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Assessing Psychological Effects of Essential Oil on Sleep through Longitudinal Measured Data Using Wearable Devices

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While there are numerous reports on the transient effects of essential oils, the establishment of evidence concerning their efficacy on long-term mental and physical states remains insufficient. The purpose of this study is to investigate the relationship between essential oils and longitudinal changes in mental and physical stress levels through a subacute study using wearable sensors, salivary stress markers, and questionnaires. Thirteen healthy adult Japanese women participated in this study, who wore wearing portable monitors continuously for 24 h over five weekdays to measure daytime activity levels and sleep depth. The essential oil fragrance was administered by applying scented lotion at bedtime, and the relationship between the essential oil and the sleep state was examined. Subjective evaluation using a preference questionnaire indicated that the odor was generally well-received by the participants. Wearable devices were effective in visualizing experimental conditions, such as the lack of significant differences in daytime activity levels. Correlations were observed between subjective assessments from mental and physical state questionnaires and salivary amylase activity results. Additionally, sympathetic nerve activity, as measured by salivary amylase activity, significantly decreased from the first to the fourth day, indicating a reduction in mental stress level due to the fragrance presentation. As a short-term effect, the exposure of the fragrance before sleep suggested the potential to improve sleep quality by increasing the proportion of deep sleep.

1. Introduction

In addition to vital signs such as blood pressure, pulse, respiratory rate, and body temperature, various physiological indicators and behavioral data are being measured, and they are beginning to be applied for various purposes. These applications range from medical uses, such as life-saving, disease diagnosis, and treatment planning, to health management based on psychobiological stress and comfort, as well as industrial applications such as biometric authentication and virtual reality.[1,2] To facilitate data collection without requiring specialized knowledge and without disrupting daily life, wearable sensors have been proposed, and portable devices such as wristwatch-type blood pressure monitors, activity trackers, electrocardiographs,

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and body motion sensors have been either proposed or commercialized.[3,4] Methods for portability include skin-attachable sensors, ring-shaped sensors, and non-invasive biosensors, including sensors sewn into clothing. Furthermore, as represented by devices such as the Apple Watch, there are emerging attempts to visualize cardiopulmonary functions and blood oxygen levels through software-based approaches.[5,6] In the future, these devices are expected to play a significant role in the real-time, longitudinal measurement and monitoring of dynamic biological functions, such as those related to the circulatory, respiratory, and nervous systems. However, issues related to measurement accuracy remain, and these efforts are still in their early stages.[7]

The authors have been conducting research on the societal implementation of the benefits of scents, particularly essential oils extracted from natural aromatic plants. Essential oils are utilized not only in aromatherapy, but also in gaining attention from a medical perspective for their anxiolytic[8] and anti-inflammatory effects.[9,10] Previous experiments have demonstrated that the presentation of blended essential oils following mental task performance induces the alleviation of acute mental stress, which is measurable through multiple salivary biomarkers that enable the non-invasive analysis of physiological responses.[11] However, the establishment of evidence regarding the long-term psychobiological effects of essential oils remains insufficient.

This study aims to examine the relationship between psychobiological states, particularly sleep depth, and essential oils over a subacute period of one week by comprehensively utilizing wearable sensors, salivary sympathetic markers, and questionnaires. Healthy adult women with full-time office jobs were recruited as participants, and they were equipped with portable monitors continuously for 24 h over five weekdays to measure daytime activity levels and sleep depth during the night. Psychobiological stress levels were recorded each day by administering questionnaires and measuring salivary sympathetic markers immediately before sleep (hereafter referred to as bedtime). The relationship between essential oils and sleep states was assessed by applying a scented lotion containing essential oils at bedtime (hereafter referred to as the fragrance test).

