Chapter

Olfactory Imagery and Emotional Control

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Abstract

Olfaction and gustation are important survival mechanisms. These sensory modalities also have an impact on memory and emotions. Olfactory stimulation has recently been used in virtual reality environments to treat emotional distress. There is evidence that olfactory and gustatory stimuli reach the insula, where they influence a number of other brain networks. There is little research on the use of smell and taste during mindfulness, but it will be shown that they can foster balanced emotional responses. In this chapter, we will look at how to incorporate olfactory and gustatory memory-based experiences during mindfulness exercises to bring about emotional homeostasis.

Keywords: smell, olfaction, taste, gustatory, mindfulness, olfactory virtual reality, insula

1. Introduction

It is true that the senses of smell and taste are often overlooked nowadays, but the fact remains that the mind relies heavily on olfaction and gustation to communicate with the body. Furthermore, certain scents and tastes can have a profound effect on moods and emotions, and these ancient sensory modalities have ensured humanity's survival. In addition to supporting our daily lives, they are used for the appreciation of perfume and wine, and scent-based therapies have been shown to be effective treatment for conditions such as anxiety [1] and depression [2].

The most powerful human sense may also be the least used. The scent is a sense rapidly activated when we are born and is also a fierce memory encoder during development. Science has repeatedly demonstrated how deeply the olfactory system is linked to an individual's emotional state [3]. Scent has been shown to have a connection with the brain areas responsible for motivation and decision-making [4], and it may emerge as a powerful strategic tool for changing our behavior and moods.

2. A painful experience

An interesting experiment has shown how common people unconsciously smell their hands [5]. Ninety-four percent of 400 respondents acknowledged engaging in smelling their hands. The study also showed that simultaneous motor expression was crucial for that because the nasal airflow more than doubled when the hands were at the nose, indicating that people were in fact sniffing their hands' smell.

Movement appears to be important during odor appreciation as reducing the sniffing movement of the nose impacts the degree of pleasantness of the smell [6]. Sniffing seems to happen in a certain order during olfaction, and it may serve the same purpose as moving the eyes during visual imagery.

Regarding why such an unconscious smell of the hands takes place, it appears that, similarly to what happens when one looks at herself/himself in the mirror, smelling one's hands could be related to obtaining a notion of one's self through olfaction. Thus, by sniffing their hands, humans may subconsciously obtain reassurance about themselves.

When most people think about the sense of smell or taste, they might imagine something like enjoying a fragrant flower or savoring a delicious meal. However, smell and taste may play key roles in emotional well-being. In this respect, it could be argued that smelling one's hands could in fact lead to emotional homeostasis—trying to return to the present moment when emotional balance swings.

It appears that a connection has been made between olfaction and pain. It has been shown that exposure to odors results in an elevated pain threshold in people who suffer from persistent low back pain [7]. How could such a process be explained? An experiment has shown that at the level of the mouse input trigeminal system, olfactory stimulation seems to modify nociceptive processing [8]. In the presence of pain, the floral odorants phenylethyl alcohol and lavender oil decreased the amount of network activity in the caudalis trigeminal nucleus. It was hypothesized that olfactory inputs excite hypothalamic networks, which in turn alter network activity in the trigeminal nucleus. It would appear that exposure to odors stimulates activity in the hypothalamus and inhibits the processing of painful stimuli, a form of descending inhibition of the pain modulation mechanism. The fact that smelling includes a significant hedonic component lends weight to the idea that it can be used as a technique for relieving pain. The authors suggest that such an approach could transform olfaction into a therapeutic tool for the management of headaches.

In his book "The Brain's Way of Healing: Remarkable Discoveries and Recoveries from the Frontiers of Neuroplasticity," Canadian psychiatrist and researcher Norman Doidge described the case of a woman who sustained a lower back injury with multiple lumbar vertebrae fractures [9]. After the traumatic event, she suffered from intractable pain for years, necessitating ever-increasing opioid medications. A new possibility emerged when she met Dr. Michael Moskowitz, a chronic pain specialist. Moskowitz had himself suffered a cervical injury and, after many years of increasing pain, resorted to attempting to ease his pain by trying to mentally modify the cerebral maps that underlined it. He thought that rewiring the brain's pain connections was possible, so he began to support brain neuroplasticity as a way to treat pain.

