Synesthetic Interactions: Exploring the Multisensory Relationships Between Color and Scent in Human Perception

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Introduction

The interplay between our senses shapes our perception of the world in fascinating ways. Among these sensory interactions, the relationship between odors and colors is particularly intriguing, offering insights into how our brains integrate different types of information. This multisensory integration is not just a curiosity; it has practical implications in fields ranging from marketing and product design to psychology and neurology. From a sensory perspective, the association between odors and colors is rooted in cross-modal perception. This phenomenon occurs when a sensory stimulus in one modality (such as smell) involuntarily elicits a perception in another modality (such as vision). Research often explores how certain odors evoke specific color experiences and vice versa. For instance, the smell of lemons is frequently associated with yellow, whereas the scent of lavender might evoke the color of purple.[1]

The underlying mechanisms of these associations are complex and involve innate and learned aspects. Some theories suggest that these connections may be partly hardwired in the brain, a concept known as synesthesia, where stimulation of one sensory pathway leads to automatic, involuntary experiences in a second sensory pathway.[2] However, much of the odor-color relationship is also believed to be learned and culturally influenced. The associations can be shaped by personal experiences, cultural background, and even linguistic factors.[3] Understanding the relationship between odors and colors has practical applications. In marketing, for example, congruence between the color of the packaging and the expected odor of a product can influence consumer perceptions and behavior.[4] This relationship can be leveraged in aromatherapy and multisensory therapy in therapeutic settings, potentially aiding in relaxation and mood improvement.[5]

This research explores the intricate relationship between colors and odors, a subject of growing interest in multisensory

1 Charles Spence, "On the Psychological Impact of Food Colour," *Flavour* 4, no. 1 (2015), https://doi.org/10.1186/S13411-015-0031-3/FIGURES/1; Sarah E. Kemp and Avery N. Gilbert, "Odor Intensity and Color Lightness Are Correlated Sensory Dimensions," *American Journal of Psychology* 110, no. 1 (1997): 35–46: https://doi.org/10.2307/1423699.

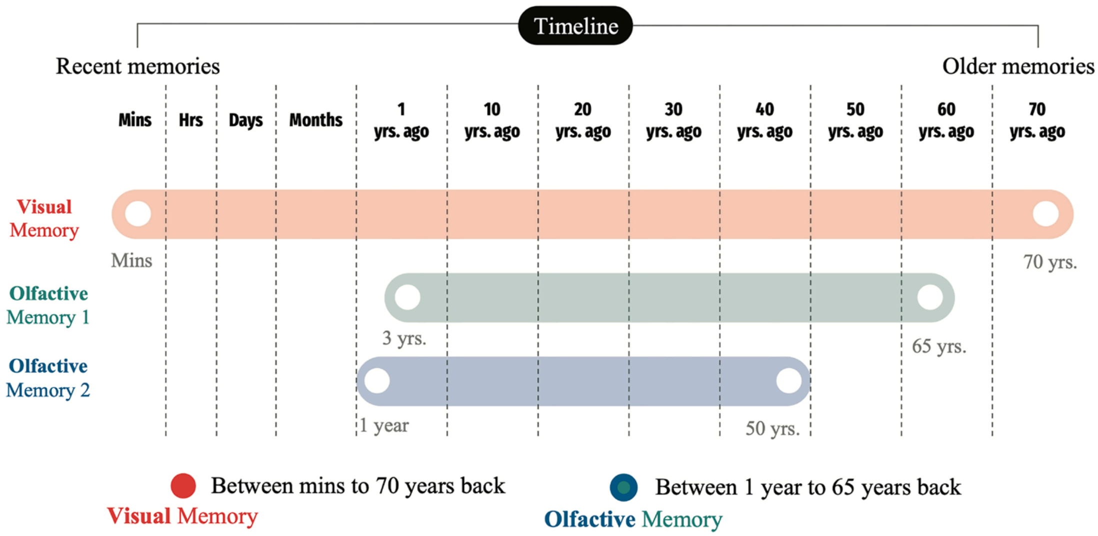
2 Richard E. Cytowic, *Synesthesia: A Union of the Senses*, 2nd ed. (Cambridge, MA: MIT Press, 2002), https://doi.org/10.7551/MITPRESS/6590.001.0001.

