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Enhancing the Eating Experience of Anosmic Patients through AR Games

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Abstract:
Olfaction is one of the essential ways humans perceive the world, influencing not only our gustatory experiences but also playing a crucial role in emotional and memory formation. Anosmia, or the loss of the sense of smell, can lead to a diminished awareness of one's surroundings, significantly increasing the risks in daily life. Unlike traditional olfactory training methods, this paper explores the use of Augmented Reality (AR) technology to provide a more immersive and personalized experience by visualizing odor molecules through a designed AR-based virtual game. The study aims to investigate effective approaches for enhancing the eating experience of patients with anosmia using AR technology. This multi-sensory approach intends to rebuild patients' cognition of smells and rekindle their interest in food, thereby alleviating psychological stress. The experimental results are obtained using a quantitative method to test various metrics during the sensory compensation process through AR games, with data being recorded and analyzed.

Keywords: Anosmia; AR technology; multi-sensory perception; Odor molecule visualization

1. Introduction

Anosmia is a common yet often overlooked olfactory disorder, where patients cannot perceive smells normally. This condition may be temporary or permanent and can severely impact the quality of life. A study from the UK shows that 43% of anosmic patients report symptoms of depression, 45% experience anxiety, up to 92% face difficulties while eating, 57% feel socially isolated, and 54% report interpersonal communication issues. Furthermore, the risks of depression and anxiety are significantly higher in anosmic patients compared to the general population. Therefore, the effects of anosmia on eating behavior, mental health, and social interaction are destructive and harmful, severely impairing patients' social functioning and quality of life [1].

Traditional treatments mainly include medication, surgical intervention, and olfactory training, but these methods are limited in effectiveness and do not apply to all patients. In recent years, with the maturation of AR technology, it has been applied in various fields such as medical rehabilitation, education, and entertainment. AR builds an interactive channel between the real and virtual worlds, providing new ways for humans to understand, interpret, and change the world [1]. Anosmia, as a sensory functional deafness disorder, essentially involves obstacles and defects in

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the central nervous system's ability to establish a connection between olfaction and the environment. AR technology's superior features can compensate for this shortcoming [2].

Based on this, this paper constructs a new channel for anosmic patients to indirectly perceive olfactory experiences using AR technology. By combining visualized games and multi-sensory perception, the olfactory-sensitive signals are simulated, constructed, interpreted, and analyzed. This helps anosmic patients compensate for the loss of smell through visual, auditory, and tactile senses, providing an effective tool to enhance the realism and richness of their eating experience, thereby improving their sense of well-being.

2. Solution Design

2.1 Background Research and Potential Applications

Based on the personalized characteristics of anosmia, through mechanism studies and literature analysis, it was found that multi-sensory stimulation holds great potential in compensating for the loss of smell. Multi-sensory integration, as a fundamental mechanism of human perception, allows other senses to partially compensate when one sense is impaired. By overlaying virtual reality and augmented reality technology, these multi-sensory signals can be integrated and mapped into specific visual symbols, effectively helping anosmic patients re-establish their cognition of smells and perceive food through visualization. Further research reveals that color psychology can provide synesthetic effects, and the distinction between warm and cool tones correlates with taste and smell, creating pathways for olfactory reconstruction using the visual impact of colors and shapes to stimulate gustatory and olfactory associations.

2.2 Color Psychology

In design, color is the soul of emotional expression. Rich colors attract attention, convey emotional needs, and act as a crucial medium for communication in design. Different colors evoke different sensations, stimulating visual perception and achieving design intent [3].

The synesthetic relationship between color, smell, and taste is a widely studied physiological phenomenon. The human brain sometimes links stimuli from different senses, creating a "synesthetic" experience. Certain colors can trigger sensations related to smell and taste [4].

The warm or cool properties of colors can be linked to taste. For instance, green is often associated with freshness and nature, linked to refreshing flavors. Yellow is commonly associated with sour foods like lemons, with sourness connected to orange and yellow. Similarly, yellow-green may evoke astringency, as many unripe fruits present this color, which is often linked to a sour, astringent taste. Pink is often associated with sweetness, stemming from associations with desserts like strawberries and cherry blossom candies, which often feature pink as a dominant color. Thus, when people see pink, they naturally associate it with sweetness. Additionally, brown tends to evoke bitterness. Bitter foods like coffee, chocolate, and tea are typically brown, creating a psychological connection between this color and bitter taste.