He explained to his patient that he was convinced, he had no other effective means to bring her pain relief, and he advised her to try the visualization technique he had used on himself. It was not an easy task, but with a persistent and focused approach, the patient began to realize she had some moments of feeling no pain. After some months, she was able to live for days without pain. Many months later, she was pain-free and, after years of monitoring, she was declared cured.

Expanding on the brain maps for pain, Doidge argues that the abnormal connections of the central nervous system circuits underlying chronic pain are brought together under the principle that neurons that fire together, wire together. Hence, if properly directed by visualization, such connections could be unlearned by progressively unwiring the pain connections.

Moskowitz discovered that in the use-it-or-lose brain, there is constant competition for cortical estate because the brain's activities take up more and more circuits by capturing resources from other areas. He drew three brain images: one in acute pain, with activity in 16 brain areas; one in chronic pain, with the same areas expanded; and one in which the brain registers no pain at all [9]. As a result, whenever Moskowitz felt pain, he immediately began visualizing his brain maps. To begin, he would visualize the image of the brain in chronic pain and note how much that map had expanded due to newly added neuroplastic neurons. Then, he imagined the firing areas shrinking until they resembled a painless image of the brain. He was aware, for instance, that the posterior cingulate cortex and posterior parietal lobes co-processed vision and pain. He knew that by visualizing these brain maps repeatedly, he was forcing their neurons to limit pain processing in order to accommodate visual inputs. He imagined; he was transferring pain to vision. His experience demonstrates that he achieved success. He had been in excruciating pain for 13 years before using his visualization technique and was pain-free in 6 weeks.

In point of fact, Moskowitz's strategy can be construed as an instance of practicing a specific form of mindfulness. The results of a study conducted on female college students who were experiencing stress, anxiety, and sadness and who participated in an 8-week program that combined visualization and meditation found that the combination of these two techniques increased self-awareness and decreased anxiety [10]. Pain relief was associated with orbitofrontal cortex and rostral anterior cingulate cortex regulation of low-level nociceptive neural targets (the thalamus and primary somatosensory cortex). Following mindfulness-based mental training, it appears that a reappraisal mechanism was activated, possibly by rewiring these neuronal circuits [11].

There is some evidence to suggest that olfactory inputs to the brain can alleviate physical pain by having an effect on the connections that house emotionally painful experiences. The amygdala, orbitofrontal cortex, and hippocampus, for example, are all involved in the process of odor-elicited emotion as well as in the recalling of odor-associated emotional memory [12]. The citrus fragrance has been shown to have a beneficial effect on the mental states and immune function of patients who are depressed [13]. It has also been demonstrated that rose essential oils prevent the disruption of the skin barrier and the elevation of salivary cortisol in humans caused by stress [14], and that the aromas of orange and lavender counteract the anxiety experienced by patients in a setting similar to that of a dental office [15].

The influence of gustation on both physical pain and emotional experience is much less well understood. When evaluated using heat detection thresholds and the perception of painfully hot stimuli, solutions of sucrose and sucralose exhibited no evidence of analgesic activity [16]. Positive emotions were associated with increased sweet and decreased sour intensities, while negative emotions were associated with increased sour and decreased sweet tastes. On the other hand, positive emotions were associated with increased sweet and decreased sour intensities [17].

3. Memory storage

Invoking positive autobiographical memories has been shown to be an effective therapeutic technique for reducing feelings of emotional distress in a wide variety of clinical conditions. In general, one could say that positive autobiographical memories have the ability to improve mood (for a review, see [18]). Odors may be particularly helpful for enhancing mood states because they elicit more profound emotional memories than other types of stimuli and because the memories that are evoked by odors are typically pleasant. It was discovered that men and women who were exposed to the scent of a perfume that personally reminded them of themselves experienced more positive emotions, an increased mood of happiness, and decreased anxiety when compared to when they were exposed to a pleasant fragrance that did not elicit personal memories.

In accordance with the principles of odor-associative learning, when an odor becomes linked to the emotional properties of an event, it can produce a downstream effect on physiology. A calming odor, for example, will also slow heart rate and respiration rate, as well as improve immune responses [19]. On the other hand, an odor that evokes an important event from one's past emotional history can cause one's heart to race and a jolt of adrenaline to be released. Because of the direct link between olfactory processing and the amygdala-hippocampal complex, emotions elicited by odor-evoked memories can arise immediately upon perception. An odor-evoked memory can thus be defined as possessing emotional primacy, which occurs when affect is elicited before a cognitive understanding of why that emotion occurred in the first place.