3 Paul Kay and Terry Regier, "Language, Thought and Color: Recent Developments," *Trends in Cognitive Sciences* 10, no. 2 (2006): 51–54, https://doi.org/10.1016/J.TICS.2005.12.007.

4 Bertil Hultén, "Sensory Cues and Shoppers' Touching Behaviour: The Case of IKEA," *International Journal of Retail and Distribution Management* 40, no. 4 (2012): 273–89, https://doi.org/10.1108/09590551211211774.

5 J. Lehrner, G. Marwinski, S. Lehr, P. Johren, and L. Deecke, "Ambient Odors of Orange and Lavender Reduce Anxiety and Improve Mood in a Dental Office," *Physiology & Behavior* 86, nos. 1–2 (2005.): 92–95, https://doi.org/10.1016/J.PHYSBEH.2005.06.031.

https://doi.org/10.1162/desi_a_00790



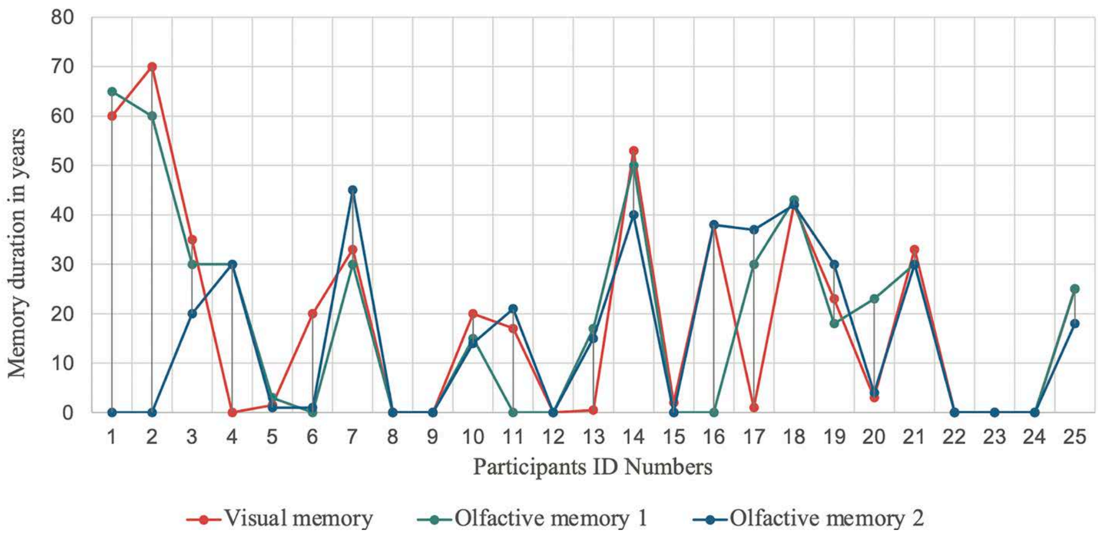


Figure 1
Visual and olfactive memory duration ranges. Source: Authors.

Figure 2
A chart represents the visual and olfactive memory duration. Source: Authors.

perception studies. The article presents five experiments scrutinizing the interplay between visual and olfactory stimuli. These experiments include examining the durability of visual and olfactory memories, investigating how color influences the perception of fragrance purity, exploring the neurological connections between colors and smells, studying the effect of color intensity on scent perception, and understanding how visual and olfactory elements combine to create pleasant atmospheres. This comprehensive approach aims to deepen our understanding of multisensory integration and its implications for cognitive science and practical applications.

