activity (Inner Open Field) video analysis system. The experimental data were analyzed using Excel 2010 and IBM SPSS Statistics 24.0 statistical analysis software.

Interventionary studies involving animals or humans, and other studies require ethical approval must list the authority that provided approval and the corresponding ethical approval code.

## Results

### Impact Analysis of *Cinnamomum burmannii* VOCs on Human Physiological Indicators in Indoor and Outdoor

#### Systolic Blood Pressure

The systolic blood pressure, diastolic blood pressure, and heart rate among the human physiological health indicators can reflect vascular function and are also related to ventricular contractility and peripheral resistance [21]; a decrease in systolic blood pressure can have a relaxing effect [22].

As shown in Fig. 2a) and Fig. 3a), comparing the control groups indoors and outdoors, the systolic blood pressure values of the volunteers in the experimental groups I<sub>1</sub> and O<sub>1</sub> were significantly decreased ( $p < 0.05$ ), their concentration treatment was located at the low point, and the volunteers were in the most relaxed state.

#### Diastolic Blood Pressure

Studies have shown that being in a plant environment can reduce the diastolic blood pressure of the body to some extent, allowing the body and mind to be in a calmer and more relaxed state and relieving stress [23]. As can be observed in Fig. 2a) and Fig. 3a), compared with the control groups indoor and outdoor, the volunteers showed a decreasing trend in the diastolic blood pressure values in the experimental groups I<sub>1</sub> and O<sub>1</sub>, and their diastolic blood pressure values were at the lowest point relative to the other treatments, indicating that the human body was in the most relaxed state. However, with the increase in concentration, the diastolic blood pressure values showed a significant increase ( $p < 0.05$ ), and the human body tended to be in a tense state.

#### Heart Rate

A lower heart rate value can lead the body and mind to a calmer and more relaxed state [23]. As shown in Fig. 2a) and Fig. 3a), compared with the control groups indoors and outdoors, the volunteers showed an increasing trend in the heart rate values in the experimental groups I<sub>1</sub> and O<sub>1</sub>, but a significant decrease in the heart rate values at I<sub>2</sub> and O<sub>2</sub> ( $p < 0.05$ ),

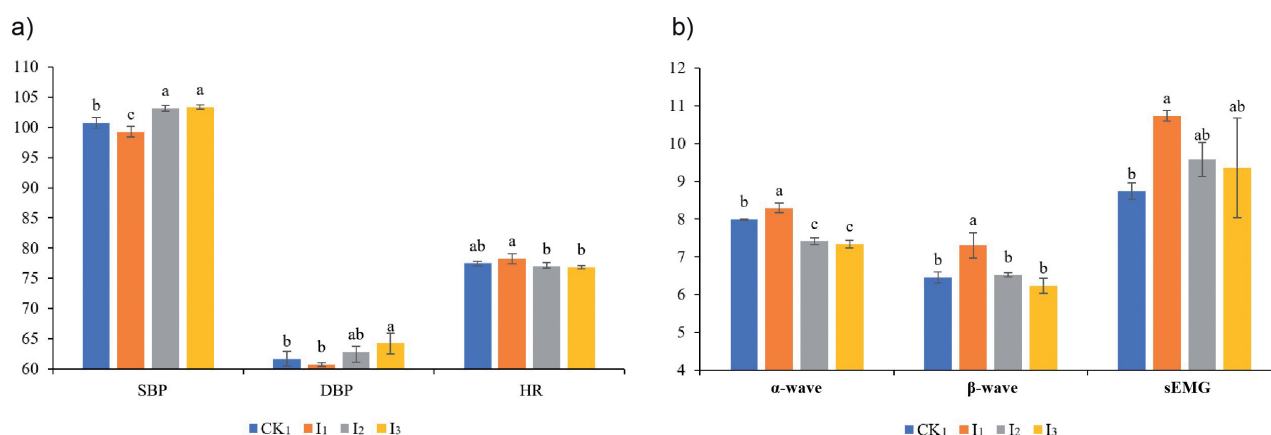


Fig. 2. Effects of different concentrations of *Cinnamomum burmannii* on Physiological Indexes of volunteers indoors. a) Systolic blood pressure (SBP), Diastolic blood pressure (DBP), Heart rate (HR). b)  $\alpha$ -wave,  $\beta$ -wave, Surface electromyography (sEMG). Different lowercase letters indicate that there are significant differences among the indexes ( $P < 0.05$ ).

