Designing a Systematic Experiment to Investigate the Effect of Ambient Smell on Human Emotions in the Indoor Space; Introducing a Mixed-Method Approach

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Abstract. Studies have indicated that built environments affect all aspects of human life such as emotion, perception, behavior, health, and well-being (Cooper et al. 2011). Built environments are formed from the combination and juxtaposition of visible and invisible environmental variables. In recent years, common techniques such as virtual reality, augmented reality, digital twins, and artificial intelligence have enabled researchers in the field of architecture and urban design to simulate environmental conditions to investigate the impacts of environmental variables on humans. However, the studies conducted in this field of human comfort are mostly focused on the impact of environmental variables such as form, temperature, humidity, and sound, and in fewer studies, up-to-date methods and technologies have been used to simulate and investigate the impact of smell on humans. Most of the studies that have investigated the effect of ambient smell on humans, carried out in the discipline of architecture and urban design, have used traditional tools and methods (questionnaire, interview, observation) rather than advanced technology and tools drawing on neuroscientific knowledge and technique to measure the effectiveness of the ambient smell on human. They have used unmasked scents or real-world environments rather than being able to simulate environmental conditions. This article highlights the significance and necessity of employing simulation methods to investigate the impact of environmental smells on humans. Additionally, it presents the methodology of an experiment for studying the effect of indoor environment smells (with a case study of an office environment in the initial phases) on human emotions, utilizing a mixed-method approach. Analysis of some parts of the data from this experiment showed that exposure to the fragrance of the jasmine flower pleasant (flower) and the odor of the rotten orange peel (unpleasant) can cause changes in the electroencephalography (EEG) power across different bands among participants.

Keyword: Ambient smell · Built environment · Simulation methods · Electroencephalography · Neuroarchitecture · Physiological signals

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1 Introduction

Our built environments comprise both visible and invisible environmental variables such as geometry, color, material, sound, temperature, and humidity, working together to create an atmosphere in our built environment that provokes certain perceptions or triggers certain emotions in individuals. So, in combination these environmental variables can affect our multi-sensory experience of space and have significant impacts on our emotions, behaviors, health, and well-being in a number of ways, both positively and negatively (Countryman and Jang 2006). Accordingly, it is essential to study and investigate how these variables can enhance the overall experience of a space. One of the invisible environmental variables in every space is "ambient smell". Smelling is part of the breathing process, and while breathing, a person willingly or unwittingly inhales the smells of the environment and the space around them, which can affect various aspects of a human's existence (Goel and Grasso 2004; Lehrner et al. 2005; Sowndhararajan and Kim 2016).

Many studies conducted in different disciplines have shown that smells can have a wide range of effects on different dimensions of human existence. According to literature the sense of smell has a special relationship with the processing of emotions due to the unique connection of the olfactory system to limbic system, and for this reason, triggers the recall of memories and emotions of experiences associated with a particular smell (Croy et al. 2011; Perkins and McLean 2020; Kadohisa 2013; Bowring 2006). Just as smells can create identity for individuals, they also have the ability to create identity for spaces in a positive or negative way, in such a way that a person can recognize the smell of an environment as acceptable or unacceptable in terms of identity (Maria 2016). Studies show that environmental fragrances can reduce the stress experienced by employees in workplaces. Ambient fragrances can increase aesthetic appreciation, optimize performance and increase creativity, as well as improve air quality as a remedy for multi-symptom health problems such as "sick building syndrome" (Damian and Damian 2006). It has also been found that smells can have a great impact on behavior and encourage or prevent individuals from doing something (Kuppens et al. 2017). For example, extensive research conducted in the discipline of marketing and business on investigating the impact of odor indicates that smell can change customer behaviors such as spending, gambling, purchasing desire, the length stay in the store, searching and choosing products, the desire to buy more (Lin et al. 2018).

2 Neglect of Smell in Architecture

Although many studies carried out in other disciplines show the role and impact of smells on different aspects of human experience, the parameter of ambient smell has received little attention in architecture and urban design and is mostly limited to removing unpleasant odors from indoor and urban spaces (Quercia et al. 2015; Barbara and Perliss 2006). It seems that the full potential of smell has not been utilized in a deliberate and strategic way (Bouchard 2021). It is perhaps because of this kind of viewpoint and thinking towards the olfactory dimension that studies investigating the impact of environmental odors are very limited, incomplete, and undeveloped, and in most cases, they still seek to investigate the impact of unpleasant odors on humans rather than investigating and the role of positive smells.