Visual and Olfactive Memory Duration

A significant aspect of the workshop was providing a rich data

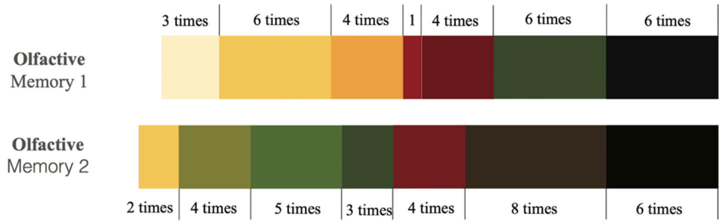


Figure 3
Frequent colors chosen by the participants per time. Source: Authors.

set that offers insights into the complex interplay between visual and olfactory memory duration through the first exercise of the workshop. The collected data reveals a broad demographic range among the participants, spanning ages 22 to 77, encompassing both genders and representing various cities across Italy. The data collected from 24 participants, with ages ranging from the early 20s to late 70s, reveals fascinating patterns in how individuals connect sensory experiences to memory.

Participants were asked to recall their earliest visual and olfactory memories, revealing a diverse range in the age of these memories. For instance, one recalled a visual memory from 60 years ago and an olfactory memory from 65 years ago; another had a visual memory from 70 years ago but no corresponding olfactory memory. This diversity suggests a complex relationship between sensory modalities and the persistence of memories over time.

Participants were also asked to associate colors with their olfactory memories, which yielded a spectrum of responses. The number of colors associated with each olfactory memory varied, with some participants linking as many as three colors to a single memory. This exercise underscored the multisensory nature of memory, where a single experience can evoke a constellation of sensory responses.

The findings revealed significant insights into the comparative duration and characteristics of visual and olfactive memories. Participants demonstrated a broader range of visual memory, from minutes up to 70 years, in contrast to olfactive memory, which spanned from 3 to 50 years, as shown in Figures 1 and 2.

Intriguingly, olfactive memories were often older than visual ones for the same individual. The exercise of associating scents with colors yielded a varied color palette, predominantly encompassing yellow, red, green, brown, and black. These findings underscore the enduring nature and unique associations of olfactive memories, suggesting a robust and nuanced connection between scent and color perception, illustrated in Figure 3.

Color-Dependent Fragrance Purity

The second exercise consists of five sessions per user: three round cards of three different colors, on which the same amount or mix of essential oils was sprayed. It includes choosing which of the three cards smells of a single fragrance in purity, without contamination.

Table 1. Structure of the experiment.

Session	Scent	Card Colors
1	Pure orange	Orange, red, blue
2	¾ ylang ylang ¼ neroli	Yellow, white, green
3	⅗ cinnamon ⅕ ylang ylang ⅕ orange	Brown, black, orange
4	Pure geranium	Red, green, black
5	½ orange ½ lemongrass	Orange, yellow, green

Table 2. Experiment results.

Session	Scent	Answer
1	Pure orange	**Orange (50%)**, blue (27.8%), red (11.1%), all (11.1%)
2	¾ ylang ylang ¼ neroli	**Yellow (44.4%)**, green (38.9%), white (11.1%), none (5.6%)
3	⅗ cinnamon ⅕ ylang ylang ⅕ orange	**Orange (50%)**, brown (33.3%), black (16.7%)
4	Pure geranium	**Green (44.4%)**, red (16.7%), black (16.7%), none (11.1%), all (11.1%)
5	½ orange ½ lemongrass	**Yellow (38.9%)**, orange (33.3%), green (16.7%), none (5.6%), all (5.6%)

"None of them" or "all of them" responses were also expected, and what fragrance smelled was also asked.

The exercise aims to analyze whether the color of the cards influences the possibility of smelling pure smells, both when they are and when they are not. There was always a wrong answer between them, as the three cards of each session were identical from an olfactory point of view. Instead, only "none of them" or "all of them" responses were correct, as shown in Table 1.