2. Materials and Methods

2.1 Patients

The participants were 13 healthy Japanese adult women, aged 25 to 40, residing in Tokyo and employed full-time in office work [*mean* ± standard deviation (*SD*) = 31.4 ± 3.5 years]. Non-smokers were selected. Participants were excluded if they met any of the following conditions that could affect salivary amylase analysis: pregnant, breastfeeding, within three months postpartum, the lack of menstruation resumption after childbirth, a current or past history of breast cancer, taking medication for chronic diseases, or testing positive for occult blood in saliva. Prior to participant selection, saliva was tested for the presence of blood contamination using a hemoglobin kit (PerioScreen, Sunstar Inc., Tokyo, Japan). Participants were prohibited from undergoing dental treatment or teeth whitening within 24 h before the start of the trial, and during the trial period, they were also prohibited from consuming alcohol, pungent foods, spicy foods, or substances with strong odors.

The research protocol for the fragrance test was approved by the Ethics Committee of Shinshu University (approval number: 353). Prior to beginning the fragrance test, the participants were fully informed of the purpose of the study both verbally and in writing, and written consent was obtained.

2.2 Essential oil

An essential oil presented to the participants was compliant with the International Fragrance Association (IFRA) safety standards.[12] A fragranced lotion (flower concentrate milk; Colours Inc., Tokyo, Japan), which was created by blending essential oils into an unscented lotion, was used. The composition of this blended essential oil, analyzed by gas chromatography–mass spectrometry (GC: 6890N, MS: 5973N, Agilent Technologies Inc., Tokyo, Japan), is shown in Table 1. The component analysis of the essential oil blend used in this study revealed that it contained high concentrations of linalool, geraniol, and linalyl acetate.

2.3 Subjective evaluation

A visual analogue scale with seven levels was used in the questionnaires, and two types of questionnaire were employed. One was a questionnaire on scent preference (Preference Questionnaire: Q_A), in which participants rated their preference on a scale from “strongly dislike (1)” to “strongly like (7)”. The other was a questionnaire on psychobiological state (Psychobiological Questionnaire: Q_B), which consisted of five items: “Q_{B1}: Stress-free”, “Q_{B2}:

Table 1
Components of blended essential oil.

Ingredients	Oil A (%)
Linalool	28.54
Geraniol	10.94
Linalyl acetate	7.36
Limonene	6.36
1,8-Cineole	4.56
α-Pinene	3.79
Camphor	3.63
Thujopsene	3.34
Cedrol	2.69
Geranyl acetate	1.92
γ-Terpinene	1.77
Terpinen-4-ol	1.54
p-Cymene	1.52
β-Caryophyllene	1.46
Sabinene hydrate	1.26
Citronellol	1.04
β-Pinene	0.94
Benzyl acetate	0.35
Geranial	0.14
Neral	0.09

Calm", "Q_{B3}: Clear-mind", "Q_{B4}: Positive", and "Q_{B5}: Light bodies". Participants rated these items on a scale from "strongly disagree (1)" to "strongly agree (7)".

2.4 Wearable sensors

Daytime activity levels were measured using a waist-mounted activity monitor (23 g of weighing; HJA-750C, Omron Healthcare Co., Ltd., Tokyo, Japan). This activity monitor records physical activity data every 10 s and logs it in metabolic equivalents (*METs*) using a dedicated application. According to the WHO guidelines on physical activity, the relationship between physical activity and *METs* is classified with thresholds of 3 and 1.5. [13] Taking into account the resolution of the device used, activity levels in this study were categorized into high ($METs \geq 3$), medium ($3 > METs \geq 1.5$), and low ($1.5 > METs \geq 1$). Values below 1 *METs* were considered measurement errors and excluded for accuracy purposes. Additionally, periods with no data for more than 20 consecutive minutes were regarded as instances where the participant forgot to wear the device, and such data were treated as missing values.