The environmental variable of smell has a complex, transitory, ambiguous, and unstable identity. Every smell is a complex mixture of hundreds of different volatile chemicals that change every moment, making it very difficult to record and capture (Margolies 2001; Henshaw and Cox 2009). So, the study of ambient scent is a complicated task due to invisibility of the parameter, the subjective nature of odor perception and individual's perception, the difficulties in quantifying and measuring odor intensity and composition, and the interaction of other sensory stimuli. These unpredictable and dynamic characteristics of smell make it difficult to develop comprehensive and robust methods for evaluating and controlling ambient scent in various settings.

In addition, the lack of a systematic methodology for carrying out research in architecture and urban design on the impact of smells on human experience has caused the studies conducted in this field to suffer from many shortcomings. Most of the studies (Henshaw 2014; Bouchard 2013; McLean 2012, 2013, 2017) carried out in this field are limited to identifying, categorizing and investigating the impact of smells in urban spaces in the form of smellscape, smell walking and smell mapping projects. Many studies lack standard and systematic empirical criteria and protocols, and the instruments and techniques used in these experiments are very limited (Balez 2002) and in most cases include methods and tools such as questionnaires, interviews, and observations, which have been traditionally and historically used in architecture (Quercia et al. 2015; Nanda et al. 2013). Given the complexities inherent in the field of ambient odor study, it is crucial to adopt innovative methods, tools, and techniques from other disciplines to be able to support designers to get better insight on the impacts of smells on human perception and be able to consider smell as part of design process. This necessitates a multidisciplinary research approach to integrate knowledge and techniques from a broad range of fields such as olfactory sciences, psychology, neuroscience, aromachology, and cognitive sciences, to be able to apply in architecture.

Based on this, we need to apply and use methods and techniques that can have the necessary capacity and potential for research and study in the field of investigating the impact of the smell of the environment on humans with multidisciplinary approaches. One of the solutions that can help to define, plan, and design studies and research in the field of environmental smell, in the form of systematic experiments with empirical criteria, is the use of methods and techniques of environmental simulation studies. Simulation is a process by which real world scenarios can be studied and analyzed by creating a virtual world or minimizing the scale of the real world (Mishra and Patnayaka 2015). Simulation generally refers to experimental modeling or representation of particular environments and events, which can include computer models, laboratory studies, role-playing and game analogs of social situations, scale models and designs related to architectural design projects (Maransa and Stokols 1993). Using the powerful environmental simulation techniques and tools in the discipline of architecture and urban planning can help designers to evaluate and analyze various environmental parameters and their impact on the environment user (Mishra and Patnayaka 2015).

3 Simulation and Study of Ambient Smell

In recent decades with the development of computer technologies and digital tools and various technologies such as virtual reality, augmented reality, advanced computing tools, digital twins, etc., new simulation techniques have been adopted by architects (Werner and Schindler 2004; Drettakis et al. 2007; Franz et al. 2005). The recent advancements in computer technology and digital tools, have enabled designers and researchers to integrate performance analysis into design processes and gain a deeper understanding of the impact of invisible environmental variables on design and human perception. However, despite these cutting-edge technologies, the field of ambient odor has not yet fully leveraged these tools and techniques to identify, categorize, and understand the behavior of ambient scents and their impacts on various dimensions of human life. Still less are these new techniques supporting designers to design with smell as a constituent environmental material.

To know which methods, tools and techniques related to simulation studies to use for ambient smell studies, it is necessary to first identify all the criteria, standards and protocols that can affect the research results from the point of view of different branches of science and then to choose appropriate methods and technologies to conduct the research. The studies conducted on environmental odors in the discipline of architecture and urban planning are very few and in many cases this research does not employ standard protocols and criteria. Therefore, the variables affecting these studies have not been accurately identified and categorized. It is thus necessary to investigate and study a wide disciplinary range of research on environmental odors and their effects on humans, to identify the variables that can affect the experiment method and results, and based on that, design experiments.