This experiment involved 18 participants; Table 2 shows the answers for each session with their percentage of answers to the question "Which cardboard presents a fragrance in purity?" From the results, when a fragrance in purity or the highest percentage fragrance in a mix or fragrances in an equal mix that was most well-known (sessions 1, 2, 3, 6), the most chosen answer was the one relating to the card of the color closest to the fragrance in the popular imagination.

For session 1, with three cards sprinkled with orange fragrance, the most chosen card was the orange one. In session 2, the most chosen card was yellow, the color of the Cananga odorata (Ylang-ylang) flower. Maybe this was not the motivation that prompted most participants to provide this answer, but it was a color that recalled flowers. The second card with the highest percentage was the green one, which also reflects a floral and green atmosphere.

The results in session 3 are interesting because the two colors that often recall cinnamon were the most chosen (orange and brown). Session 6 had an equal percentage of orange and lemongrass fragrancies; this mix, citrusy and herbaceous, produced results that corresponded with these olfactory accords.

In sessions where the single fragrance was less known (as in the case of session 4, with the scent of geranium in purity), the answers were more varied and distributed among the five choices. In total, only nine of the answers, "none of them" or "all of them" were chosen, though they were the only correct answers. This fact demonstrates that the question of the exercises and the colors of the cards may have led the participants to provide the solutions described above.

When considering the results, it was helpful to provide in advance the name of the fragrance in purity that participants had to search for and see if this influenced the results more. It has also been observed that essential oils are not optimal because of their high and persistent concentration and rapid evolution. Adopting strategies to combat olfactory fatigue, such as sniffing coffee beans, in the future was considered valid.

The Relationship Between Colors and Smells from a Neurological Point of View

This experimental hypothesis is based on two main principles from the cognitive science world. The first one is the free energy principle, a mathematical model that through a Bayesian approach to brain function describes the brain's cognitive abilities based on statistical principles. Specifically, this theory analyzes the mind as a predictive machine, a simulator that through evolutionary processes anticipates sensory stimuli before they are perceived. According to this theory, the reason minimizes the gap between expectations and sensory impulses. It makes its predictions using precise mathematical formulae in which the probability of an event is calculated in advance based on previous experience. In other words, our mind uses observed frequencies to assign a priori probability to a given event before it occurs. When the expectation is not met, it is necessary to make a new calculation, which lowers the level of free energy available.[6]

The second principle is based on the processing fluency theory. According to this approach, when people process information about an object quickly, they feel a positive effect. Consequently, they prefer things that are simple to comprehend and use. Therefore, low processing fluency occurs when we find something challenging to interact with or understand. This

6 Karl Friston, James Kilner, and Lee Harrison, "A Free Energy Principle for the Brain," *Journal of Physiology–Paris* 100, nos. 1–3 (2006): 70–87, https://doi.org/10.1016/J.JPHYSPARIS.2006.10.001.

causes people to expend more cognitive or physical effort, resulting in negative feelings and associations.[7] This study applies processing fluency to sensorial stimuli to examine its effects on cognitive performance.

The third experiment is composed of two different phases. The first one is presented as a predictive context (e.g., red as a visual stimulus and pomegranate smell as an olfactory stimulus) for which it is hypothesized that subjects would react with better cognitive performance. The second one is presented as a nonpredictive context, in which the processing fluency effects and the mismatch between expectations and sensory impulses result in a worse cognitive performance than the previous one.

Based on these two approaches, we hypothesize that matching the odor and visual stimuli could lead to better cognitive performance. To measure this, the speed through which the participants complete the neuropsychological tests of the two cases is compared (coherent versus noncoherent color-smell association). If the time required to complete the test after the coherent association is shorter than that after noncoherent associations, it is possible to conclude that the experience of coherent color-smell associations improves people's cognitive performance versus the experience of noncoherent associations.

If the conclusions demonstrate that a match between the fragrance smelled and the colors seen in the environment enhances people's cognitive performance, these data would be relevant for designing architectural spaces and product design, as it could improve people's well-being.