Odor-evoked memories could thus elicit specific emotions such as self-confidence, motivation, and energizing behavior. All of these states, for example, could be triggered by an odor that evokes the memory of winning a significant event, resulting in positive physiological effects [20]. Considering that olfactory cognition is not affected by retroactive interference, a specific odor associated with a significant past personal event can be considered a potential therapeutic agent.

Because odor-evoked memories are emotionally charged, they recall our past in a visceral way more than any other type of memory experience. This exceptional feature of olfaction can be seen in people who suddenly lost their sense of smell, taste, or both during the COVID-19 pandemic. Olfactory training has been shown to be the only disease-specific intervention with evidence of efficacy for the treatment of postinfectious olfactory dysfunction. Treatment based on sniffing and trying to identify scents, such as rose, eucalyptus, lemon, and clove, over the course of several months should be implemented as soon as possible [21].

It has been reported that emotional distress caused by the COVID-19 pandemic is expected to be a major mental health issue in the coming years, including post-traumatic stress disorder (PTSD). Perhaps a remarkable example of using odor treatment for emotional distress is its use to treat patients with PTSD. In recent years, we have seen the emergence of olfactory virtual reality (OVR) as an effective means to treat PTSD [22, 23].

Virtual reality (VR) technology is becoming more prevalent in healthcare settings. It provides an experience that is unrivaled in real life. VR applications have the potential to transform the assessment, understanding, and treatment of mental health problems, and have been used in studies to treat pain in patients undergoing treatments such as chemotherapy [24], as well as emotional disorders, such as stress and low self-efficacy [25].

When VR alters other senses, such as sight and spatial perception, olfactory stimuli can reconnect oneself with the other senses. Olfactory stimuli can influence psychosocial functioning by altering negative emotional states such as hostility, jitteriness, upset, and distress. Reduced negative effect improves these emotional responses. Because confidence is increased, improvements in self-efficacy are frequently observed.

Odors are common and debilitating triggers of distressing emotions, and OVR technology is being adapted to treat such disorders. It appears to be uniquely positioned to be used in the treatment of PTSD symptoms due to unique emotional features of olfactory processing and odor-evoked memory. Systematic desensitization, prolonged exposure, reappraisal strategies, and conditioning odors are being used for emotional calming and are examples of OVR treatment strategies for PTSD [22].

Preventing PTSD in vulnerable groups can be accomplished by neutralizing potential odor triggers, such as burned fuel or flesh, through preemptive habituation and reappraisal training. In addition to PTSD, OVR has shown promise in treating other types of emotional problems as well. In a test for improving psychosocial well-being with OVR, for example, the presence of a pleasant odor significantly reduced negative affect on several measures, such as hostility, anxiety, and distress, compared to when there was no odor. OVR is a computer-simulated, three-dimensional environment where the user wears a headset that blocks out most of the outside world and replaces it with new information. It is the experience of presence—the illusion of "being there"—in a world that exists outside of the self [26], where the external physical environment disappears from the user's phenomenal awareness. It is created by a headset that provides its own sensory and psychological landscape. The desired state in OVR is presence, a complex psychological experience formed by the multifaceted interaction between sensory stimulation, including smell, and the resulting cognitive responses. Also, the person can interact with the virtual environment and become "immersed" in it by using hand controls or other interface devices [27].

PTSD is a severely debilitating emotional disorder characterized by extremely distressing thoughts and intrusive traumatic memories. Depression, substance abuse, sleep problems, and anxiety are all common symptoms. According to the American Psychiatric Association, it affects approximately 3.5% of adults in the United States, with one in every 11 people suffering from it at some point in their lives [28]. Notably, alarmingly high rates of PTSD have been reported since the COVID-19 pandemic began, and there is a looming mental health crisis among healthcare workers and the general public. As a result, PTSD and all other forms of anxiety, perhaps even depression, will likely affect a much larger proportion of the population than they did prior to 2020, and rates are expected to rise over the next few years.

4. Odor and tastes return

Odors with positive emotional associations can be used to repair unpleasant emotional states and prevent unhealthy behaviors [29]. Subjectively pleasant odors, for example, can improve mood, increase nostalgia and its psychological benefits [30], reduce cigarette cravings in smokers [31], and decrease cravings for unhealthy foods [32]. An odor that induces calming emotions will also slow heart rate and respiration rate, as well as improve immune responses. Based on these principles, positive emotional associations with odors can be used to reduce the unpleasantness of traumatic memories. If a person is emotionally overwhelmed by a traumatic recollection, using a technique based on odor mindfulness can induce relaxation, de-escalate emotions, and change the mindset.