Previously, Wilde-Frenz and Schulz reported a decrease in the intensity of body movements during deep sleep.[14–16] Some studies have attempted to distinguish between sleep and wakefulness on the basis of the frequency[17] and proportion[18] of body movements. On the basis of this evidence, portable devices have been developed to monitor sleep depth by tracking body movements during sleep. In this study, sleep depth was measured using a wristwatch-type wearable blood pressure monitor (HCR-6900T-M, Omron Healthcare Co., Ltd.),[7,19–20] which estimates the proportion of deep sleep from the intensity of body movements during sleep. This blood pressure monitor records body movements using an accelerometer, classifying them into three levels: high, medium, and low. The low level indicates minimal body movement. In this study, we assumed that low-level body movement corresponds to deep sleep and evaluated the sleep depth accordingly.

Each participant was provided with one set of portable sensors, which they used in their daily lives.

2.5 Salivary marker of sympathetic nerve activity

As reported in a systematic review based on 2917 studies, indicators of psychobiological stress, such as blood pressure, perspiration, and biomarkers, have been used, each taking advantage of its specific characteristics.[21] In this study, from the perspective of non-invasiveness and simplicity, amylase was used as a marker of sympathetic nerve activity.[22,23] The salivary amylase activity was measured using a portable salivary amylase monitor (Amylase monitor, 5 kIU/L of detection limit, Nipro Co., Osaka, Japan), and participants were instructed to perform immediate analysis and record the results themselves.

2.6 Experimental protocol for fragrance test

Figure 1 shows the evaluation protocol for the fragrance test. The fragrance test was conducted in each participant's daily living environment, such as their home or workplace, over

