Impact of Aromatherapy Diffusion on Healthcare Monitoring

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***Abstract*—Aromatherapy, recognized for its therapeutic benefits in stress reduction and relaxation enhancement, uses heat diffusers to disperse aromatic compounds, creating an environment where the aroma mixes with the vapors. These study aims to categorize aromas based on their effects and contributes to understanding aromatherapy's impacts on healthcare. By systematically exploring the effects of specific aromas on physiological parameters, this research seeks to optimize aromatherapy practices and expand its therapeutic applications in healthcare settings. This study provides insights into how aromatherapy can be tailored to enhance well-being and support holistic approaches to health management. Participants were exposed to each aroma in sessions structured to include baseline (neutral phase) measurements followed by aroma exposure phases. Physiological parameters including heart rate, heart rate variability, respiratory rate, blood oxygen saturation, and galvanic skin response were continuously monitored using a multichannel sensing system based on photoplethysmography signal processing algorithms and galvanic skin response acquisition. Participants categorized each aroma as stimulating or relaxing and rated its intensity on a scale from 1 to 3. The study presented good results in terms of validating the effects of the different aromas, as well as correlating these effects with variations in physiological parameters, validating aromatherapy's potential in healthcare and promoting its effective use for enhancing overall well-being.**

Keywords—Aromatherapy, Digital signal processing, Embedded systems, Photoplethysmography, Healthcare ecosystem, Physiological parameters monitoring, Heat diffusers, Holistic health, Stress management

I. INTRODUCTION

Stress has a considerable impact on the quality of life and is strongly associated with both physical and mental health. It leads to reduced alertness and productivity, which in turn affects daily activities and can even contribute to car accidents [1]. Furthermore, the fast pace and increasing demands of modern society contribute to high stress levels, resulting in a range of health problems such as hypertension, depression, anxiety, worsening of diabetes, and more [2].

In addition, western health care traditionally relied on medications like opioids for pain and other conditions, but widespread abuse led to overdoses and fatalities [3]. Recent progress in phytopharmacology has highlighted the potential of natural compounds as complementary or alternative treatments for diabetes, especially where synthetic drugs are inaccessible [4]. All of this prompted a shift towards alternative treatments, including practices from eastern medicine such as yoga, meditation, and acupuncture. Among these, aromatherapy has emerged as a popular alternative treatment that helps improve emotional states, sleep, and physical and mental health issues related to stress [5].

Aromatherapy, with its ancient origins and historical endorsement by individuals such as Hippocrates, has established itself as a credible therapy that incorporates both holistic and therapeutic approaches. This rapidly growing field, with a projected market expansion to $5 trillion by 2050, is classified as integrative medicine. Integrative medicine has the ability to completely replace conventional treatments, unlike alternative medicine which only enhances them [3].

Aromatherapy involves using essential oils from plants for therapeutic purposes, which can be absorbed through the skin or inhaled. The mechanism of action involves the stimulation of olfactory and cutaneous pathways, which in turn affect the release of neurotransmitters and physiological reactions such as blood pressure and Heart Rate (HR), leading to perceived well-being and symptom relief [6]. Essential oils can be applied through several methods such as diffusers (inhalation), baths, massages, and compresses, with each method having a distinct impact on the body. Diffusers are the predominant technique employed [7].

Although the advantages of aromatherapy are well-established, there is a lack of research especially focused on the effects of compound essential oils on both physical and emotional well-being. Several studies indicate that aromatherapy may relieve pain in different situations such as postoperative pain, fibromyalgia, and dysmenorrhea. Nevertheless, the therapeutic benefits of it are not well substantiated by clinical research, as a significant portion of the information is found in books rather than in peer-reviewed scientific journals. Although numerous clinical trials are available, their findings are ambiguous, which underscores the necessity of developing novel solutions [7].

