BubblEat: Designing a Bubble-Based Olfactory Delivery for Retronasal Smell in Every Spoonful

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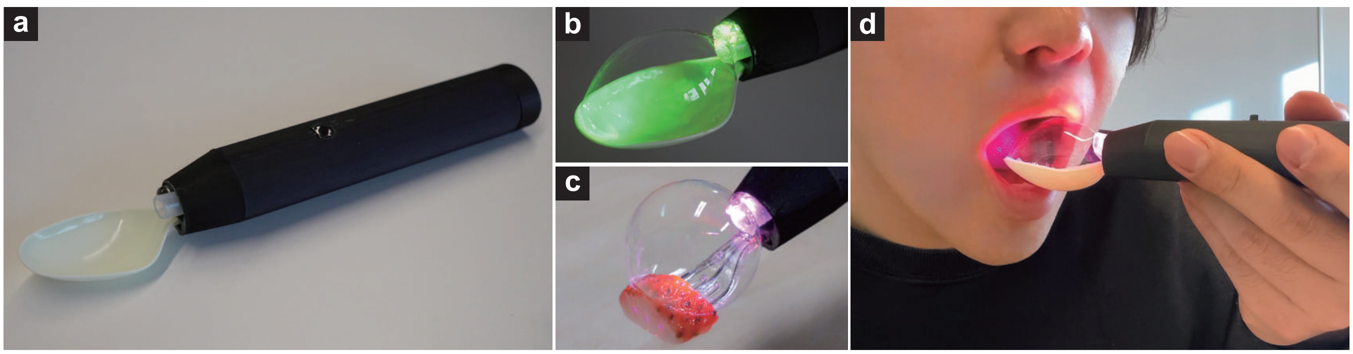

Figure 1: The prototype of BubblEat - (a) Overview of BubblEat, a cutlery-type device for intraoral aroma delivery. (b) The device generates scented bubbles and alters the color of food using RGB lighting, leveraging the effect of color in enhancing aroma perception and helping users recognize the intended scent. (c) A fork is used to apply a scented bubble to a strawberry, for example, introducing a milk scent to create a strawberry-milk flavor experience. (d) Users can use it like regular cutlery, and the bursting of scented bubbles inside the mouth modifies the perceived taste.

Abstract

Traditional olfactory delivery methods, such as airflow, vaporization, heating, and atomization, struggle to effectively deliver retronasal smell during eating. This study introduces *BubblEat*, a cutlery device that places aroma-infused bubbles on a spoon, releasing scents upon bursting in the mouth to enhance retronasal olfactory perception. To optimize bubble-based aroma delivery, we examined liquid viscosity, key factors influencing stability and aroma release. Based on these findings, we developed a *BubblEat* prototype with a bubble generation mechanism capable of delivering stable, user-friendly aroma-infused bubbles. We designed *BubblEat* to achieve enhancing dining experiences by effectively presenting retronasal smells. This study demonstrates the feasibility of bubble-based aroma delivery, complementing orthonasal smell and opening new avenues for sensory-enhanced dining.

CCS Concepts

• **Human-centered computing → Interaction devices**; **Human computer interaction (HCI)**.

Keywords

Olfactory device, Interactive device, Retronasal smell, Internet of things, Tasting change

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1 Introduction

Eating is more than a mere act of nutrient intake, it plays a crucial role in providing psychological comfort and fostering cultural and social engagement [6, 9, 28]. Among the various sensory aspects of eating, aroma is closely linked to flavor perception and significantly influences dining satisfaction [15, 31, 36]. In particular, retronasal smell is perceived when food and beverages pass through the oral cavity, plays a central role in taste experiences. Effective methods for presenting retronasal smell could elevate eating experiences to a new dimension [32].

Recent research has explored retronasal smell presentation during beverage consumption [19, 20]. However, conventional aroma delivery techniques primarily rely on nasal delivery using air pressure, heating, or atomization [37]. Despite the significant impact of retronasal smell on the dining experience, HCI research has largely focused on orthonasal smell (the direct perception of scents through the nose), leaving retronasal smell relatively underexplored. Addressing this gap is crucial for enriching dining experiences through HCI research.