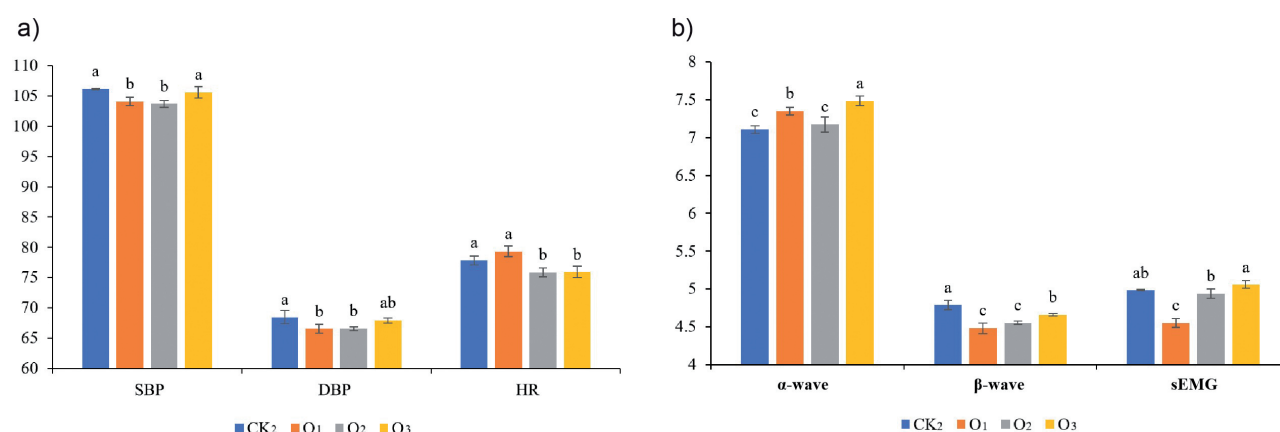


Fig. 3. Effects of different concentrations of *Cinnamomum burmannii* on Physiological Indexes of volunteers outdoors. a) Systolic blood pressure (SBP), Diastolic blood pressure (DBP), Heart rate (HR). b)  $\alpha$ -wave,  $\beta$ -wave, Surface electromyography (sEMG). Different lowercase letters indicate that there are significant differences among the indexes ( $P < 0.05$ ).

indicating that the human body was in the most relaxed state. As the concentration increases, the heart rate value tended to rise, and the body tended to be stressed.

#### $\alpha$ Brain Waves

Brain waves reflect changes in the central nervous system indicators and are a more sensitive indicator of when the human olfactory sense is affected by the environment and produces corresponding emotional changes [24].  $\alpha$  waves (Alpha, 8-12 Hz) are the main human activity rhythms when the body is in the awakened and quiet state [25-27]; when the  $\alpha$ -wave amplitude increases, negative emotions diminish, and the body is in the relaxation phase [28]. As can be observed in Fig. 2b), the  $\alpha$ -wave amplitude in indoors showed a significant increase compared to when the CK<sub>1</sub> volunteers were at I<sub>1</sub> ( $p < 0.05$ ), which was located at the highest point relative to the other treatments, i.e., the volunteers were in the most relaxed state; however,

as the concentration increased, the  $\alpha$ -wave amplitude of the volunteers exhibited a significant decrease ( $p < 0.05$ ). From Fig. 3b), the volunteers that were outdoors compared to those in CK<sub>2</sub> showed a significant increase ( $p < 0.05$ ) in the  $\alpha$ -wave amplitude at O<sub>1</sub>, which was at the level of the relaxed state, whereas at O<sub>2</sub> the  $\alpha$ -wave amplitude returned to the level of CK<sub>2</sub>. However, with the increase in the treatment concentration, the  $\alpha$ -wave amplitude showed a significant increase ( $p < 0.05$ ) at O<sub>2</sub>.