In contrast to previous studies, which used subjective scales to assess the effects of aromatherapy, this study aims to establish objective physiological indicators to prove its effectiveness [8]. For this purpose, the authors developed a multichannel sensing system, based on the acquisition and processing of Photoplethysmography (PPG) signals, to which was added the acquisition of Galvanic Skin Response (GSR) data, which is a significant indicator of stress levels. Through a developed mobile application, users can monitor their health status by accessing detailed information about their vital signs. This allows users to receive feedback on how their environment affects their health management, specifically the impact of stress and the effectiveness of aromatherapy [9].

To assess the effectiveness of this study, the authors employ an experimental approach that investigates the potential of aromatherapy in reducing stress by collecting and analysing PPG signals, focusing on several physiological parameters such as, HR, Heart Rate Variability (HRV), Respiratory Rate (RR), Blood Oxygen Saturation (SpO2) and GSR. The results obtained suggest that specific aromas have a significant stress-reducing effect, while they may also possess stimulating properties. Therefore, it is essential to determine the most suitable aromas for each situation. This approach offers a new method for objectively assessing and addressing stress through aromatherapy.

This article is organized as follows. Section II discusses the methodology adopted, including executed work, materials used, and significant concepts. Section III provides a detailed analysis of the results obtained from the experimental procedures conducted. Section IV draws the conclusion and outlines potential future work.

II. Materials and Methods

This section presents the methodology applied, detailing the monitoring of physiological parameters, aromatherapy concepts considered and the diffusion system, and finally the experimental protocol applied.

A. *Physiological Parameters Aquisition*

A previously developed and presented multichannel system, as described in [9] and illustrated in Fig. 1, was utilised for monitoring the physiological parameters. This system consists of three layers: the sensing system, the mobile application, and the database. The sensing system employs PPG signal processing to measure HR, HRV, SpO2, and RR. This system also has an additional channel for GSR acquisition, which is crucial for stress assessment. Figure 2 illustrates the internal structure of the sensing system, which presents a sampling rate of 300 samples per second, allowing it to faithfully replicate the PPG signal.

The sensing system consists of an ESP32 Microcontroller, which is characterised by a Dual-Core 32-bit CPU with a maximum clock speed of 240 MHz. This system also includes a MAX30102 PPG sensor that allows for the PPG detection and the estimation of HR, HRV, RR and SpO2. Furthermore, a GSR sensor was integrated to quantify variations in sweat gland activity induced by stress. The system is furnished with a real-time data display screen and Li-Po batteries, providing a maximum of 4 hours of continuous monitoring autonomy. The system components establish connection with the ESP32 using the Inter-Integrated Circuit (I2C) protocol.

The sensing system acquired data is subsequently sent by Bluetooth 5.1 to the mobile application for storage. The data can be stored locally or remotely in Google Firebase (NoSQL database), using a Wi-Fi connection. Furthermore, the application offers several features, including user authentication, ongoing monitoring of their physiological data, and the ability to input glucose and blood pressure measurements, among others. Some of the application's main features are illustrated in Fig. 3.

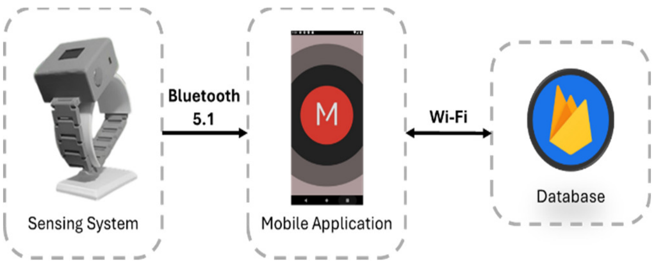

Fig. 1. Multichannel system architecture

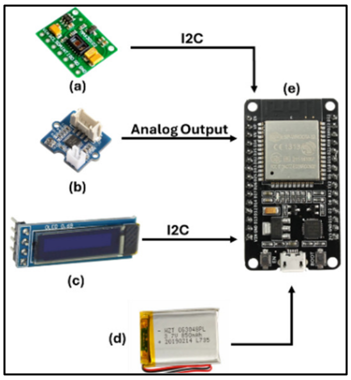

Fig. 2. Internal structure of the sensing system. (a) PPG sensor. (b) GSR sensor. (c) OLED LCD display. (d) 850mAh baterry. (e) ESP32 microcontroller.