This synesthetic relationship between color and taste/smell not only influences food perception but also plays a vital role in commercial design, advertising, and brand packaging. Designers can utilize color-induced sensory associations to better attract consumers and enhance product experience. By combining color with taste and smell, designers can effectively influence emotions and behavior (Fig.1).

Fig. 1 Gustatory Color Card (Photo/Picture credit : Original)

2.2 Solution Overview

The core of this research is the design of an augmented reality (AR)-based game prototype. The overall solution focuses on food recognition and prototype design. The purpose of food recognition is to associate food with visual symbols, laying the foundation for visual association. Prototype design, on the other hand, achieves the interaction between visual input and environmental feedback. By using environmental changes to provide input for visual interpretation of olfactory information, the system supports decision-making for anosmic patients in identifying olfactory signals through the matching of information and visual symbols.

2.3 Food Recognition Process

The key steps in food recognition include target detection and analysis, signal identification and matching, and the generation of AR system symbols. The specific process is outlined in the food recognition flowchart, with the key steps explained as follows (Fig.2):

Image Capture: The user places real food in a designated recognition area, where the AR device captures the image of the food using a camera. The captured image includes the shape, color, and other visual characteristics of the food.

Image Processing and Mark Recognition: The captured image is processed using the YOLOv5 model for target detection [5]. Then, based on deep neural network image processing algorithms, the target food is analyzed, identifying visual markers within the image. These markers may include predefined AR markers, QR codes, or other specific visual symbols corresponding to the food information stored in the system database.

Food Database Matching: The recognized markers are then matched with the food database, which contains detailed information about various foods, including nutritional content, smell description, taste characteristics, and more. Through matching, the system can determine the type of food and its related information.

Generation of Virtual Visual Symbols: Based on the identified food information, the system generates corresponding visual symbols in the AR environment. For example, the system may generate specific colors, shapes, or patterns to represent the food's smell and taste. These symbols are displayed within the user's field of view, appearing alongside the real food, helping the user perceive the food's gustatory and olfactory characteristics through visual cues.

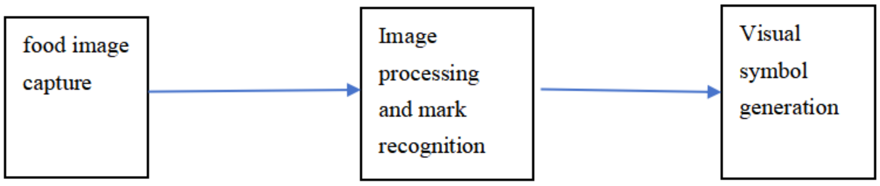

Fig. 2 Food identification and symbols generated (Photo/Picture credit : Original)

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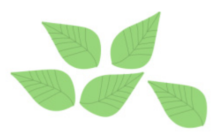
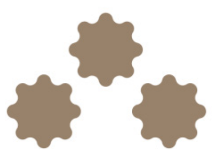
2.4 Prototype Design

The prototype design consists of three main components: the visualization of scent molecules, user interaction methods, and the feedback mechanism for environmental changes. Scent molecules will appear as interactive models within the user's field of view. Players interact with these molecules using hand gestures, such as reaching out to grab, pinching, or waving. Upon grasping a scent molecule, the virtual environment will respond by changing the background, simulating sensory attributes of different foods. Additionally, when the user touches the AR sandbox with the captured scent molecule, the environment within the sandbox will also change. These changes are designed to help users create visual associations with various smells, enhancing their sensory perception through a more immersive experience.

2.4.1 Visual analysis of odor molecules

Patients with anosmia are unable to perceive the aroma of food through their sense of smell, but this deficiency can be compensated by other senses. In the design, this paper associates some common scents with specific visual patterns. These symbols are used to represent different olfactory characteristics through visual forms (Table 1).