On their arrival, participants were asked to reply to a couple of questions for profiling, and they were associated with a number, which they carried along in all exercises. The materials used for the experiment were four colored papers (red, light blue, orange, white) and eight essential oils (pomegranate, white musk, citrus, vanilla, mint, cloves, cinnamon, lavender).

Coherent fragrance/color associations:

1. pomegranate/red
2. white musk/light blue
3. citrus/orange
4. vanilla/white
5. Noncoherent fragrance/color associations: mint/red
6. cinnamon/light blue
7. lavender/orange
8. cloves/white

The subjects were asked to look at one colored sheet while smelling the associated essential oil for a couple of seconds, in the order above, starting from the group of colors and smells that were coherently associated.

7 Angela Y. Lee and Aparna A. Labroo, "The Effect of Conceptual and Perceptual Fluency on Brand Evaluation," *Journal of Marketing Research* 41, no. 2 (2004): 151–65, https://doi.org/10.1509/JMKR.41.2.151.28665; Rolf Reber, Piotr Winkielman, and Norbert Schwarz, "Effects of Perceptual Fluency on Affective Judgments," *Psychological Science* 9, no. 1 (1998): 45–48, https://doi.org/10.1111/1467-9280.00008; Rolf Reber, "Processing Fluency, Aesthetic Pleasure, and Culturally Shared Taste," in *Aesthetic Science: Connecting Minds, Brains, and Experience*, ed. Arthur P. Shimamura and Stephen E. Palmer (Oxford: Oxford University Press, 2011), 223–49, https://doi.org/10.1093/ACPROF:OSO/9780199732142.003.0055.

After administering the first group of associations—coherent fragrance/colors associations, the participants were instructed to perform the trail-making test.[8] This is a neuropsychological test used to measure visual attention and task switching, processing speed, mental flexibility, and executive functioning. It is divided into two parts. In the first one, trail-making test A (TMT-A), the participant must connect, using a pen, a set of 25 dots as quickly as possible in numerical order. In the second part of trail-making test B (TMT-B), the 25-dot set must be connected in numerical and alphabetical order (1-A, 2-B, 3-C, etc.). The time spent for each exercise was timed with a stopwatch, and the data were written on the paper sheet at the end of the test.

After the first set of TMT-AB, the subjects were asked to experience the noncoherent associations in the same modalities as the first set (the coherent associations): After administering visual and olfactive stimuli, they were asked to perform another set of trail-making tests. The time spent on each exercise was written on the paper sheets again.

The TMT-AB sets were downloaded from the website CogniFit. The results show that the hypothesis is confirmed: the time spent on the first set of cognitive tasks was shorter than the time for the second set. However, the scientific value of this experiment is weakened by the atmospheric conditions in which it was conducted. The colors and fragrances experienced by the participants should be the only stimuli that influence the cognitive tests, and the whole experience should take place in a fully controlled laboratory ambiance, in which other incentives would be absent or remain constant. Moreover, the available time to test each participant needed to be longer to administer more than one test to measure cognitive performance, which would have contributed to a broader view of the effects that the two different exposures generated. Finally, for more reliable conclusions, the test design should be between-subjects instead of within-subjects: two different groups of participants should test the two conditions of coherent and non-coherent associations. In conclusion, more research is needed to support the hypothesis of this study. Even so, the experiment was a helpful starting point to examine the effects that coherent versus noncoherent color-smell associations have on human cognitive performance.

An Investigation into Whether the Intensity of Color Can Affect the Perceived Intensity of a Scent

For the fourth exercise, the investigation took place over two hours with randomly selected participants as part of a giant festival. The experiment consisted of three sets of three bottles (a total of nine bottles) with varying intensities of lemon essential oil (EO) mixed with alcohol. This liquid was tinted with different concentrations of yellow, ranging from very light to very strong.

8 Christopher R. Bowie and Philip D. Harvey, "Administration and Interpretation of the Trail Making Test," *Nature Protocols* 1, no. 5 (2006.): 2277–81, https://doi.org/10.1038/NPROT.2006.390.