Fig. 3. Mobile application layouts. (a) Physiological parameters realtime assessment. (b) Daily and monthly averages (description). (c) Daily and monthly averages (graph).

B. *Aromatherapy*

Aromatherapy can be implemented through several methods, with the most prevalent being the use of aroma diffusers, as previously stated. This study used the SILVERCREST ultrasonic aroma diffuser [10], shown below in Fig. 4. This diffuser uses ultrasound technology to generate a fine mist, thereby increasing the humidity in the air and enhancing overall well-being. The product features a configurable lighting option, including the choice of a specific light colour, a sequence of colour changes, or the option to have no light at all. This versatility makes it ideal for the use in bedrooms, both during daytime and nighttime. Additionally, it is equipped with a timer that allows for operation durations of 1 hour, 3 hours, or 6 hours. The device functions silently at around 35 dB in night mode, guaranteeing undisturbed sleep. This diffuser features a water tank that can hold around 300 ml of water. It can operate for up to 20 hours in day mode and up to 27 hours in night mode, depending on the surrounding temperature and humidity. When the water tank is empty, a safety feature called an automated switch-off function is performed, enhancing safety.

Fig. 4. SILVERCREST ultrasonic aroma diffuser [10]

Regarding essential oils, there are a wide range of options [3], however, with the aim of providing people with an alternative healthcare solution, we decided to select a group of affordable aromas, which are presented below in Table I.

TABLE I. EFFECTS OF ESSENTIAL OILS

Aroma	Description	Effect
Cherry Blossom	Smooth, floral, delicate and sweet	Relaxing
Gardenia	Floral, intense and immersive	Relaxing
Lavender	Smooth, floral and sweet	Relaxing (decrease blood pressure, alleviate anxiety, and promote wound healing)
Lemongrass	Refreshing, with citrus and herbaceous notes	Stimulating
Lotus	Sweet and floral or herbaceous, depending on the variety and extraction method	Relaxing (treatment of hypertension, diarrhea, fever and infections)
Peony	Floral, sweet and delicate	Relaxing
Rose	Highly fragrant, pleasant aroma, floral and soft. It is frequently employed in the field of perfumery (elegance, luxury)	Relaxing (nerve-calming agent, anxiety-reducing substance, sedative, uterine tonic, and wound-healing agent)
Sandalwood	Woody, soft, warm and sweet.	Relaxing (ability to calm the nervous system, antiseptic, and is also used as a tonic)
Spice	Mixture of substances, heat sensation, warm, exotic and very aromatic	Stimulating
Vanilla	Sweet and recomforting[a]	Relaxing[a]

a. Depending on the dosage/person, it can be nauseating, thus causing the opposite effect (stimulating)

C. *Experimental Protocol*

The aim of this experiment is to assess the influence of aromatherapy on the physiological parameters of participants, aiming to determine how aromatherapy induces measurable variations in physiological parameters, with distinct aromas producing varying effects.

The necessary materials for this experiment consist of the mentioned multichannel system for acquiring physiological data, the mentioned aromatherapy diffusion equipment, 10 aroma mixtures (each containing 6% essential oil diluted in water), and coffee beans. The experimental setup can be seen below in Fig. 5.The study involved 8 volunteers, including men and women aged between 25 and 72. Given the nature of the study, verbal consent was obtained from all participants.

During the experiment, each participant was seated comfortably in a controlled environment. Physiological parameters were acquired during a first 2-minute period without any exposure to the aroma to establish a baseline (1st phase). During the aroma exposure period (2nd phase), one of the prepared aroma mixtures was diffused into the air near the participant, at a distance of 15-20 cm. The participant was exposed to the aroma for 2 minutes while their physiological parameters were continuously acquired. After exposure to the aroma, there was a 1-minute period (3rd phase) during which no physiological data was acquired. During this time, participants were asked to smell coffee beans to neutralise the previous aroma, thus preventing contamination for the next aroma. During this period, participants were also asked to classify the aroma as 'relaxing' or 'stimulating' and to rate its intensity on a scale of 1 to 3. This process was repeated for each one of the 10 aromas, ensuring a consistent sequence for all participants.