Table 1.Scents and Symbols

□	Neutral scent	Sour	The fresh fragrance of herbs and plants.	A faint, salty scent like seawater.
Sign	white square	orange square	leaf-like	blue raindrop shape
Pattern				
Analyze	White is often considered a symbol of purity and odorlessness, and the square's simple, regular shape conveys a neutral, non-irritating feeling, similar to the odorlessness of water or air.	Orange is a lively and energetic color, and the square shape conveys the intense sensation of sourness, reminiscent of citrus fruits or the sourness of vinegar.	The leaf-like symbol visually expresses the scent of nature and plants, conveying a vibrant, natural aroma, such as the smell of lavender or grass.	The blue raindrop-shaped symbol symbolizes the ocean, freshness and salty atmosphere, while the raindrop shape conveys a fresh, cool atmosphere, such as sea breeze or coastal air.
Movement state	The white square floats slowly and smoothly, expressing its bland, featureless odor.	The orange square can move at a brisk pace or occasionally bounce, representing the stimulation brought by a sour taste.	The leaf-shaped symbol can gently sway, simulating the natural growth of plants and the effect of rustling in the wind.	The blue raindrop-shaped symbol can slowly fall or gently float, simulating the tranquility and freshness of the ocean.
Scent	Sweet fragrance.	Rich, spicy aroma.	Bitter scent.	
Sign	Pink heart.	Flame.	The brown ball with synapses.	
Pattern				

Analyze	The pink heart represents the soft and warm sweetness. The shape of the heart strengthens this pleasant and warm feeling, and is easily reminiscent of sweet smells such as candy, flowers, honey, etc.	The red or orange-red flame shape gives people a hot and energetic feeling, directly conveying the pungent and strong smell of spicy food such as chili, ginger, and pepper.	Brown often symbolizes thick, bitter taste, and the shape of the synaptic globule conveys a complex, rich and persistent flavor, such as the bitterness of coffee, cocoa, or herbs.	
Movement state	Pink hearts can beat gently or slowly expand, expressing a warm, soft sweetness	The flame symbol can flash quickly and have a random beating effect, showing the excitement brought by spicy food.	The small brown balls can move heavily and slowly, showing the depth and depth of the bitter taste.	

In the game, players can grab these odor molecules through visual and tactile interactions, and each odor molecule carries a corresponding taste pattern. Players grab and use these molecules to change the color, shape and state of the virtual island, simulating the olfactory sensory experience of actually eating.

2.4.2 User interaction methods

The core of visual association is that users need to be able to interact with gas molecules. Through three basic actions such as grabbing, pinching, and waving, it can not only achieve benign interaction between users and gas analysis, but also provide odor perception. For effective reference, the specific interaction method is as follows (Fig.3):

Fig. 3 User flow (Photo/Picture credit : Original)

Hand Grabbing: Users can select odor molecules by reaching out and grabbing them. This natural action enhances user immersion. After grabbing, the odor molecules will emit light or vibrations to indicate a successful capture.

Pinch Operation: Users can control the intensity or concentration of odor molecules by pinching them. For example, pinching a white square (mild scent) can reduce the color contrast of the virtual environment, while pinching a pink heart (sweet scent) can increase the warmth of the background.

Swiping Operation: Swiping the hand can disperse or change the position of odor molecules, spreading them across different areas of the virtual environment. This interaction not only adds to the game's fun but also helps users intuitively perceive the diffusion of odors in space.

It can be seen that similar to human behavior in perceiving gases, "grabbing" allows for precise selection of gas molecules, identifying the preferred target. "Pinching" provides a deeper sensory experience of the odor by controlling its intensity or concentration. Swiping changes the

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concentration of gas molecules in space, aiding in accurate identification.