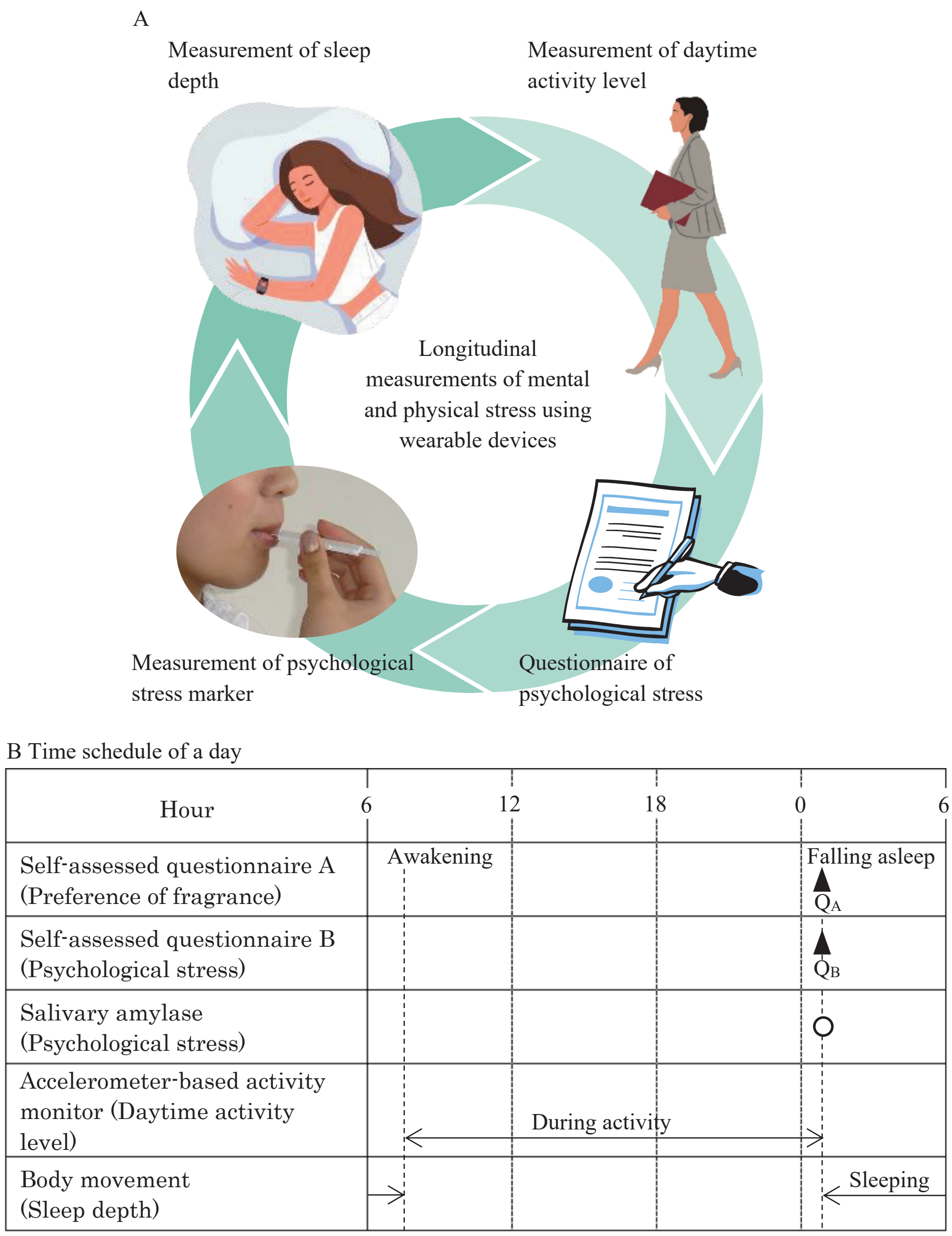

Fig. 1. (Color online) Protocol for longitudinal measurements of psychological stress and effects of essential oil on sleep by using wearable devices.

five consecutive weekdays, starting from Monday morning upon waking and continuing until Saturday morning upon waking. In this protocol, the period from Monday morning to Tuesday morning was considered Day 1. Participants were not given specified sleep or wake times and were instructed to follow their normal daily routines.

The participants conducted two comparative trials: one with the application of a fragranced lotion (0.6 mg, three pumps) to the face before bedtime (fragranced lotion application) and the other without the application of the fragranced lotion before bedtime (control: non-fragranced lotion application). The order of the two trials, with and without fragrance exposure, was randomized to avoid any ordinal bias. Additionally, the interval between the two tests was set to at least one week.

The data collection procedure before bedtime involved administering the psychobiological questionnaire, measuring salivary amylase, applying the fragranced lotion, followed by another round of the psychobiological questionnaire, salivary amylase measurement, and finally the preference questionnaire. This sequence allowed for the evaluation of changes in psychobiological stress before and after the scent presentation, and participants performed the tasks themselves. However, to reduce participant burden, the preference questionnaire was only administered on days 1 and 5.

The two portable sensors were retrieved from the participants at the conclusion of the five-day scent trial, which also served as a data collection process.

2.7 Statistical analysis

All statistical analyses were performed using statistical analysis software (Statistical Package for Social Sciences, SPSS Ver. 29, IBM Japan, Ltd., Tokyo, Japan). The Wilcoxon signed-rank test was used to analyze the temporal changes in subjective evaluations and salivary sympathetic markers following the presentation of essential oils. For the analysis of daytime activity levels and sleep depth, the analysis of variance (ANOVA) was applied. Unless otherwise noted, data are presented as *mean* ± *SD*, and significance was tested at a two-tailed probability of $p < 0.05$ or using the test statistic tables.

3. Results

3.1 Subjective evaluation

In the subjective evaluation based on the preference questionnaire, 10 out of 13 participants showed a preference with a score of 4 or higher from the first to the last day of the trial, and “strongly dislike” was never selected (Fig. 2).

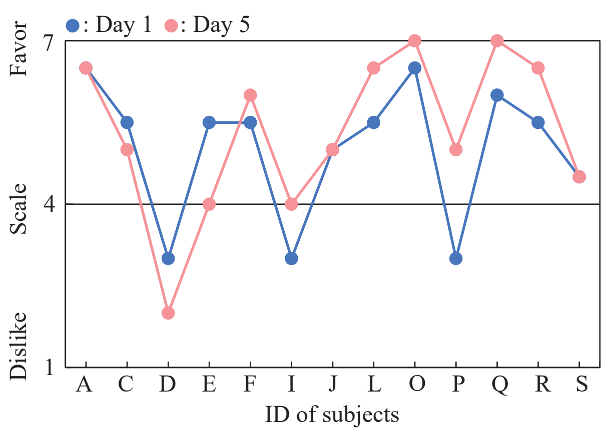

Fig. 2. (Color online) Results of self-assessed questionnaire on preference of fragrance.