The experiment's independent variable is the type of aroma used, consisting of 10 distinct aromas. The dependent variables consist of the variations in physiological parameters, specifically HR, HRV, RR, SpO2, and GSR. The control variables include the aroma diffusion distance (15-20 cm), the duration of exposure (2 minutes) and the inter-aroma clearance period (1 minute with coffee bean odour).

The data analysis involves comparing the physiological parameters during the reference and aroma exposure periods. Changes in physiological parameters were then correlated with participants' subjective feedback, including whether they found the aroma relaxing or stimulating and their intensity rating. Statistical methods were also used to analyse the significance of the observed changes.

Safety precautions were taken to ensure that all aroma mixtures were safe and non-irritating at the specified concentration. Participants were monitored for any adverse reactions during the experiment. Verbal consent was obtained, and participants were informed about the procedure.

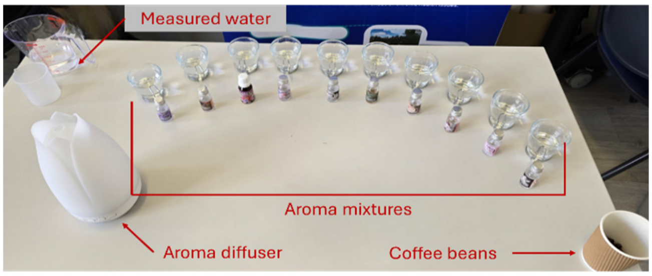

Fig. 5. Experimental setup (missing sensing system)

III. Results and Discussion

This section discusses the results obtained in this study regarding the impact of aromatherapy on healthcare monitoring. To this end, a comparison is made between the theoretical effects of the aromas and how the participants rated them in practice (relaxing and stimulating). Furthermore, the study analyses the correlation between the impact of different aromas and physiological parameters, exploring innovative ways to mitigate the effects of stress in daily life.

A. *Comparison between Theoretical and Practical Aroma Effects*

As mentioned earlier in the experimental protocol, 10 essential oils were used for aroma diffusion. Every essential oil holds a theoretical description and potential effects. However, as stated previously in the introduction, there is a lack of scientific evidence supporting these effects. Therefore, in this study, we opted to investigate first the correlation between the theoretical and practical effects by analysing the feedback provided by the participants. The following information is presented below in Table II. Note that highlighted in green is the participants' classification, which coincides with the theoretical effect. In contrast, highlighted in red is the participants' classification that does not coincide with the theoretical effect.

TABLE II. Table Type Styles

Aroma	**Theoretical Effect**	**Participants' Classification**[b]							
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Cherry Blossom	Relaxing (R)	R	R	R	R	R	R	R	R
Gardenia	Relaxing (R)	R	S	R	R	S	R	S	R
Lavender	Relaxing (R)	R	R	R	R	S	R	S	R
Lemongrass	Stimulating (S)	S	R	S	S	S	S	S	S
Lotus	Relaxing (R)	R	R	S	S	R	R	S	R
Peony	Relaxing (R)	R	S	R	S	S	R	S	R
Rose	Relaxing (R)	R	S	R	R	S	S	R	R
Sandalwood	Relaxing (R)	R	S	R	R	R	R	R	R
Spice	Stimulating (S)	S	S	S	S	S	S	S	S
Vanilla	Relaxing (R)	R	R	R	S	S	R	R	R

[b] The numbering refers to the number of each participant

Table II reveals inconsistencies between the projected theoretical effect and the participants' actual classification. Among the aromas evaluated for their relaxing properties, only Cherry Blossom had a flawless correlation, indicating significant promise for further investigation. In terms of stimulating aromas, Spice stood out as a perfect match, indicating significant possibilities for further research. It is noteworthy to mention two distinct aromas, one known for its relaxing properties, Sandalwood, and the other known for its stimulating effects, Lemongrass. It is important to mention that both of these aromas are different for participant nº2 (subject 02), who has a distinct cultural and geographical background compared to the other participants. Nevertheless, further research should be conducted to substantiate this fact, potentially by enlarging the number of participants.