As exposure to an olfactory stimulus has been shown to reduce pain, improve negative affect and increase emotional resilience, it opens up an avenue to question whether these effects can be obtained through an odor *willfully recalled* from memory.

For many years, it was assumed that odor could not be perceived when the primary chemosensory substance was absent. However, like visual mental imagery, olfactory mental imagery shares many neural processes with true olfactory perception. Methods from neuropsychology [33] and neuroimaging [34] have revealed striking similarities between visual perception and visual imagery. When positron emission tomography is used, it reveals that odor mental imagery is associated with the activation of odor-processing regions such as the piriform and orbitofrontal cortices [35].

Not only does the activity elicited by imagining odors mirror that is elicited by perceiving real odorants in specific brain regions but it also has a hedonic-specific pattern [36]. Its net effect is that during mental imagery of olfactory events, primary and secondary sensory cortical structures are activated and then expanded to emotion-processing brain centers.

It is important to emphasize that olfaction integrates a sensory and a motor component (the sniff for olfaction). It appears that olfactory perception is not simply passively induced but includes the reenacting of some form of motor input. Therefore, sniffing, the motor component of olfaction, is likely to be a prominent feature of olfactory reenactment [37].

Olfactory mental images can be generated from long-term memories. However, information in long-term memory is implicit and poorly accessible, as opposed to information in short-term memory, which is explicit and accessible. Therefore, sniffing during olfactory imagery is likely to activate an internal representation stored in long-term memory; this is used to generate the mental image, which includes a sensory-type representation in short-term memory. Sniffing while recalling an odor makes the information explicit and thus accessible.

If remembering an odor from memory activates the very same cortical areas that smelling itself does, and considering olfaction influences the emotional behavior of humans, could we use mental imagery of odors as a potential means to target feelings and behavior? In order to provide a response to this question, I will first examine how odor imagery can influence activity in the olfactory and nonolfactory regions of the brain.

5. The power of the insula

The primary olfactory cortex (piriform cortex), the secondary olfactory cortex (posterior orbitofrontal cortex), and the insula have all been shown to be activated during odor imagery. Perfumers have larger gray-matter volumes in areas associated with olfactory processing, such as the insula and anterior cingulate, which is an important region for emotional and cognitive integration [38].

A thicker and denser insular cortex has been shown to be associated with better olfactory performance in healthy people [39], while patients with various degrees and forms of olfactory dysfunction show loss of insular gray matter [40]. It is also well established that both olfactory and gustatory sensory modalities project to the prefrontal and insular cortices, and both odor and gustatory stimuli can exert calming effects when an olfactory or gustatory stimulus is presented [41, 42].

Mindfulness meditation has been shown to be capable of treating pain and emotional-related disorders [43–45], though its effect in the long run still remains to be elucidated. Mindfulness is a self-administered reflexive technique that has an impact on several brain structures. It is capable of increasing blood flow to the insula [46] and enriching the gray-matter volume in the insular cortex [47].

More recently, a groundbreaking approach to treating chronic pain has been advanced, whereby patients seek to *willfully activate* a particular brain region while receiving real-time functional magnetic resonance imaging. It was shown that participants could voluntarily self-activate the cingulate and insula using real-time functional magnetic resonance imaging (rtf-MRI) and that such activation resulted in pain reduction [48] as well as a better balance between stress-involved brain structures [49]. It was clear that when given feedback about their performance with rtf-MRI, participants were able to learn a strategy to control their minds.

Participants in such studies were able to change neuronal processing within the insula, but the precise mechanism by which this was accomplished is still unknown. It has been demonstrated in normal subjects [49] as well as in a small group of patients with a psychopathic disorder [50]. The anterior insula was clearly regulated by one criminal psychopathic individual. This participant not only learned to up-regulate the left anterior insular cortex, increasing the number of connections in the emotional network, but he also learned to increase the insula's difference between outgoing and incoming connections.

The brain insula is a region that possesses connectivity to various other brain centers. It is involved in interception and decision-making, connecting worldly events to inner states, and everyday activities such as pain, love, emotion, craving, addiction, music enjoyment, or even wine tasting. The insula may be partly responsible for all of these seemingly disparate things because it lies at the center of the concept of self-awareness—the fact that humans can be aware of themselves, their bodies, and their emotions, and motivate actions that define the present moment [51].