For example, studies in the discipline of aromachology that investigate the effect of odors on human mood, physiology, and behavior have specified criteria for conducting experiments in this field, which include: clarity of test objectives and hypotheses, measurement of odors using appropriate laboratory methods, appropriate number of participants and control groups, data analysis using appropriate statistical methods, as well as review of data and results by scientific peers and publishing them in reputable scientific journals (Herz 2009). Also, studies conducted in the disciplines of olfactory science and psychology have shown that not only the intensity of a smell in a scale of high, low or medium can change a person's perception of that smell and the environment and affect the test results, but the strength of the smell and the level of perception and individual's sensitivity to smells can greatly affect the test results (Maggioni et al. 2020). Therefore, to conduct simulated experiments, it is necessary to consider criteria such as odor intensity, concentration, evaporation rate and stability. In addition to the characteristics of odor such as intensity of smell and chemical compositions, a person's biological and personal characteristics can affect how individuals perceive and experience smell.

Regarding the role of data collection tools and techniques, Lin et al. (2018) state that the review of 20 studies that examined the effect of smell on human emotions, both through laboratory experiments and field experiments using measurement tools, revealed that self-reporting showed no significant difference with only marginal statistical divergence between the two methods. This shows that in addition to using subjective methods, such as self-reporting tools, it is necessary to use objective tools and techniques to collect data. In many cases, for various reasons, the participant cannot express and describe her/his mood and emotions towards a stimulus (Jatupaiboon et al. 2013). So, recording and analyzing brain and peripheral signals makes it possible to understand the internal aspects of human emotions (Khalili and Moradi 2009). In addition to the important criteria and parameters from other disciplines, it was also necessary to consider the parameters and criteria within the discipline of architecture and urban planning for simulation studies of the impact of environmental odor.

4 Designing an Experiment to Study Smell Using a Mixed-Method Approach

This research proposes a mixed method to investigate the effect of ambient smell (pleasant and unpleasant) on human emotions in the indoor environment (office) using simulation techniques and qualitative and quantitative data collection tools. A series of experiments was designed and conducted based on a comprehensive literature review and the collaboration of a team consisting of experts in architecture, urban design, and psychology. The parameters affecting the smell of the environment and its perception by humans were identified and categorized.

In order to achieve a rigorous framework, pilot studies were carried out involving 14 participants. These pilot studies were conducted to evaluate the test method and data collection tools (which were developed based on a thorough literature review contextualized in the field of architecture). The findings from the pilot studies are used to refine and, if needed, modify the research method. This experiment is designed by considering the criteria and protocols of different disciplines for research on smell and considering the influential parameters of architecture in this field including:

- Space type, function and activities: In many other fields, such as aromachology, neuroscience, or psychology, experiments are conducted to investigate the impact of odors, without considering the environment in which they exist. However, the purpose of research conducted in the disciplines of architecture and urban planning is to investigate the impact of smells on humans within the context of built environments. For example, the type of space, whether open space, semi open space or closed space, functions and activities in the space are amongst effective parameters.
- Visible and invisible environmental variables: Visible environmental parameters (form, geometry, proportions, color, light) and invisible ones (temperature, humidity, sound, air quality, air flow) can have wide, different and complex effects on human perception of the atmosphere and space, and subsequently affect human perception of the odor of the environment. The form and content of built environments can affect individual's recognition and identification of smells. The importance of this issue becomes clear when we examine and analyze the distances that odors can travel in the environment (Henshaw 2014). Therefore, these environmental factors were measured in a controlled manner to be able to consider the influence of these factors on the results of the experiment.
- Characteristics of odor in the context of the environment: In most of the studies conducted in other disciplines, the odor emitting material is placed under the person's nose and he is asked to sniff it, while in architecture, odors are tested in the context of

the environment. Therefore, the indices and the characteristics of odors in the environment such as concentration, intensity, persistence of odors, and rate of evaporation of odors must be taken into account in simulation experiments.

– Type of sniffing: Naturally, when a person is in a given environment, (s)he does not smell the atmosphere actively (intentionally and consciously), but passively (unintentionally and unconsciously) smells and perceives the odor of the environment along with the air she/he inhales. The knowledge and insight on the type of sniffing can inform design of experiments, and particularly to avoid potential impacts from participants consciously focusing on their sense of smell during the tests. Humans unconsciously detect scents in their environment in various contexts without actively seeking them out. Therefore, it is important to keep the objectives of relevant experiment undisclosed to the participants. Accordingly, the objective of the study is kept undisclosed during recruitment and before conducting the experiments to prevent conscious detection of the scent by participants. Moreover, as a crucial strategy to prevent visual identification of the scent sources by participants, the source of the scent used in the experiment is concealed and visually unidentifiable in the test rooms.