Regarding the intensity of the aromas, particularly the relevant ones identified above, the quantification established by the participants was used, namely the rating from 1 to 3. Cherry Blossom got a rating of 15 out of 24, Spice got a rating of 17 out of 24, Sandalwood got a rating of 17 out of 24, and Lemongrass got a rating of 12 out of 24.

B. *Impact of Different Aromas on Physiological Parameters: Relaxing Effect*

In order to analyse the impact of the different aromas on healthcare monitoring, in particular on the relaxing effect, we will focus on the aromas that obtained the best score, previously identified as Cherry Blossom and Sandalwood.

In the case of Cherry Blossom, the theoretical effect and practical classification determined it to be relaxing, and we can confirm this through the evolution of the physiological parameters over the course of the experiment. Note in Fig. 6 below the decrease in HR for all participants, as a function of the number of samples acquired. The same behaviour was observed for the other physiological parameters acquired. Figure 7 shows this evolution for a single participant (the most noticeable decrease), which presents more details, including the trend line and its equation, which also allows us to predict the trend regarding the long-term impact of this aroma.

In the case of Sandalwood, the theoretical effect and practical classification determined it to be mainly relaxing, and we can confirm this through the evolution of the physiological parameters over the course of the experiment. Note in Fig. 8 below the decrease in GSR for all participants (except subject 02), as a function of the number of samples acquired. The same behaviour was observed for the other physiological parameters acquired. Figure 9 shows this evolution for a single participant, including the trend line and its equation. In this specific case, the results are the opposite of those presented by the other participants, in that instead of a noticeable decrease, an increase was observed. This discrepancy may be attributed to various factors, namely the divergence in cultural and regional backgrounds of the participants. Specifically, participants from regions where aromas are more prevalent and used in a wide range of products may contribute to this variation. Further research will be required in the future to demonstrate a correlation.

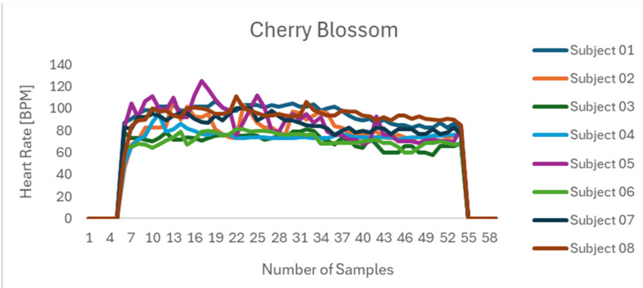

Fig. 6. Effect of cherry blossom aroma on HR for all participants

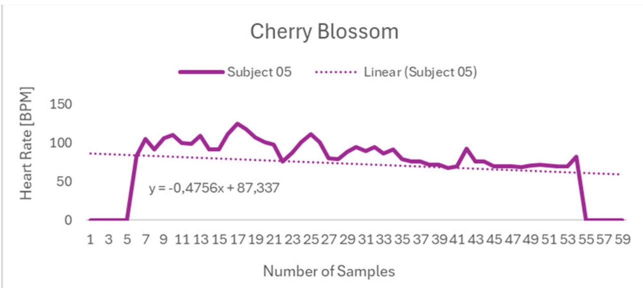

Fig. 7. Effect of cherry blossom aroma on a particular case (subject 05)