According to Damasio's [52] somatic marker hypothesis, people use bodily signals to help them make decisions. The insula uses its connections to influence decision-making because it is involved in the processing of these bodily sensations. Because of its constant bombardment with information about the body's location, condition, subjective emotions, and key features of its environment, the insula plays an important role in the foundation of our overall awareness. This compiled data is incorporated into what Craig refers to as a "global emotional moment" (51), a snapshot of ourselves at a single point in time that contains all of the information that is important to us—for example, being happy while hungry. It is the insula's role in stringing together these global emotional moments that allow us to be aware of the day's ongoing moments.

It has been shown that the insula can be a target region for rtf-MRI-based treatment for patients with emotional disorders. Further, this part of the brain can be activated consciously with feedback or without it. It has been shown to be activated during real time functional magnetic resonance imaging [53] and also when biofeedback was subsequently removed [54]. So, it would be reasonable to think that reenacting smelling and tasting may activate the insula in a way not based on feedback.

Odor and gustatory recollection from memory both activate the insula. Hence, I propose the mechanism of a switch, whereby recalling an odor or having a gustatory-based sensory experience activates the insula and brings us back to the present moment. During a mindfulness exercise, reenacting stored interoceptive (smell and gustation) and exteroceptive (sniffing and tasting) information into working memory engages the insula. For instance, mindfully reenacting a smell or taste or both could be brought about at a time of the day when one falls prey to negative thoughts or bad feelings. As the insula is shifted to the present moment, rumination is stopped by the recall of the pleasant olfactory and gustatory imagery. Furthermore, if practiced repeatedly, it could stimulate the insular cortical system, leading to neuroplasticity. Learning to mindfully recollect olfaction and gustation could be envisioned as a way to facilitate living in the present moment, increasing emotional appraisal, and facilitating decision-making.

6. Focused mindfulness

Mindfulness could be viewed as a method for activating the insula, whether through real time function neuroimaging, after-feedback learned to control, or mindful olfactory-gustatory recall. Borrowing from Kabat-Zinn, mindfulness could be defined as awareness that arises from activating the insula by paying attention on purpose, in the present moment, and non-judgmentally [55]. The mindful reenactment of a memory odor or flavor redirects insular resources away from pain, emotional rumination, and helplessness.

It is also possible that repeated application of this gustatory or smell-based mindfulness technique will result in increased insular neuroplasticity. It has been shown, for example, that olfactory perception regulates the olfactory brain's experience-dependent neuroplastic properties. This mechanism underpins the acquisition of fine-grained percepts that distinguish the perfume of Rosa damascena (Bulgarian Rose) from that of Rosa centifolia (Rose Maroc), allowing us to appreciate the wide range of aromas encountered in daily life [56].

It has also been demonstrated that olfactory training induces changes in functional connectivity in the left and right piriform cortices in anosmic patients with long-term smell loss due to infection before and after a 12-week period of olfactory training [57]. Prior to olfactory training, a broad network encompassing predominantly nonolfactory regions, such as the prefrontal areas, left inferior frontal gyrus, and left premotor cortex, was active; following training, these nonolfactory functional linkages were reduced. This suggests that after olfactory training, a process of brain remodeling occurs. It may play a similar role in mindfulness-based exercises involving gustatory or olfactory reenactments.

Only recently has science begun to comprehend how intimately the olfactory and gustatory systems are tied to an individual's emotional state. It has been demonstrated that smell and taste influence regions of the brain involved in emotion and motivation, and that actions, such as what we eat and drink, affect our daily productivity. Consequently, it could be a formidable strategic instrument for modifying behavior and emotions.

Does this suggest that we can achieve a runner's high or a state of mindfulness merely by recalling odors or tastes? Perhaps. The limbic system, which is the portion of the brain responsible for smell and emotion, contributes to a wide range of processes, including motivation, long-term memory, behavior, and, of course, smell. However, the most important function of the limbic system is to set the tone for our emotional self, altering throughout the day to generate the appropriate energy and emotions to execute tasks and preserve memories.

During this time, the olfactory and gustatory regions engage directly with the hippocampus in order to recover memories assisted by smell or taste. Consider the rush of recollections that accompanies getting a whiff of a loved one's scent or the aroma emanating from a glass of wine reminiscent of a memorable meeting.

Smelling and tasting are sensory experiences that imprint in memory the sense of well-being felt at the time they occur. We know that these memories can be recovered whenever a sensory stimulation occurs by chance; evidence demonstrates that we can act on them by deliberately recalling fragrances or tastes, giving us the opportunity to be touched by the initial emotions.