4.1 Method and Procedure

In this experiment, two test rooms are considered, in one room the smell of jasmine is emitted and in the other the odor of rotten orange peel is spread. At first, the participant is placed in the preparation room, and the explanations required about the test are delivered to them and they sign the consent form. Then, the biosensors are worn to measure Physiological signals and the participant enters the first test room. The participants are asked to sit on a chair in the test room for 3 min without any movement and then perform a task and complete the questionnaire. After a few seconds of sitting on a chair in the room, it is expected that the smell of the environment can be perceived and smelled by the participant. The psychological task performed by the participant simulates a personal office activity adding to the environmental simulation of an office. This is also an important diversionary tactic that makes participants think they are being tested on the puzzle they are doing and so never consider smell. Also, the analysis of the results of this task is an important criterion for whether the smell affects their cognition by recording the speed and efficiency of completing the task or not. Throughout the whole period of the participants' presence in the test room, their brain and peripheral signals are recorded by biosensors. Then, the person leaves the first test room, sits in the waiting room for 3 min until the effect of the smell of the first room is removed (washout period) and then enters the second test room, and all the steps are repeated again. All test steps are summarized in Fig. 1.

4.1.1 Setting (Controlled Experimental Conditions)

To perform this experiment, three rooms (two test rooms and one preparation room) were prepared, all of which have the same visible environmental parameters, including form, geometry, proportions and color. Each testing room is 4.30 m^2 with identical visual and insulation conditions. The interior environment is considered to be a one-person office in terms of functionality. The furniture inside the test rooms includes a desk, a chair, a

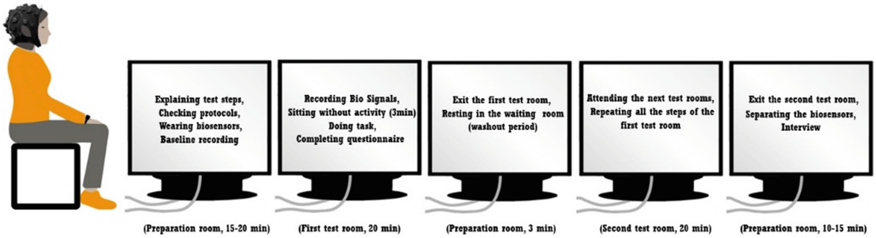

Fig. 1. Test steps

drawer (To hide the source of smell) and a device for recording environmental variables (see Fig. 2). The studies that have investigated the cross-modal perception of the sense of smell with other senses such as auditory and visual show that this interaction between different senses can have an effect on human perception of the environment and their emotions (Morrison et al. 2011; Mattila and Wirtz 2001; Gottfried and Dolan 2003). For this very reason, the color of the test rooms was considered white to reduce the effect of the visual sense on the sense of smell. In addition, it is necessary to measure and monitor the environmental variables to ensure that the values of each of these variables are the same during the experiment and for all participants. The research conducted by Nimmermark and Gustafsson (2005) shows that the emission of odor is strongly related to the water vapor pressure and the control of temperature and humidity may reduce the concentration and emission of odor. So, microclimatic changes of the environment including temperature, humidity, air quality (CO_2 level), and noise are recorded by the Netatmo (NHC-P2) Smart indoor air quality device to ensure that environmental conditions of the experiment are identical and stable in both rooms. The temperature of the rooms is 20–22 °C, the humidity is 45–55%, the air quality is 400–500 ppm, and the noise is 40–45 db.

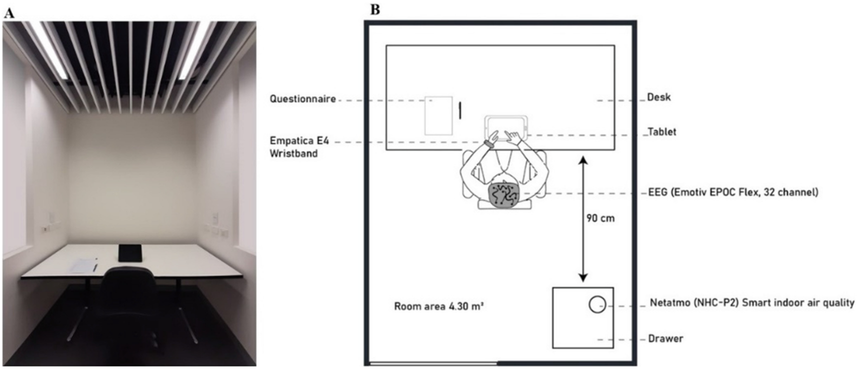

Fig. 2. A, Photo of experiment room. B, Floor plan indicating the position of participant and the items in the experiment rooms

4.1.2 Ambient Smells

In one room, the smell of jasmine flower (pleasant) is spread from an invisible and unannounced source and in another room, smell of rotten orange peel (unpleasant) is similarly spread and can be smelled by the participants. The smell source is hidden in the drawer and at a distance of 90 cm behind the participant's head. It is necessary to calculate the intensity and concentration of odors as well as the rate of their evaporation in the environment before conducting the experiment and according to that, the odors are distributed in the room.