#### $\beta$ Brain Waves

$\beta$  waves (Beta, 12-25 Hz) are generally the main rhythm of activity in the human body during states of tension [29], thinking, and high concentration [30]. When the  $\beta$ -wave amplitude decreases, emotions tend to settle [31]. From Fig. 2b), the  $\beta$ -wave amplitude of the volunteers that were indoors compared to the CK<sub>1</sub> volunteers at I<sub>1</sub> significantly increased ( $p < 0.05$ ) and was at the highest point relative to the other

treatments, i.e., the volunteers were the most nervous; as the treatment concentration increased, the  $\beta$ -wave amplitude of the volunteers significantly decreased ( $p<0.05$ ), and at  $I_3$  the  $\beta$ -wave amplitude was lower than the control value, and the volunteers were relieved of their nervousness. It can be concluded from Fig. 3b) that, in the outdoors compared with  $CK_2$ , the  $\beta$ -wave amplitude of the volunteers showed a significant decreasing trend ( $P<0.05$ ) at three different concentrations, and the  $\beta$ -wave amplitude was the lowest at  $O_1$  with the best effect of human emotion stabilization compared to other treatment groups.

#### Surface Electromyography

Surface electromyography is an index of human muscle comfort evaluation, reflecting the relaxation state of human muscles. When the value of the surface electromyography increases, the higher the degree of muscle relaxation, and the body shows relaxed and positive emotions [32]. From Fig. 2b), the volunteers showed a significant increase ( $p<0.05$ ) in the surface EMG mean at  $I_1$  inside the room compared to  $CK_1$ , and its surface EMG mean was located at the highest point relative to the other treatments, indicating that the

human forehead muscles were in the most relaxed state. Fig. 3b) shows the values when the volunteers were at  $O_1$  in the outdoors compared to  $CK_2$ .

The mean value of the surface EMG showed a significant decrease ( $p<0.05$ ), but as the concentration increased, the mean value of the surface EMG tended to increase and was located at the highest point at  $O_3$ , when the forehead muscles were at their most relaxed state.

To sum up the results of the human physiological indicators analysis, *Cinnamomum burmannii* VOCs at low concentrations  $I_1$  ( $0.10\pm0.04$  m<sup>3</sup>/m<sup>2</sup>) and  $O_1$  ( $0.10\pm0.05$  m<sup>3</sup>/m<sup>2</sup>) in indoor and outdoor respectively is when the volunteers were in the most relaxed state, which has a positive effect on the human body and mind and can produce the effect of stress relief and mood relaxation.

#### Analysis of the Effect of *Cinnamomum burmannii* VOCs on Human Psychological Indicators in Outdoor

The SCL-90 is a commonly used clinical self-rating scale for psychiatric symptoms [33], and is one of the most well-known mental health testing scales in

Table 1. SCL-90 value of the volunteers before and after sniffing the *Cinnamomum burmannii* VOCs.

Index	Before smelling	After smelling	T-value	P-value
General symptom	0.289±0.256	0.197±0.174	3.639	0.001**
Negative items number	68.833±15.069	74.310±12.712	-4.640	0.000**
Positive items number	21.167±15.069	15.690±12.712	4.640	0.000**
Average score of positive symptom	1.072±0.346	1.041±0.284	0.898	0.374

\* are statistically significant differences ( $P<0.05$ ).

\*\* are statistically extremely significant differences ( $P<0.01$ ).

Table 2. Score changes of SCL-90 factors of the volunteers before and after sniffing the *Cinnamomum burmannii* VOCs.