2.4.3 Feedback mechanisms for environmental change

In this game, each odor molecule corresponds to a specific interactive mechanism, which induces changes on the virtual island. A bland smell symbolizes a lack of stimulation or neutrality, reflected in the island transforming into a barren rocky terrain, symbolizing an environment devoid of richness or vitality, much like the sensation of blandness in olfaction. Sourness activates the island, filling it with vibrant orange gold nuggets, reflecting the sharp and invigorating sensation associated with sour flavors, evoking the intensity and refreshing quality of sour tastes. Herbal or plant-based aromas turn the island into a lush green forest, symbolizing freshness and natural vitality, conveying the calm and refreshing qualities of herbal and plant-based scents (Fig.4).

The salty smell of the ocean transforms the island into a tranquil beach environment, highlighting the fresh and purifying nature of this scent. Sweetness turns the island into a pink, soft landscape, reflecting the pleasure, comfort, and delightful characteristics of sweetness, similar to the warm feelings evoked by sweet foods. Spicy aromas transform the island into an erupting volcanic terrain, directly conveying the intensity and heat of spiciness, symbolizing energy and stimulation.

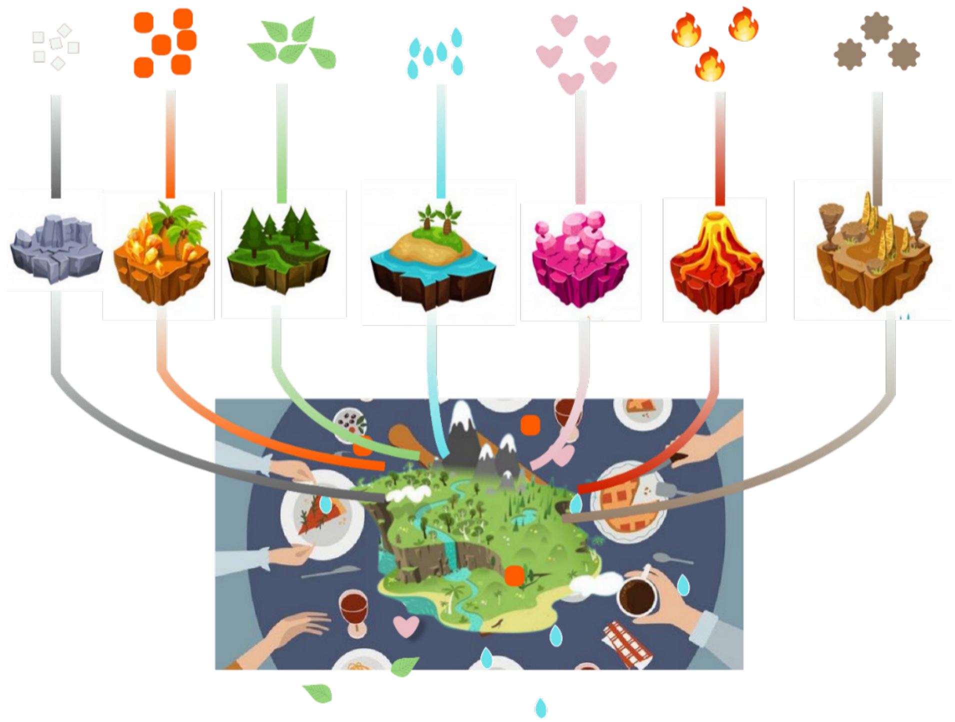

Fig. 4 Smell and the corresponding VR environment (Photo/Picture credit : Original)

3. Test

This study involved 29 participants, including 14 male and 15 female individuals with anosmia, who completed the game independently. The participants followed the gameplay flow for odor recognition and perception while being recorded to capture detailed data. Afterward, they completed subjective evaluations of the system. The experiment was conducted in a controlled environment to minimize external factors and maintain data accuracy.