4.1.3 Participants and Sampling Method

Criteria have been defined for participation in this experiment, which were: men and women between 25 and 50 years old, right-handed, non-smokers, with academic background (student, faculty, or academic staff) without any special disease (heart disease, mental illness, migraine, Epilepsy), without any problems or respiratory diseases (anosmia, hyposmia, nasal polyp, allergies, etc.), not having allergies to smells, perfumes, flowers, foods, without suffering from Corona disease and sufficient English language skills. Epidemiological studies have revealed that the olfactory function of individuals over 70 years old decreases significantly or they suffer from olfactory disorders. Also, the olfactory function of individuals is at its peak in the age range of 30–50 years (Doty et al. 1984; Kondo et al. 2020; Boyce and Shone 2006). Since the Corona disease can affect the person's sense of smell for a period of several weeks or months, all the participants were selected from persons who were not infected with the corona disease, and if they were infected, their sense of smell had returned completely. The number of participants in this experiment was 14 individuals (7 women and 7 men) who randomly entered the room with the fragrance of the (Jasmine flower) and the smell of rotten orange peel.

4.1.4 Protocols of Attend on the Experiment Day

Some protocols have been defined for the attendance of the participants on the day of the test. To ensure that the olfactory perception (sense of smell) of the participants is complete on the day of the test they should not be suffering from a cold or COVID-19. In detail, these protocols include: not using any perfume, body/oral deodorant, and clothes deodorizers on the testing day, not suffering from colds, the flu, allergies, nasal congestion, allergies, etc. two weeks before the test until the testing day, not eating any food (especially spicy foods) for at least one hour before the test, not drinking coffee for at least one hour before the test, not chewing gum on the testing day, not brushing one's teeth for at least one hour before the test, not wearing any metal jewellery (earrings, bangles, bracelets, necklaces, etc.) in the testing rooms and not having any communication and electronic devices (Mobile phone, smartwatch, etc.).

4.1.5 Data Collection and Data Analysis

This test is a mixed methods design. On this basis, various tools and techniques were used to collect data so that both quantitative and qualitative data, as well as subjective and objective data, could be recorded and analyzed. In each of the test rooms, after the participant spends 3 min without any activity, she/he is asked to perform one touch Stockings of Cambridge (OTS) psychological task. The OTS is a 10 min task of executive function based on the *Tower* of *Hanoi* task and designed by CANTAB and assesses spatial planning and working memory in an individual (Backx et al. 2020; Blum Redden and Grant 2018). After that, participants completed a questionnaire that includes questions about their emotions and perceptions of the space.

In addition, brain activity (EEG) and peripheral signals of participants were recorded in the test rooms, borrowing from neuroscience. This was in addition to the questionnaire and the semi-structured, open-ended interviews conducted at the end of the experiment. To record brain signals in this test, a 32-channel Emotiv EPOC Flex saline system was used, which was placed on the heads of the participants in the form of a cap to record brain signals wirelessly. The EEG electrode location of this system is the standard 10–20 electrode placement system. Also, Empatica E4 wristband device was used to record peripheral signals (see Fig. 3). This device is worn on the wrists of the participants like a wristwatch to measure the data related to blood volume pulse (BVP), heart rate (HR), electrodermal activity (EDA) and skin temperature (SKT) and send them via Bluetooth to a computer or a mobile. By integrating qualitative and quantitative, subjective and objective data, we can have a more accurate and standardized analysis and improve interpretation of the impact of environmental odors on human emotions.