Scale	Before smelling	After smelling	T-value	P-value
Somatization	0.161±0.247	0.121±0.187	1.897	0.065
Obsessive Compulsive	0.576±0.444	0.445±0.370	3.265	0.002**
Interpersonal Sensitivity	0.344±0.337	0.257±0.233	2.173	0.036*
Depression	0.260±0.300	0.156±0.187	3.344	0.002**
Anxiety	0.271±0.273	0.140±0.187	3.417	0.001**
Anger-Hostility	0.167±0.218	0.071±0.152	3.736	0.001**
Phobic Anxiety	0.238±0.323	0.204±0.301	1.532	0.133
Paranoid Ideation	0.234±0.310	0.139±0.184	2.524	0.016*
Psychoticism	0.307±0.320	0.212±0.233	2.980	0.005**
Others	0.282±0.373	0.177±0.214	2.685	0.010*

\* are statistically significant differences ( $P<0.05$ ).

\*\* are statistically extremely significant differences ( $P<0.01$ ).

the world. As can be observed from Table 1, the scores and number of items of the volunteers before and after sniffing the *Cinnamomum burmannii* produced certain changes. The overall symptom level of the subject population decreased, the general symptom index score showed a highly significant decrease ( $p < 0.01$ ), the negative items number increased ( $p < 0.01$ ), the positive items number decreased ( $p < 0.01$ ), and the mean positive symptom score also decreased. The results indicated that after sniffing *Cinnamomum burmannii* VOCs in the outdoor environment of the labeled experimental group  $O_1$  ( $TGB/m^2$  of  $0.10 \pm 0.05$   $m^3/m^2$ ), the psychological condition of the human body was improved, and it also had a positive effect on the human physical and mental health.

From Table 2, it was concluded that the volunteers exhibited an overall decreasing trend in the SCL-90 factor scores after sniffing *Cinnamomum burmannii*, with a highly significant decrease in the obsessive-compulsive, depression, anxiety, anger-hostility, and psychoticism ( $p < 0.01$ ), and a significant decrease ( $p < 0.05$ ) in the interpersonal sensitivity, paranoid ideation, and other items, whereas the changes in the somatization and phobic anxiety were not significant. The results indicated that the *Cinnamomum burmannii* VOCs in the experimental group  $O_1$  can play a significant role in relieving stress, relaxing the body and mind, and improving the mental state.

#### The Behavior Analysis of Mice from *Cinnamomum burmannii* VOCs in an Open Field

Researchers are currently using laboratory mice to study changes in the behavioral activities or physiological indicators of the animal organism in different concentrations of plant environments to verify their effects on human mental health by simulating human cognition or emotions [13, 34, 35].

##### Total Exercise Distance

The total exercise distance reflects the amount of exercise in mice, and a high amount of exercise is associated with excitement in the central nervous system of mice, and vice versa; mice present a certain state of depression [36]. As can be observed in Fig. 4a), the total exercise distance traveled by the mice in experimental group  $R_1$  during the 6 days of the experiment was the greatest and was significantly different from those in the control group  $CK_3$  on days 2 and 4 ( $P = 0.003$ ;  $P = 0.015$ ). The trend of the total exercise distance over the 6 days of the experiment was that each experimental group had a lower total exercise distance than  $CK_3$  on day 1, but each experimental group had a higher total exercise distance from day 2 to day 6 than in  $CK_3$ . In conclusion, it can be inferred that *Cinnamomum burmannii* VOCs played an excitatory role in the locomotion of mice, and the experimental group  $R_1$  treated with lower concentration had the best

effect in increasing the excitability of mice and also had a good antidepressant effect.