In the subjective evaluation using the psychobiological questionnaire, a significant increase was observed in the "Q_{B3}: Clear-mind" on day 5 compared with day 1, based on the difference in score before and after fragrance exposure (Table 2, $p < 0.05$). In the comparison between the two groups, with and without fragrance exposure, there were no significant increases in scores across the five days. However, in the "Q_{B3}: Clear-mind" item, the group exposed to fragrance (after the application of the fragranced lotion) had significantly higher scores than the control group on four out of the five days (Fig. 3, $p < 0.05$).

3.2 Daytime activity levels

During the fragrance test, the participants' daytime activity levels ranged from a maximum of 2.0 MET·h/day to a minimum of 0.8 MET·h/day. The average daytime activity levels over the five days for the 13 participants were 1.40 ± 0.23, 1.35 ± 0.21, and 1.37 ± 0.22 MET·h/day for the fragrance group, the control (non-fragrance) group, and all participants, respectively. An ANOVA on the activity monitor results, which classified the activity levels into three categories, revealed no significant differences between the fragrance and non-fragrance conditions across the five days (Fig. 4).

Table 2
Results of the self-assessed questionnaires on psychological stress (*mean* ± *SD*).

Questionnaire	Fragrance	1	2	3	4	5	*mean*
Q_{B1}: Stress-free	Fragrance	4.5 ± 1.4	5.1 ± 1.4	4.7 ± 1.7	4.0 ± 1.0	4.7 ± 1.7	4.6 ± 1.5
	Control	4.2 ± 1.6	4.8 ± 1.5	4.4 ± 1.8	4.1 ± 1.3	4.4 ± 1.5	4.4 ± 1.6
Q_{B2}: Calm	Fragrance	4.7 ± 1.3	5.3 ± 1.3	5.0 ± 1.2	4.6 ± 1.2	4.9 ± 1.2	4.9 ± 1.3
	Control	4.4 ± 1.6	5.1 ± 1.2	5.0 ± 1.4	4.4 ± 1.4	4.2 ± 1.5	4.6 ± 1.5
Q_{B3}: Clear-mind	Fragrance	5.0 ± 1.3	5.3 ± 1.3	4.9 ± 1.2	4.4 ± 1.3	4.8 ± 1.3	4.9 ± 1.3
	Control	4.1 ± 1.3	4.5 ± 1.5	4.1 ± 1.7	3.8 ± 1.1	4.6 ± 1.6	4.2 ± 1.5
Q_{B4}: Positive	Fragrance	4.7 ± 0.9	4.7 ± 1.2	4.8 ± 1.2	4.2 ± 1.0	4.9 ± 1.3	4.7 ± 1.2
	Control	4.3 ± 1.2	4.3 ± 1.2	4.1 ± 1.2	3.9 ± 1.2	4.3 ± 1.1	4.2 ± 1.2
Q_{B5}: Light-bodies	Fragrance	4.0 ± 1.3	4.3 ± 1.2	4.5 ± 1.2	4.6 ± 1.4	4.2 ± 1.4	4.3 ± 1.3
	Control	3.5 ± 1.3	3.8 ± 1.5	4.0 ± 1.7	3.8 ± 1.4	3.8 ± 1.5	3.8 ± 1.5