Table 3. Experiment results for each session.

Test	Correct (out of 24 People)	Percentage
1	13	52
2	3	12
3	7	28

The 24 participants were required to smell the unlabeled bottles and rearrange them from weakest to strongest smelling. We were looking to see how many could correctly identify the odor strengths despite the randomly assigned color concentration.

We assume that the intensity of the color would enhance the power of the scent perceived. However to test this further, we used tests 2 and 3, varying the color but not the odor, strength, and vice versa.

The three tests consisted of:

1. Bottle A = 1% EO + Dark Yellow
   Bottle B = 10% EO + Medium Yellow
   Bottle C = 100% EO Very Light Yellow

2. Bottle A = 10% EO + Very Light Yellow
   Bottle B = 10% EO + Medium Yellow
   Bottle C = 10% EO + Dark Yellow

3. Bottle A = 10% + No Color
   Bottle B = 100% + No Color
   Bottle C = 1% + No Color

Results

Overall, the results contradict what we had expected, but some exciting results exist (see Table 3).

For test 1, the results show that 13 of the participants could correctly arrange the bottles in order of odor intensity despite the "misleading" colors. This would suggest that despite the color intensity being inversely related to odor intensity, it did not affect their scent perception overwhelmingly.

However, 11 of the participants got it wrong, which is a significant proportion and therefore could suggest that the color intensity slightly affected their ability to recognize odor strength. Within this, six of the total participants chose bottle C as the weakest odor, pale yellow, which aligned with our hypothesis.

A follow-up test would be helpful to see whether the color intensity matched the odor intensity, and more participants would be able to identify the order correctly.

In test 2, where all the scents were equally diluted, but the color intensity varied, three of the participants could correctly identify the smell. This is not exceptionally high and, when compared with test 3, could be evidence to suggest that they found it more challenging to correctly identify the smell because of their trained associations with color intensity. It is also possible that this low score was because it was a trick question, and they did not consider it an option that allowed all the odors to be in the same concentration.

Interestingly, eight participants all gave the same wrong answer (CAB). This again goes against our hypothesis (that color enhances the perceived intensity). In this case, they commonly chose dark yellow as being perceived as the weakest scent; further exploration is needed to understand why.

Test 3 was made up of three bottles with no color and three different odor intensities (strengths). This was designed to examine whether participants could better identify odor intensity without color cuing. Still, in this case, we found that the ability to place the correct order was not increased but reduced to 7 out of 24. This alone would suggest that color can be helpful in identification, but when presented next to the results of test 1, it is not conclusive as they are contradictory results.

In conclusion, the highest percentage of correct answers would have been in test 3 because there was no color cuing. The lowest we expected was in test 2 because it was unexpected. We hoped that a higher percentage of the participants incorrectly would arrange the test 1 bottles due to their coloring.

The use of alcohol as the base was commented on as being misleading because while the subjects were asked to identify the most robust lemon scent, this was often confused with the strength of alcohol.

The Mental Processing of a Pleasant Atmosphere: Visual and Olfactory Elements as Driving Evocative Forces

The fifth experiment was conducted in the framework of a cultural festival that involved a varied group of participants organized in groups of up to three. The investigation aimed to guide participants through a creative mental process, focusing on developing a pleasant atmosphere and gathering data concerning the visual and olfactory elements influencing their choices.

The physical experience of a pleasant atmosphere is a well-defined process: it starts from sensory perception, moves to the activation of immediate sensations, is filtered through cognitive associations, and is finally recorded emotionally. When investigated in reverse, the process lends itself to reflections on the sensory forces that lead to the imaginative reconstruction of the pleasant atmosphere we would like to reach. The experiment aimed to explore this reverse process, where imagination, slightly stimulated by external inputs, reaches the elaboration of an atmosphere that involves the tested people both sensorially and emotionally.