Table 2. Records of participants' performance

Score Range	Interaction Level (Description)	Number of Participants	Accuracy of Odor Recognition (%)	Response Time (Seconds)	Error Rate (Mistakes per Game)
(90, 100]	Highly Interactive: Strong engagement, frequent use of AR features, accurate recognition	5	95	5	0

(80, 90]	Very Interactive: Consistent interaction, good understanding of visual-odor connections	4	90	8	1
(70, 80]	Moderately Interactive: Adequate use of AR features, some difficulty in recognition	6	85	12	1,2
(60, 70]	Somewhat Interactive: Partial use of game mechanics, occasional misidentification	5	75	15	1, 2
(50, 60]	Minimally Interactive: Limited engagement, difficulty connecting visual cues to odors	2	65	18	2,3,4
(40, 50]	Low Interaction: Infrequent use of AR tools, struggled with identification	3	55	22	5,6
(30, 40]	Poor Interaction: Limited interaction, significant challenges in perception	2	45	25	5,6
(20, 30]	Very Poor Interaction: Difficulty using the system, frequent errors	1	35	30	7,8
(10, 20]	Barely Interactive: Minimal engagement, struggled with recognition	1	25	35	10
	No Interaction: Did not effectively interact with the system	1	10	40	12

3.1 Usability Testing and Key Metrics

This paper conducted a usability test focusing on three aspects: responsiveness, error tolerance, and feedback. Responsiveness and feedback were quantified by recording response times and feedback consistency, while error tolerance was measured by the number of odor recognition errors.

Participants' interactions were scored based on their engagement with the game. Scores were distributed across 10 interaction levels, as shown in Table 2. The levels ranged from highly interactive, with strong engagement and accurate recognition of odors, to barely interactive, where users struggled to perceive and connect odors with visual cues.

The usability testing revealed the following:

Higher Interaction Levels: Participants in the higher interaction levels (e.g., 90–100, 80–90 ranges) demonstrated more accurate odor recognition, faster response times, and fewer errors. Their strong engagement with the system facilitated precise control of the AR environment. Moderate Interaction Levels: Participants who scored in the 70–80 and 60–70 ranges engaged with the system but faced some difficulties in recognizing odors, leading to slightly lower accuracy and slower response times. Lower Interaction Levels: Participants in the 50–60 range and below encountered significant challenges. They exhibited lower accuracy in odor recognition, slower response times, and higher error rates, indicating a lack of engagement and difficulty using the system effectively.

3.2 Analysis of Results

The analysis of the interaction data reveals a strong positive correlation between the level of interaction with the AR game and the accuracy of odor recognition. Participants who engaged more frequently with the system demonstrated higher accuracy in identifying odors, as well as providing feedback that aligned with the intended visual-odor connections. This suggests that the AR-based game successfully enhances sensory compensation by immersing users in a highly interactive environment, where the visual representation of odors fosters better perception and recognition.

The innovative aspect of this study lies in the use of AR as a tool to visualize odor molecules, making odor recognition a more intuitive and engaging experience. Unlike traditional methods of olfactory training, where individuals

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passively sniff various scents, the AR game introduces an interactive, multi-sensory approach that promotes active participation. The study's findings reinforce the hypothesis that engagement and interaction are critical to the success of sensory compensation for anosmia. Higher interaction levels led to increased accuracy and quicker response times, suggesting that immersion in the AR environment improves the cognitive association between visual and olfactory cues.

For participants with lower interaction levels, the data indicates a clear struggle in recognizing odors, likely due to reduced engagement and a lack of connection between visual cues and odor perception. These findings suggest that while AR technology is effective in enhancing sensory compensation, its success is largely dependent on user engagement. The more immersive and interactive the experience, the more likely patients are to rebuild their olfactory cognition.

4. Conclusion

This study presents a novel approach to sensory compensation for anosmia patients through an AR-based game. By utilizing visual-odor associations, the game translates odor signals into visual cues, allowing patients to reconstruct their perception of smell and enhance their eating experience. The game features food target detection, gas molecule visualization, and interactive feedback, all designed to create an immersive, multi-sensory experience for users. The results indicate that high levels of interaction significantly improve the effectiveness of sensory compensation. Participants who were more engaged with the game demonstrated better recognition of odor cues, faster response times, and fewer mistakes. This suggests that interaction quality is crucial to maximizing the benefits of the AR system for anosmia patients.

In the future, this AR-based sensory compensation model can be expanded to incorporate more complex interactive models and combined with other technologies such as virtual reality and artificial intelligence. Such advancements could provide further applications in psychological health support, education for sensory impairments, and even commercial uses in food, perfume marketing, and product personalization.

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