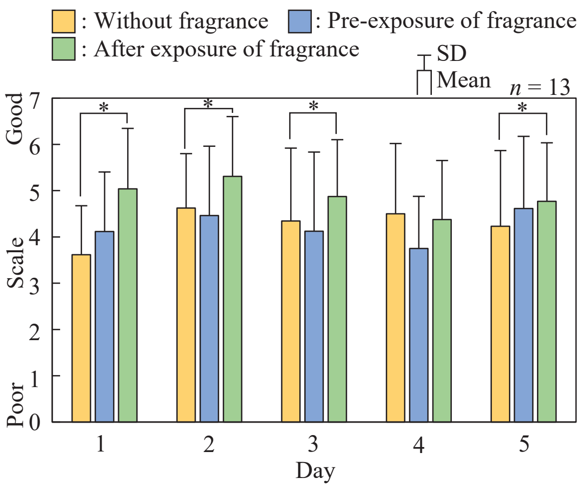

Fig. 3. (Color online) Results of self-assessed questionnaire on psychological stress (Q_{B3}: Clear-mind, *$p < 0.05$).

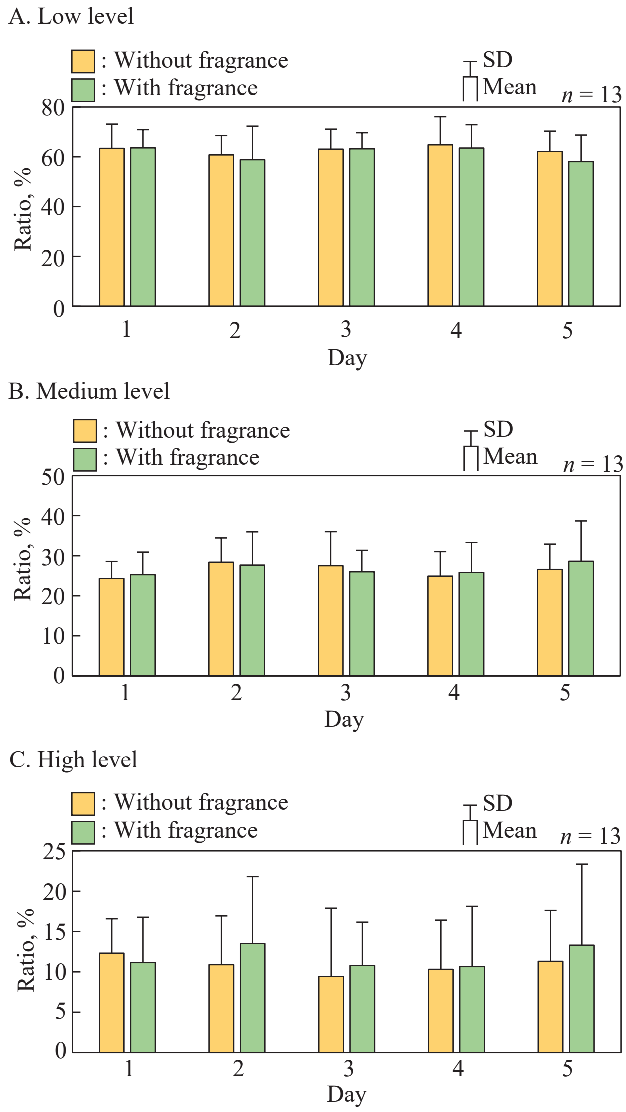

Fig. 4. (Color online) Measured results of daytime activity levels using accelerometer-based activity monitor.

3.3 Sleep depth

The average sleep durations were 368.7 ± 80.6 min/day for the fragrance group and 380.8 ± 93.4 min/day for the non-fragrance group. The average bedtimes were 12:53 a.m. ± 100 min for the fragrance group and 1:01 a.m. ± 134 min for the control group. The average wake-up times (the times when activity levels showed a rapid and continuous increase) were 7:22 a.m. ± 74 min for the fragrance group and 7:15 a.m. ± 162 min for the non-fragrance group. An ANOVA over the five-day period showed no significant difference in sleep duration between the fragrance and non-fragrance groups. When comparing the amount of time spent in low-level body movement, which was used as an indicator of sleep depth, the fragrance and control groups showed averages of 115.9 ± 40.9 and 117.8 ± 44.03 min, respectively. Similarly, when comparing the percentage of time spent in low-level body movement relative to total sleep time, the fragrance group and control group showed 29.8 ± 9.6 and 29.9 ± 10.7%, respectively. In other words, there were no notable differences between the two groups in terms of deep sleep duration or ratio.