The insula, which is concealed within the lateral sulcus of the human brain, has a unique functional profile at the intersection of the internal and external environment, the crossroads of cortical and subcortical neural hierarchies, and as a functional lever at the intersection of the major large-scale functional brain networks. The insula gets a large number of cross-modal afferents and is best viewed as a multimodal integration site [58]. As it is connected to the limbic system, the reward system, and the frontal cortex, which are all engaged in cognitive, affective, and executive activities, it lays the groundwork for a rich functioning experience.

The hypothesis that recalling memories of gustatory and olfactory experiences during focused mindfulness strengthens the insula's role as a functional switch, leading to greater executive and emotional control, no doubt, needs to be tested further. Meanwhile, we could just be a step back from demonstrating that the pleasure of living one's life to the fullest is only a sniff or a taste away.

7. Conclusion

Smell and taste are complex mental experiences, and like hearing and vision, they can be reenacted. You can shut your eyes and visualize the music concert you attended. You can also vividly hear the chord progression of your favorite tune without any music in the background. Similarly, the smells of baked cake, coffee, or wine, as well as the tastes of barbecue, cheese, and beer, can be recreated. These odor and taste reenactments have the property of quickly building a bridge from a past experience to appreciation in the present moment, leaving ruminating unwanted thoughts or unpleasant feelings at bay. Sniffing and tasting have been important for evolution. Maybe we kept them in our memories as a way to help us get through hard times.

Conflict of interest

The author declares no conflict of interest.

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References

[1] Sánchez-Vidaña DA, Ngai SP, He W, Jk C, Lau BW, Tsang HW. The effectiveness of aromatherapy for depressive symptoms: A systematic review. Evidence-Based Complementary and Alternative Medicine. 2017;**2017**:586

[2] Barati F, Nasiri A, Akbari N, et al. The effect of aromatherapy on anxiety in patients. Nephro Urology Monthly. 2016;**8**:e38347

[3] Mouly AM, Sullivan R. Memory and plasticity in the olfactory system: From infancy to adulthood. In: Menini A, editor. The Neurobiology of Olfaction. Boca Raton: CRC Press/Taylor & Francis; 2010

[4] Shanahan LK, Bhutani S, Kahnt T. Olfactory perceptual decision-making is biased by motivational state. PLoS Biology. 2021;**19**:e3001374

[5] Perl O, Mishor E, Ravia A, Ravreby I, Sobel N. Are humans constantly but subconsciously smelling themselves? Philosophical Transaction on Royal Society. 2020;**375**:20190372

[6] Bensafi M, Porter J, Pouliot S, Mainland J, Johnson B, Zelano C, et al. Olfactomotor activity during imagery mimics that during perception. Nature Neuroscience. 2003;**6**:1142-1144

[7] Gossrau G, Baum D, Koch T, Sabatowski R, Hummel T, Haehner A. Exposure to Odors increases pain threshold in chronic low back pain patients. Pain Medicine. 2020;**21**:2546-2551

[8] Papotto N, Reithofer S, Baumert K, Carr R, Möhrlen F, Frings S. Olfactory stimulation inhibits nociceptive signal processing at the input stage of the central trigeminal system. Neuroscience. 2021;**479**:35-47

[9] Doidge N. The Brain's Way of Healing: Remarkable Discoveries and Recoveries From the Frontiers of Neuroplasticity. New York: Viking; 2015

[10] Margolin I, Pierce J, Wiley A. Wellness through a creative lens: Meditation and visualization. Journal of Religion & Spirituality in Social Work: Social Thought. 2011;**30**:234-252

[11] Zeidan F, Emerson NM, Farris SR, Ray JN, Jung Y, McHaffie JG, et al. Mindfulness meditation-based pain relief employs different neural mechanisms than placebo and sham mindfulness meditation-induced analgesia. The Journal of Neuroscience. 2015;**35**:15307-15325

[12] Kadohisa M. Effects of odor on emotion, with implications. Frontiers in Systems Neuroscience. 2013;**7**:1-6

[13] Komori T, Fujiwara R, Tanida M, Nomura J, Yokoyama MM. Effects of citrus fragrance on immune function and depressive states. Neuroimmunomodulation. 1995;**2**:174-180

[14] Fukada M, Kano E, Miyoshi M, Komaki R, Watanabe T. Effect of "rose essential oil" inhalation on stress-induced skin-barrier disruption in rats and humans. Chemical Senses. 2012;**37**:347-356