Participants were asked to mentally elaborate on a pleasant and appealing landscape in black and white. Then they were asked to complete their mental image by introducing visual and olfactory elements inspired by five groups of artworks and five perfumes. The artworks proposed were selected by color groups: warm, cool, dark, vibrant, and desaturated hues. The essential oils proposed were melissa, neroli, cedar, cinnamon, and cloves, representing the herbal, citrus, woody, and spicy fragrance families.

Among visual and olfactory inputs, participants were asked to identify the sensory force that helped them to elaborate on the pleasant image. Fifty-two percent of the respondents identified color as the primary activating element, compared with 17% who identified the olfactory experience as the driving force. Meanwhile, 30% of the respondents simultaneously elaborated on an image using colors, shapes, and olfactory suggestions. When scent was the primary driver, the atmosphere was more specifically associated with a particular geographical location or a familiar lived experience, confirming the vital link between odors and memory. Neroli was the scent most associated with a feeling of pleasantness at the olfactory level, followed by cinnamon. At the visual level, warm and cool colors, mainly vivid ones, were chosen equally. A few participants identified a sense of pleasantness in dark colors.

The sensations associated with the landscape, once completed with colors and scents, were cheerfulness, warmth, rest, darkness, serenity, security, joy, energy, freedom, boundlessness, purity, fullness, relaxation, sweetness, hope, change, wildness, peace, sensorial heaviness, tranquility, softness, love, nostalgia, changeability, silence, and freshness.

In conclusion, the results of this experiment provide insights into the mental process involved in actively conceiving a pleasant fantasy atmosphere, as opposed to the more usual passive reaction of experiencing an atmosphere and perceiving it as pleasant. The experiment demonstrated the predominance of visual inputs on nonvisual stimuli in elaborating a pleasant panorama, although multisensorial integration was also important to better compose an engaging image. The wide range of colors identified by the participants indicates that no colors are universally conceived as pleasant, as people are influenced by their histories and visual sensitivities when making their choices. Different situations for smells are more uniformly categorized by the sample as pleasant, probably due to cultural origin.

Findings

This research delves deeply into the relationship between colors and odors, highlighting several key findings. In the first experiment, it was observed that olfactory memories are typically older than visual ones, and individuals often associate multiple colors with specific smells, indicating a complex relationship between these senses in memory formation. The study on color-dependent fragrance purity revealed that people's judgments about the purity of fragrances are influenced by the color they associate with those scents, suggesting a solid interplay between visual cues and olfactory perception.

Neurologically, the research found that matching color and smell stimuli could enhance cognitive performance, indicating a potential application in cognitive enhancement strategies. However, the effect of color intensity on the perceived intensity of scent showed mixed results, suggesting that this relationship could be more straightforward and might depend on other variables.

Finally, the study exploring the mental processing of a pleasant atmosphere highlighted that although visual elements dominate perceptions, olfactory elements also significantly contribute to creating an evocative and emotionally resonant atmosphere. This underscores the importance of both visual and olfactory elements in designing experiences and environments.

Overall, this research not only unveils the intricate relationship between color and scent but also offers valuable insights into various design fields. By incorporating these findings, designers can create multisensory experiences that go beyond aesthetics. Strategic use of color and scent combinations can enhance cognitive function in educational settings, elevate product perception through packaging design, and influence emotional responses and memory formation in interior design. This paves the way for the development of multisensory design principles that contribute to a more engaging and impactful user experience.

Conclusion

The article explores the intricate relationship between colors and odors through five experiments. These experiments include analyzing visual and olfactory memory duration, the influence of color on perceived fragrance purity, neurological connections between colors and smells, the effect of color intensity on scent perception, and the role of visual and olfactory elements in creating pleasant atmospheres. Key findings indicate that visual memories often outlast olfactory ones, color can influence scent perception, and a match between color and scent enhances cognitive performance. In addition, the study reveals that colors dominate emotional responses, whereas scents are significantly tied to memories and comfort. Integrating sensory cues in mental processes highlights the complexity of human experiences related to environmental stimuli.