##### Distance of Central Region Activities

The central region is not favored by mice, and the frequency of activity of mice in this region can reflect their exploratory behavior. When specific physiological situations such as alertness, central excitation or inhibition occur, the frequency of activity of mice in the central region will increase or decrease [37]. From Fig. 4b), it can be observed that on day 1, all experimental groups had less locomotor distance in the central region than in the control group  $CK_3$ . However, the results of the multiple comparison analysis showed that both experimental groups  $R_1$  and  $R_2$  had a higher locomotor distance in the central region than  $CK_3$  from day 2 to day 6, and the experimental group  $R_3$  only had more compared to  $CK_3$  on days 3, 5, and 6. On day 2, the change in the experimental group  $R_1$  versus  $CK_3$  was significantly different ( $P = 0.022$ ). This showed that the treatment with lower concentrations of *Cinnamomum burmannii* VOCs is more beneficial to the exploration ability of mice.

##### Body Mass

Changes in the body mass of mice reflected the effect of the experimental treatments on the appetite, and the difference between the mean final body mass and the mean initial body mass of each group was compared as a measurement standard [38, 39]. No mice died during the experiment period and were in good health. From Fig. 4c), it can be deduced that the changes in the mean body mass of the control group  $CK_3$  and each experimental group showed a non-significant increasing trend, in which the mean body mass of  $CK_3$  increased by 1.53 g, and that of the experimental groups  $R_1$ ,  $R_2$ , and  $R_3$  increased by 0.73 g, 0.17 g, and 0.46 g, respectively. This showed that *Cinnamomum burmannii* VOCs have a tendency to reduce the appetite of mice, but the effect is not significant.

##### Fecal Pellet Count

The number of fecal pellets is an indicator of the degree of tension in animals, and the higher the number of fecal pellets, the greater the degree of tension [40, 41]. As shown in Fig. 4d), the mean number of fecal pellets in the first 3 days of the experimental group  $R_1$  was greater than that of the control group  $CK_3$ , except for the mean number of fecal pellets in each experimental group in 6 days, which was less than or equal to that of  $CK_3$ , indicating that *Cinnamomum burmannii* VOCs could relieve the tension in mice. However, there was no significant pattern of changes in the number of fecal pellets in each group of mice in the experiment, such as both  $R_1$  and  $R_3$  began to decline on day 3, thus the effect of different concentrations of *Cinnamomum*