[15] Lehrner J, Marwinski G, Lehr S, Johren P, Deecke L. Ambient odors of orange and lavender reduce anxiety and improve mood in a dental office. Physiology & Behavior. 2005;**86**:92-95

[16] Mooney ER, Davies AJ, Pickering AE. Sweet taste does not modulate pain perception in adult humans. Wellcome Open Research. 2020;**5**:43

[17] Noel C, Dando R. The effect of emotional state on taste perception. Appetite. 2015;**95**:89-95

[18] Herz RS. The role of odor-evoked memory in psychological and physiological health. Brain Sciences. 2016;**6**:22

[19] Matsunaga M, Isowa T, Yamakawa K, Kawanishi Y, Tsuboi H, Kaneko H, et al. Psychological and physiological responses to odor-evoked autobiographical memory. Neuro Endocrinology Letters. 2011;**32**(6):774-780

[20] Engen T. The acquisition of odor hedonics. In Perfumery: The Psychology and Biology of Fragrance. New York: Chapman & Hall; 1988

[21] Boscolo-Rizzo P. Smell and taste dysfunction after covid-19. BMJ. 2022;**378**

[22] Herz RS. Olfactory virtual reality: A new frontier in the treatment and prevention of posttraumatic stress disorder. Brain Sciences. 2021;**11**:1070

[23] Freeman D, Reeve S, Robinson A, Ehlers A, Clark D, Spanlang B, et al. Virtual reality in the assessment, understanding, and treatment of mental health disorders. Psychological Medicine. 2017;**47**:2393-2400

[24] Chirico A, D'Aiuto M, Pinto M, Milanese C, Napoli A, Avino F, et al. The elapsed time during a virtual reality treatment for stressful procedures. A pool analysis on breast cancer patients during chemotherapy. In: Pietro G, Gallo L, Howlett R, Jain L, editors. Smart Innovation, Systems and Technologies. Cham: Springer; 2016

[25] Kaimal G, Carroll-Haskins K, Ramakrishnan A, Magsamen S, Arslanbek A, Herres J. Outcomes of visual self-expression in virtual reality on psychosocial well-being with the inclusion of a fragrance stimulus: A Pilot Mixed-Methods Study. Frontiers in Psychology. 2020;**11**:589461

[26] Steuer J. Defining virtual reality: Dimensions determining telepresence. The Journal of Communication. 1992;**42**:73-93

[27] Spagnolli A, Gamberini L. A Place for presence: Understanding the human involvement in mediated interactive environments. Psychology Journal. 2005;**3**:6-15

[28] American Psychiatric Association. New APA Poll Shows Sustained Anxiety among Americans; More than Half of ParentsAre Concerned about the Mental Well-Being of Their Children. Available online: https://www.psychiatry.org/newsroom/news-releases/new-apa-poll-shows-sustained-anxiety-among-americans-more-than-half-of-parents-are-concerned-aboutthe-mental-well-being-of-their-children

[29] Herz RS. Mood and cognitive performance during odor exposure. In: Rouby C, Schaal B, Dubois D, Gervais R, Holley A, editors. Olfaction, Taste and Cognition. New York: Cambridge University Press; 2002. pp. 160-177

[30] Reid CA, Green JD, Wildschut T, Sedikides C. Scent-evoked nostalgia. Memory. 2015;**23**:157-166

[31] Sayette MA, Marchetti M, Herz RS, Martin LM, Bowdring MA. Pleasant olfactory cues can reduce

cigarette craving. Journal of Abnormal Psychology. 2019;**128**:327-340

[32] Kemps E, Tiggemann M. Olfactory stimulation curbs food cravings. Addictive Behaviors. 2013;**38**:1550-1554

[33] Farah MJ. Is visual imagery really visual? Overlooked evidence from neuropsychology. Psychological Review. 1988;**95**:307-317

[34] Kosslyn S. Understanding the mind's eye...and nose. Nature Neuroscience. 2003;**6**:1124-1125

[35] Djordjevic J, Zatorre RJ, Petrides M, Boyle JA, Jones-Gotman M. Functional neuroimaging of odor imagery. NeuroImage. 2005;**24**:791-801

[36] Bensafi M, Sobel N, Khan RM. Hedonic-specific activity in piriform cortex during odor imagery mimics that during odor perception. Journal of Neurophysiology. 2007;**98**:3254-3262