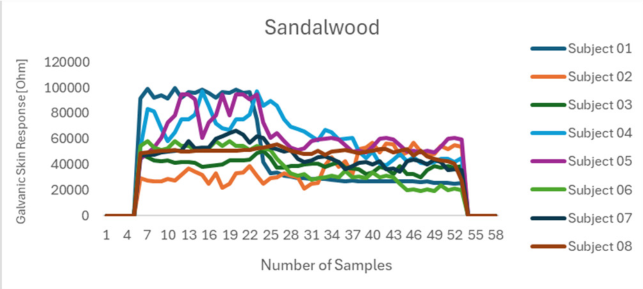

Fig. 8. Effect of sandalwood aroma on GSR for all participants

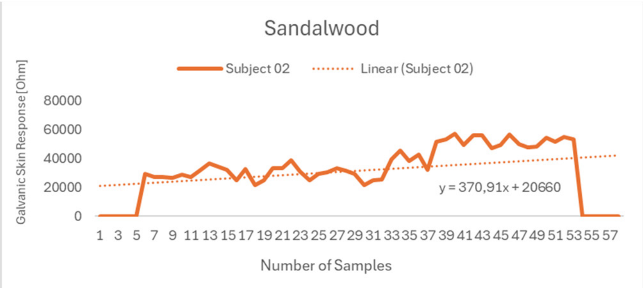

Fig. 9. Effect of sandalwood aroma on a particular case (subject 02)

C. *Impact of Different Aromas on Physiological Parameters: Stimulating Effect*

To analyse the stimulating effect of the different aromas on healthcare monitoring, we will focus on the aromas that obtained the best score, previously identified as Spice and Lemongrass.

In the case of Spice, the theoretical effect and practical classification determined it to be stimulating, and we can confirm this through the evolution of the physiological parameters over the course of the experiment. Note in Fig. 10 below the increase in HRV for all participants, as a function of the number of samples acquired. The same behaviour was observed for the other physiological parameters acquired. Figure 11 shows this evolution for a single participant (the most noticeable increase), which presents more details, including the trend line and its equation, allowing us to predict the trend regarding the long-term impact of this aroma.

Regarding Lemongrass, the theoretical effect and practical classification determined it to be mainly stimulating, and we can confirm this through the evolution of the physiological parameters over the course of the experiment. Note in Fig. 12 below the increase in RR for all participants (except subject 02), as a function of the number of samples acquired. The same behaviour was observed for the other physiological parameters acquired. Figure 13 shows this evolution for a single participant (the most noticeable increase), including more details such as, the trend line and its equation.

As mentioned above, subject 02 classified this aroma differently, identifying it as relaxing, and the same can be seen from the data acquired on his physiological parameters. However, Fig.14 above shows the evolution of subject 02's RR values, and it can be seen that in this specific case, its evolution is increasing, which indicates an increase in RR, and possible stimulation. It should be noted that all the remaining physiological parameters for subject 02 show a decreasing evolution, reinforcing its classification as relaxing. This discrepancy may be attributed to several factors, but it is crucial to highlight the contrast in the environmental conditions. The region from which this subject originates is heavily impacted by atmospheric pollution. It's also important to mention that this aroma is characterised by refreshing attributes, including effects such as clearing the airways.

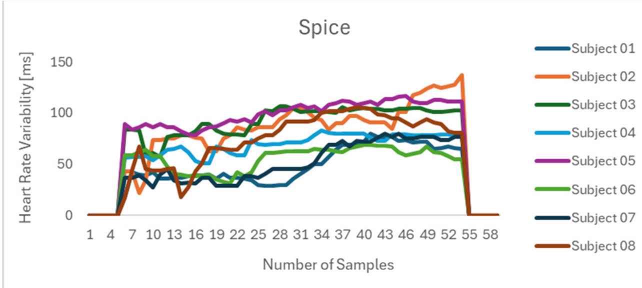

Fig. 10. Effect of spice aroma on HRV for all participants

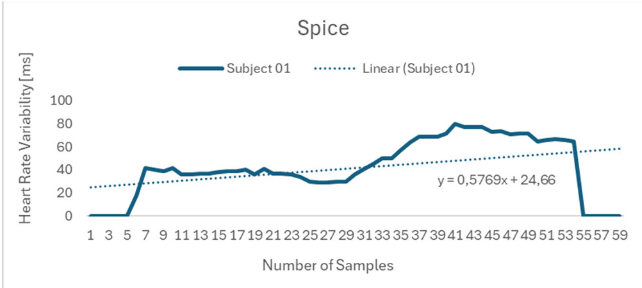

Fig. 11. Effect of spice aroma on a particular case (subject 01)