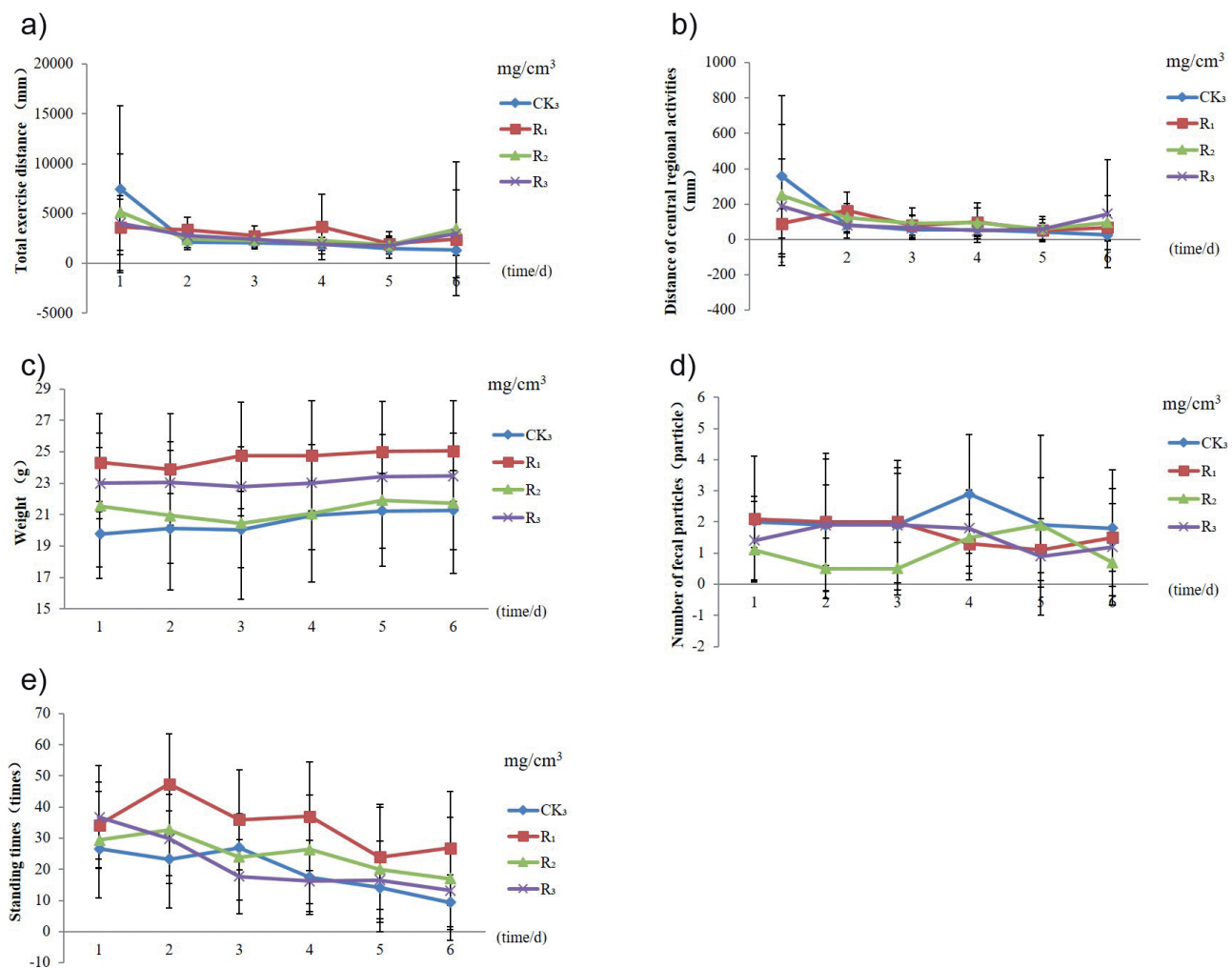


Fig. 4. Effects of different concentrations of *Cinnamomum burmannii* on open field behavior of mice. a) Total exercise distance. b) Distance of central regional activities. c) Weight. d) Number of fecal particles. e) Standing times. Numbers are mean $\pm$ SD (n = 3).

*burmannii* on relieving tension in mice did not cause a significant difference.

#### Number of Stances

The number of stances is a reflection of the animals' exploratory behavior and excitability level. As shown in Fig. 4e, the mean number of stances in the experimental group R<sub>3</sub> was higher than that in the control group CK<sub>3</sub> and the other experimental groups from day 2 to day 6 of the experiment. The results of analysis showed that experimental group R<sub>3</sub> was significantly different from CK<sub>3</sub> on days 2, 4, and 5 ( $P = 0.001$ ,  $P = 0.005$ ,  $P = 0.015$ ); from experimental group R<sub>2</sub> on days 2 and 3 ( $P = 0.037$ ,  $P = 0.042$ ); and from experimental group R<sub>1</sub> on days 2, 3, and 4 ( $P = 0.014$ ,  $P = 0.003$ ,  $P = 0.003$ ). The experimental group R<sub>1</sub> had the greatest increase in the mean number of stances in 6 days compared to CK<sub>1</sub>. This showed that *Cinnamomum burmannii* VOCs can promote the cognitive ability of inquiry in mice, and the promotion effect of R<sub>1</sub> was better in the low concentration experimental group.

In summary, the results of the open-field behavioral experiments showed that the *Cinnamomum burmannii* VOCs at low concentrations of R<sub>1</sub> ( $2.04 \times 10^{-3}$  g/cm<sup>3</sup>) were the most effective in promoting locomotor and exploratory cognitive abilities in mice.

## Discussion

The current methods for studying the effects of plant VOCs on human health include the subjective perception characteristics evaluation method [42, 43] and the objective health data measurement method [44-46]. However, the former is too subjective, whereas the latter focuses on science by measuring the human physiological and psychological health indicators and conducting research from a quantitative perspective. Matsubara et al. research results demonstrated that VOCs in the experimental room with Japanese cedar timber tend to suppress the activation of the sympathetic nervous activity, to be useful for health management, especially women's health [47].