[37] Rinck F, Rouby C, Bensafi M. Which format for odor images? Chemical Senses. 2009;**34**:11-13

[38] Arshamian A, Larsson M. Same same but different: The case of olfactory imagery. Frontiers in Psychology. 2014;**5**:1-8

[39] Frasnelli J, Lundström JN, Boyle JA, Djordjevic J, Zatorre RJ, Jones-Gotman M. Neuroanatomical correlates of olfactory performance. Experimental Brain Research. 2010;**201**:1-11

[40] Yao L, Pinto JM, Yi X, Li L, Peng P, Wei Y. Gray matter volume reduction of olfactory cortices in patients with idiopathic olfactory loss. Chemical Senses. 2014;**39**:755-760

[41] Kobayashi M, Sasabe T, Shigihara Y, Tanaka M, Watanabe Y. Gustatory imagery reveals functional connectivity from the prefrontal to insular cortices traced with magnetoencephalography. PloS One. 2011;**6**:e21736

[42] Rolls ET. Taste and smell processing in the brain. Handbook of Clinical Neurology. 2019;**164**:97-118

[43] Nakata H, Sakamoto K, Kakigi R. Meditation reduces pain-related neural activity in the anterior cingulate cortex, insula, secondary somatosensory cortex, and thalamus. Frontiers in Psychology. 2014;**5**:1489

[44] Zeidan F, Baumgartner JN, Coghill RC. The neural mechanisms of mindfulness-based pain relief: A functional magnetic resonance imaging-based review and primer. Pain Reports. 2019;**4**:e759

[45] Gibson J. Mindfulness, interoception, and the body: A contemporary perspective. Frontiers in Psychology. 2019;**10**:2012

[46] Tang YY, Lu Q, Feng H, Tang R, Posner MI. Short-term meditation increases blood flow in anterior cingulate cortex and insula. Frontiers in Psychology. 2015;**6**:212

[47] Hölzel BK, Carmody J, Vangel M, Congleton C, Yerramsetti SM, Gard T, et al. Mindfulness practice leads to increases in regional brain gray matter density. Psychiatry Research. 2011;**191**:36-43

[48] deCharms RC, Maeda F, Glover GH, Ludlow D, Pauly JM, Soneji D, et al. Control over brain activation and pain learned by using real-time functional MRI. Proceedings of the National Academy of Sciences of the United States of America. 2005;**102**:18626-18631

[49] Krause F, Kogias N, Krentz M, Lührs M, Goebel R, Hermans EJ.

Self-regulation of stress-related large-scale brain network balance using real-time fMRI neurofeedback. NeuroImage. 2021;**243**:118527

[50] Sitaram R, Cara A, Veit R, Gaber T, Ruiz S, Birbaumer N. Volitional control of the anterior insula in criminal psychopaths using real-time fMRI neurofeedback: A pilot study. Frontiers in Behavioral Neuroscience. 2014;**8**:344

[51] Craig AD. How do you feel--now? The anterior insula and human awareness. Nature Reviews. Neuroscience. 2009;**10**:59-70

[52] Damasio AR. The somatic marker hypothesis and the possible functions of the prefrontal cortex. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences. 1996;**351**:1413-1420

[53] Caria A, Sitaram R, Veit R, Begliomini C, Birbaumer N. Volitional control of anterior insula activity modulates the response to aversive stimuli. A real-time functional magnetic resonance imaging study. Biological Psychiatry. 2010;**68**:425-432

[54] Yao S, Becker B, Geng Y, Zhao Z, Xu X, Zhao W, et al. Voluntary control of anterior insula and its functional connections is feedback-independent and increases pain empathy. NeuroImage. 2016;**130**:230-240

[55] Kabat-Zinn J. Mindfulness Based Stress Reduction (MBSR). Constructivism in the Human Sciences. 2003;**8**:73-83

[56] Li W, Luxenberg E, Parrish T, Gottfried JA. Learning to smell the roses: Experience-dependent neural plasticity in human piriform and orbitofrontal cortices. Neuron. 2006;**52**:1097-1108

[57] Kollndorfer K, Fischmeister FP, Kowalczyk K, Hoche E, Mueller CA, Trattnig S, et al. Olfactory training induces changes in regional functional connectivity in patients with long-term smell loss. Neuroimage Clinic. 2015;**9**:401-410

[58] Molnar-Szakacs I, Uddin LQ. Anterior insula as a gatekeeper of executive control. Neuroscience and Biobehavioral Reviews. 2022;**139**:104736