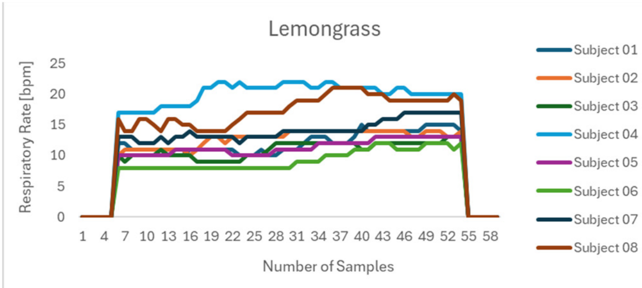

Fig. 12. Effect of lemongrass aroma on RR for all participants

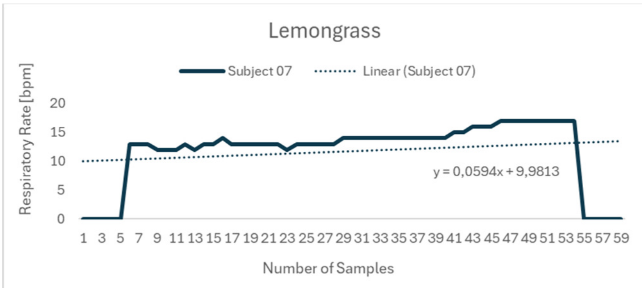

Fig. 13. Effect of lemongrass aroma on a particular case (subject 07)

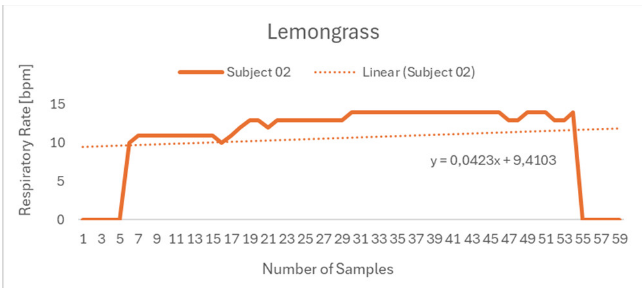

Fig. 14. Effect of lemongrass aroma on a particular case (subject 02)

IV. CONCLUSION

This study analysed the impact of new alternative methods in healthcare monitoring, with a specific focus on aromatherapy. Through the diffusion of aromas, a comparison was made between the theoretical effects defined in the literature and the real effects rated by participants. In the first part, the classification of aromas between relaxing and stimulating was analysed, including a scale of intensity from 1 to 3. The second part involved analysing the impact of the most significant aromas identified in the first part. This was done by establishing correlations between these aromas and physiological parameters. Overall, good indicators were obtained, demonstrating that theoretical predictions do not always align with practical outcomes. For instance, certain aromas that are believed to have a relaxing effect actually stimulate instead, and vice versa, thus addressing one of the problems identified, namely the lack of studies proving the effects of aromas. Regarding the impact of aromas on healthcare, this research has demonstrated a direct correlation between inhaling aromas and physiological changes, which can be used to address significant issues like stress. Therefore, using aromatherapy can be an effective method to counteract these effects and enhance overall health conditions.

Regarding future work, as previously mentioned, it is important to extend the group of participants in order to corroborate facts such as regional, cultural and environmental divergence. Furthermore, studies relating to stress induction and relief processes should also be conducted, in order to try to develop countermeasures in everyday life, for example, with the automation of diffusers that release aromas according to people's health conditions.

ACKNOWLEDGMENT

This work was funded by the Instituto de Telecomunicações and by FCT/MCTES through national funds and, when applicable, from EU funds co-financed under the UIDB/50008/2020 project. In addition, this work was also funded by ISCTE-Instituto Universitário de Lisboa, in the form of a merit scholarship awarded to the first author

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