In this study, the effects of different concentrations of *Cinnamomum burmannii* VOCs on human physiological and psychological health indicators and the open-field behavior of mice were measured. The experiment innovatively used TGB as an indicator of the VOC concentration, which provides a greater reference value for future research on the health benefits and outdoor applications of other plants. The analysis of the study results led to the following conclusions.

#### *Cinnamomum burmannii* VOCs on Human Physiological Health

Indoors and outdoors, *Cinnamomum burmannii* VOCs on the human systolic and diastolic blood pressure had a similar pattern of change; the stress reduction and relaxation effects were the best when there was a low concentration of TGB ( $0.10 \text{ m}^3/\text{m}^2$ ). When the *Cinnamomum burmannii* concentration increased, the human blood pressure rose and tended to tension, but the state of tension did not increase significantly with the increase in concentration. This is in line with the results of existing studies. Jin [22] found that the aroma of plum blossoms could lower the blood pressure of the subjects, and thus achieve a relaxing effect. Yang et al. had shown that rose fragrance could reduce blood pressure, relax people, and stabilize mood. Different concentrations had different effects, and the effect of low aroma concentration was the best [48].

The effects of *Cinnamomum burmannii* VOCs on the human heart rate are similar indoors and outdoors, and the human body is in the most relaxed state at a medium concentration ( $0.30 \text{ m}^3/\text{m}^2$ ) per unit area of TGB, which is not the same as the effect on blood pressure. By measuring the changes in the heart rate and respiratory rate of normal and critically hypertensive people before and after sniffing the aroma of *Narcissus tazetta* L. var. *Chinensis* Roem., Lu et al. [49] found that the blood pressure values of middle-aged and elderly groups had a significant decrease and a significant increase in the respiratory rate after smelling the aroma, and inferred that the effect of *Narcissus tazetta* L. var. *Chinensis* Roem. aroma on the heart rate and respiratory rate has a bidirectional effect, which is consistent with the present study and may be related to the human body's gradual adaptation to the VOCs of *Cinnamomum burmannii* during the experiment.

The  $\alpha$  waves amplitude in the room was highest at low concentrations ( $0.10 \text{ m}^3/\text{m}^2$ ), i.e., the volunteers were in the most positive mental state. *Perilla frutescens* was selected as the research material. Volunteers smelled *Perilla frutescens* in the room for 0.5 h, and its physiological indicators  $\alpha$  wave increased,  $\beta$  wave and  $\theta$  wave decreased, which can relax the spirit of college students and reduce negative emotions [28]. The results of the present study are consistent with the findings of these studies. However, the effect of outdoor *Cinnamomum burmannii* VOCs on the  $\alpha$ -wave amplitude

of the volunteers showed irregular changes, which may be correlated with the effect on the human  $\alpha$ -wave amplitude due to changes in outdoor environmental factors.

It has been shown that when the  $\beta$  waves are dominant, a person is focused and is generally in a state of anxiety and excitement [10]. In the indoor experimental group, the  $\beta$ -wave amplitude of the volunteers increased and then decreased from low to high concentration of *Cinnamomum burmannii*, and at the high concentration ( $0.60 \text{ m}^3/\text{m}^2$ ), the  $\beta$ -wave amplitude was lower than the control value, and the tension was relieved. In each of the outdoor experimental groups, the  $\beta$ -wave amplitude was lower than the control value, and the human emotions tended to be stabilized. The ratio of  $\alpha/\beta$  was used to measure the activity of the cerebral cortex, and the relaxation score was analyzed to measure the tension state of the frontal muscles. It is evident that there is no necessary correlation between the changes in the  $\alpha$ -wave amplitude and  $\beta$ -wave amplitude individually, and further comparison where these two EEG signals is more dominant is needed to determine the trend of emotional changes more accurately in humans [50].