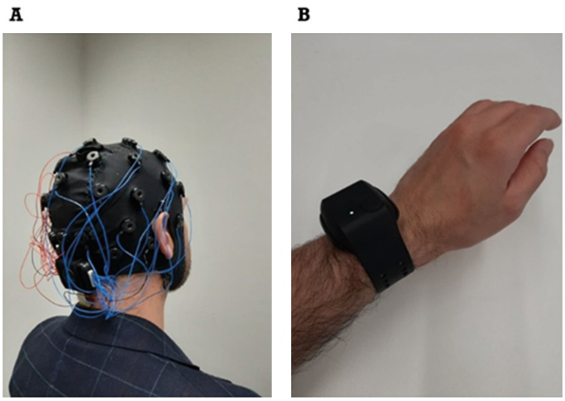

Fig. 3. Biosensors used in experiments to record brain and peripheral signals. A, Emotiv EPOC Flex (32-channel) for recording EEG. B, Empatica E4 wristband for recording aperipheral signals (heart rate, electrodermal activity, and skin temperature)

For EEG data pre-processing and processing, EEGLab which is a toolbox plugin for MATLAB is used. Examining the EEG topographic maps of all participants shows that the power of different bands exposed to pleasant (Jasmine flower) and unpleasant smell (Rotten orange peel) was different and most of these changes are related to the frontal part of the brain (see Fig. 4). The power of the theta band in the frontal part of the brain is increased when exposure to the fragrance of jasmine flower. Also, smell of jasmine increases the power of the alpha band in the frontal part of the brain, while exposure to the smell of rotten orange peel decreases the power of the alpha band in different parts of

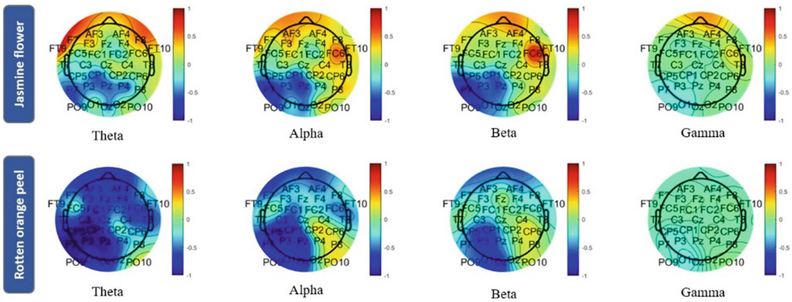

Fig. 4. EEG topography map of one of the participants in the experiment. It shows the changes in the strength of different bands (theta, alpha, beta and gamma) exposed to a pleasant smell (jasmine flower) and an unpleasant smell (rotten orange peel) in the first two minutes

the brain. Morover, the power of the gamma band exposed to the smell of rotten orange peel increased in the frontal part of the brain, while the power of this band exposed to the smell of jasmine in most areas of the brain either did not change significantly or decreased. Since the increase in alpha and theta band activity indicates an increase in relaxation (Motomura et al. 2001; Burnett et al. 2004; Sowndhararajan and Kim 2016), it can be concluded that the fragrance of jasmine flowers increased the relaxation of the participants in this experiment. Examining the results of the questionnaires also indicates that the participants felt more relaxed and pleasant in the room with the smell of jasmine flowers.

5 Conclusion

Based on what has been reported in the literature, it seems that despite the importance and impact of smell on various dimensions of human existence, the role of this environmental variable in the process of architectural design and urban planning has not been seriously considered and very few studies have been conducted to investigate the effects of ambient smell on humans. Most of the studies conducted in this field lack a rigorous framework and methodology. Also, many studies conducted in this field still use traditional methods and tools to collect data, and up-to-date tools and technologies in the field of neuroscience are less used. In addition, it seems that the research conducted in this field have not been able to use the potential capacities of simulation techniques and methods to design and conduct research in this field. To bridge the existing gap this research investigated the effect of ambient smells on humans with a structured experimental design and empirical criteria (taken from different disciplines), and utilizing tools and technologies that are common in the field of neuroscience for such a study.

Designing and conducting systematic simulation experiments to study the effects of environmental smells not only makes it possible to evaluate and analyze the results obtained and reproducibility of these experiments, but also can create a basic systematic standard framework for future studies. By examining and analyzing the results, the methodology and structure of the experiment can be modified and developed for future research. In the experiment conducted by examining the electroencephalography (EEG) data, we found out that exposure to the fragrance of jasmine (pleasant smell) and the smell of rotten orange peel (unpleasant smell) can cause implicit changes and effects (power of different bands). If the participants' brain signals were not recorded and only traditional data collection methods such as questionnaires, observations and interviews were used, it would not be possible to investigate the implicit effects and physiological responses of smells on participants. Therefore, it seems that this mixed method approach can give a more comprehensive and accurate view of the implicit and explicit effects of the smell of the environment on different dimensions of human existence.

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