The percentage of low-level body movement was compared between the fragrance and non-fragrance groups (Fig. 5). According to the Wilcoxon signed-rank test, no significant difference was observed at a two-tailed probability of $p < 0.05$. However, at a one-tailed probability of $p < 0.05$, an upward trend was noted on the first day only.

3.4 Salivary marker of sympathetic nerve activity

The average salivary amylase activities for the 13 participants before applying the fragranced lotion, after applying the fragranced lotion, and in the control group were 28 ± 27, 24 ± 24, and 24 ± 25 kU/L respectively. A comparison of the changes in salivary amylase activity over the five-day period was conducted (Fig. 6). In the fragrance group, a significant decrease in salivary

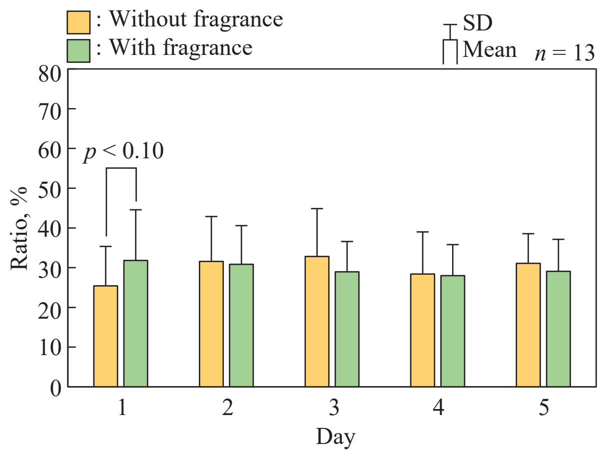

Fig. 5. (Color online) Measured results of low-level body movement used as indicator of sleep depth.

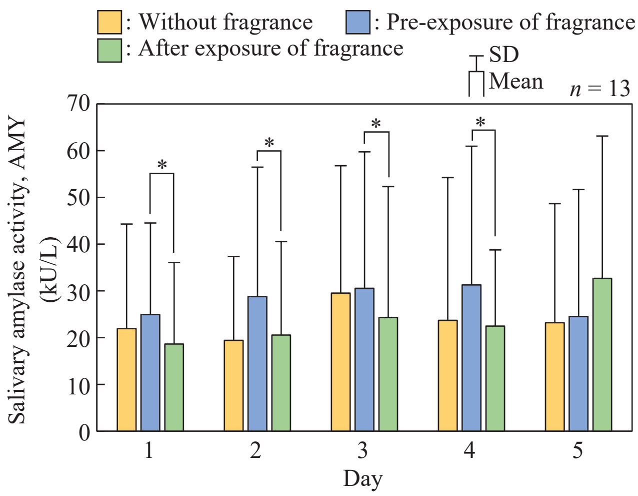

Fig. 6. (Color online) Measured results of salivary amylase activity used as indicator of psychological stress (*$p <$ 0.05).

amylase activity before and after fragrance exposure was observed from days 1 to 4, as determined by the Wilcoxon signed-rank test ($p < 0.05$).