The average value of the surface EMG at low indoor concentrations ( $0.10 \text{ m}^3/\text{m}^2$ ) is located at the highest point, indicating that the human forehead muscles are in the most relaxed state. Kang et al. [51] found that higher surface EMG values while viewing plant landscapes were more conducive to human muscle relaxation, which is consistent with the results of the present study. When outdoors, the average value of the surface EMG first increases and then decreases and is at the highest point at a high concentration ( $0.60 \text{ m}^3/\text{m}^2$ ). The forehead muscles are in the most relaxed state, which may be related to the factors that *Cinnamomum burmannii* VOCs increase the human respiratory rate at low concentrations and reduce the respiratory rate at high concentrations.

#### Effects of *Cinnamomum burmannii* VOCs on Human Mental Health

After smelling the aroma of *Cinnamomum burmannii*, the general symptom index score among the subjects decreased significantly, achieving stress relief and relaxation. This is consistent with the findings of Jia [20], through filling in SCL-90 scale before and after smelling the volatiles of aromatic plants, the factors of pressure, anxiety and fatigue among seven kinds of plants, such as *Gardenia stenophylla* Merr., *Melissa officinalis* L., *Myrtus communis* Linn., were obviously compared, and the differences before and after smelling the fragrance were significant, indicating that the volatiles of aromatic plants could reduce the degree of tension and make people feel relaxed and happy.

## Effects of *Cinnamomum burmannii* VOCs on the Behavior of Mice in Open Field

The open field and behavior of mice mainly reflect changes in the animals' exploration, habits, and emotions towards new environments [34, 52], and the open-field test enables quantitative evaluation of spontaneous activity, exploratory behavior, and anxiety in mice [53, 54]. The open-field test box was divided into a central activity area and a peripheral activity area; this is because animals have a natural tendency to avoid the central activity area because of their fear of the open field. However, animals are exploratory when faced with something new. Using mouse open-field behavior as a research tool can avoid the various complex factors influencing the living environment that social animals and humans are subjected to when used as experiment subjects [36]. Therefore, studying the changes in the open-field behavior of mice in the environment of different concentrations of plant VOCs can objectively evaluate the health benefits of *Cinnamomum burmannii* VOCs.

The analysis of the total locomotor distance, central area locomotor distance, and the mean values of standing times of mice in this study indicates that low concentrations of *Cinnamomum burmannii* VOCs have the best effect on promoting locomotor and exploratory cognitive properties in mice. The effect of *Cinnamomum burmannii* VOCs on the body mass of mice was not significant; however, there was a tendency to reduce the appetite of mice. Each experimental group had an effect on the number of fecal pellets of the mice, which could relieve the tension of mice, but the changes in different concentration treatment groups were not significant, which is consistent with the results of Wang's study, showing a pattern of trade-off changes between the number of fecal pellets of mice and different concentrations of plant treatment [55].

## Conclusions

The objectives of this study were to explore the effects of *Cinnamomum burmannii* VOCs on physical and mental health in its natural state. From the analysis of physiological indexes such as systolic blood pressure, diastolic blood pressure, heart rate,  $\alpha$  waves,  $\beta$  waves, surface electromyography, etc., it was found that the volunteers were in the most relaxed state at low concentrations of *Cinnamomum burmannii* VOCs in indoor and outdoor. After smelling *Cinnamomum burmannii* VOCs, the scores of obsessive-compulsive, depression, anxiety, anger-hostility, and psychoticism in the SCL-90 scale showed a very significant decrease trend, and general symptom decreased significantly, which could play a role in relaxation effect. From the analysis of the average value of total exercise distance, distance of central region activities and number of stances, it was found that the low concentration of

*Cinnamomum burmannii* VOCs had the best effect on promoting the exploratory cognition of mice. These findings indicated that *Cinnamomum burmannii* VOCs in its natural state had a positive effect on human physical and mental health, and the effect was the best at low concentration.

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## Conflicts of Interest

The authors declare no conflict of interest.

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