4. Discussion

In the subjective evaluation using the preference questionnaire, 9 out of the 13 participants consistently reported a preference for the fragrance from the first to the last day of the test, indicating that the fragrance was well liked by the participants. The essential oil used in this study did not contain vitamins or hormones (Table 1); therefore, the potential for the components to affect amylase analysis was considered negligible. Among the key components of the blended essential oil – linalool, geraniol, and linalyl acetate – linalool and linalyl acetate are the two major aromatic components found in lavender essential oil, which are academically recognized for their various pharmacological effects, including sedative, antispasmodic, analgesic, and antioxidant properties.(24) Geraniol is a fragrance component commonly found in essential oils such as rose and geranium, which are known for their relaxing effects.(25) Some reports have suggested that lavender essential oil can induce a sense of euphoria, but this effect is considered to be related to the origin of the lavender—such as the soil and climate conditions—affecting the composition and concentration ratios, rather than the effects of linalool and linalyl acetate.(26) The hypothesis of this study was that these components can induce a calming effect on mental stress. The subjective evaluation using the psychobiological questionnaire showed a significant improvement in mood in the "Q_{B3}: Clear-mind". These results support one of the hypotheses that exposure to essential oils can enhance mood.

On the other hand, focusing on the participants' mental and physical states over the five days, the daily activity levels ranged from 0.8 to 2.0 MET·h/day, with an overall average of 1.4 ± 0.2 MET·h/day for the two groups. This is about half of the recommended physical activity for adults (23 MET·h/week) set by the Ministry of Health, Labour and Welfare, Japan.(27) An ANOVA for the daytime activity levels over the five days showed no significant differences, suggesting that physical stress levels remained relatively constant.

Significant increases in both measures were observed before and after fragrance exposure when comparing the results of the subjective evaluation using the psychobiological questionnaire with the salivary amylase activity, indicating a correlation between them (Figs. 3 and 6). The sympathetic nerve activity, as measured by salivary amylase, showed a significant decrease from days 1 to 4, suggesting a reduction in mental stress level, considering the minimal daily fluctuations in physical stress. From these findings, it can be concluded that fragrance exposure reduced the mental stress level at bedtime, at least temporarily.

Regarding sleep depth, a significant prolongation was observed on the first day only, indicating an improvement in sleep quality due to fragrance exposure. This suggests that the presentation of fragrance at bedtime, using essential oils preferred by the participants, may improve sleep quality. However, no continuous improvement was observed during the remaining four days. Possible reasons for the lack of sustained effects include habituation to the fragrance and the presence of various stressors affecting the participants. It is possible that fragrance exposure alone may not be sufficient to achieve long-term improvements in sleep quality, and this remains a challenge for future research.

Heart rate variability and electroencephalography were excluded from the measurements due to the current lack of affordable commercial devices. Future advancements in the development of these physiological indicators are eagerly anticipated.

5. Conclusions

In this study, longitudinal data were collected by using wearable sensors capable of measuring daytime activity levels and sleep depth, and the effects of fragrance exposure using a lotion with blended essential oil on subacute mental and physical states, particularly sleep, were examined. The wearable devices proved effective in visualizing the experimental environment and conditions, such as the lack of significant differences in daytime activity levels. Continuous exposure to natural fragrances favored by the participants over five days resulted in a reduction in mental stress at bedtime. Additionally, the fragrance presentation at bedtime experimentally demonstrated the potential to improve sleep quality in the short term by increasing the proportion of deep sleep. However, in this study protocol, the effects were temporary, and it is considered that habituation or external disturbances may have contributed to the reduction in the fragrance's impact. It was concluded that identifying and mitigating stressors are crucial for achieving long-term improvements in sleep quality.

Owing to the relatively small number of validation datasets, there is a limitation in subjective evaluation, and our findings should be validated in other populations. Additionally, it will be important to explore methods of fragrance presentation, which are most effective in enhancing the impact of essential oils on sleep depth, as well as to develop protocols that allow for the appropriate selection of essential oils based on individual preferences and moods.

There is a limitation in measuring body movement, as the activity monitor was worn on the waist and did not capture total body activity. The validity of this approach will require further investigation in future studies.

In the future, it might be meaningful to compare the effects of different types of essential oils, not only sedative effects but also arousal effects and others.

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Declaration of Competing Interest

The fragranced lotion used in this study was provided by Colours Inc., where one of the authors is affiliated.

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