Presenting retronasal smell during meals remains a challenging task, as eating involves complex interactions of chewing, swallowing, and breathing, all of which influence how aromas are transported and perceived. These dynamic processes make it difficult to consistently deliver scents to the nasal cavity at the right moment and with sufficient intensity. In preliminary tests, we experimented with a straightforward approach of delivering scents directly to the oral cavity. However, the scent dissipated too quickly, making it less effective in reaching the inside of the mouth. This underscores the need for improving the sealing mechanism to enhance the delivery process. To address this challenge, we propose *BubblEat*, a novel aroma delivery device that utilizes bubbles to enhance retronasal scent presentation. These bubbles encapsulate aromatic gases and release them upon bursting inside the mouth, effectively delivering scents to the nasal cavity. Beyond olfactory stimulation, the visual appeal of the bubbles contributes to a multisensory dining experience, enabling flavor enhancement beyond conventional methods.

This paper introduces the *BubblEat* prototype, evaluating aroma release reliability. The findings demonstrate not only improvements in dining experiences but also the potential of olfactory technology in multisensory interaction design. Our research contributes to advancements in sensory technology within the Human-Food Interaction (HFI) field, offering new directions for research aimed at addressing dietary issues such as excessive salt and sugar intake.

Our research makes the following contributions:

- We designed and developed *BubblEat*, a cutlery-type device that enables retronasal smell presentation during meals—an approach that conventional aroma delivery technologies have struggled to achieve. The device generates bubbles containing aromatic compounds, which burst inside the mouth, effectively releasing aroma and creating an unique eating experience.
- *BubblEat* enhances eating experiences by simultaneously stimulating olfactory and visual senses through bubble generation. The design leverages the synergy between smell and sight, offering a novel sensory dimension beyond conventional dining experiences.
- Our research establishes a foundation for multisensory interaction design centered on olfaction, providing a new direction for enhancing the quality of eating experiences. Furthermore, it has potential applications in healthcare and entertainment, expanding research and practical opportunities within the HFI domain.

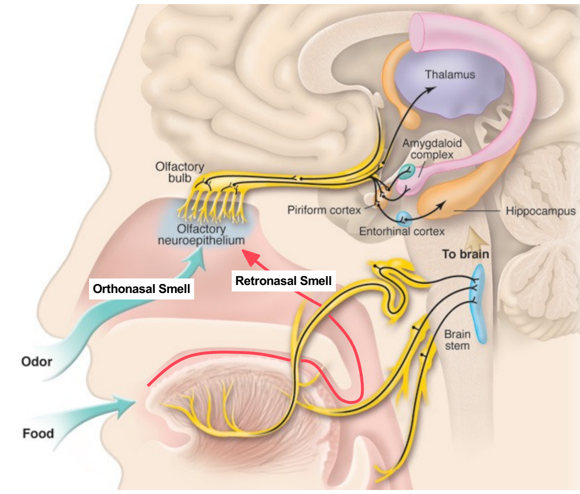

Figure 2: Olfactory mechanisms and the two nasal pathways represented as arrows [4]

2 Related Work

2.1 Mechanism of the Human Sense of Smell

First, we explain the structure of the human nasal pathway. Figure 2 illustrates the olfactory system and its two nasal pathways. Human olfaction consists of two distinct pathways: orthonasal smell and retronasal smell. Orthonasal smell refers to the direct perception of aromas from external sources through the nasal cavity, while retronasal smell occurs when the aroma of food and beverages travels from the oral cavity to the nasal passage. Notably, retronasal smell plays a crucial role in flavor perception [2, 7, 34]. In particular, it has been shown to be a key factor in shaping the flavor of food and beverages [32]. While the term "olfaction" is often associated with orthonasal smell, retronasal smell is equally essential for enhancing taste perception and enriching eating and drinking experiences.

2.2 Olfactory Device Research

Several studies have explored the use of olfactory devices for enhancing sensory experiences. Wearable head-mounted displays that deliver scents have been developed [26, 40], along with compact olfactory devices designed for everyday use [1, 5, 39]. Research has also investigated the application of olfactory devices in eating and drinking experiences. Narumi et al. [27] proposed a system that alters visual and olfactory cues using augmented reality (AR) to modify taste perception without changing the actual composition of food. Ranasinghe et al. [29] developed a device that integrates electrical stimulation, scent, and visual effects to enhance virtual beverage experiences in AR and VR environments, examining the impact of each stimulus on taste perception. Further, studies such as Aromug [17, 18] and Kaolid [19, 20] have explored how orthonasal and retronasal smell presentation can enhance the perceived sweetness of beverages. However, these studies have been limited to drinking experiences, and effective methods for delivering retronasal smell during eating have not been sufficiently explored.

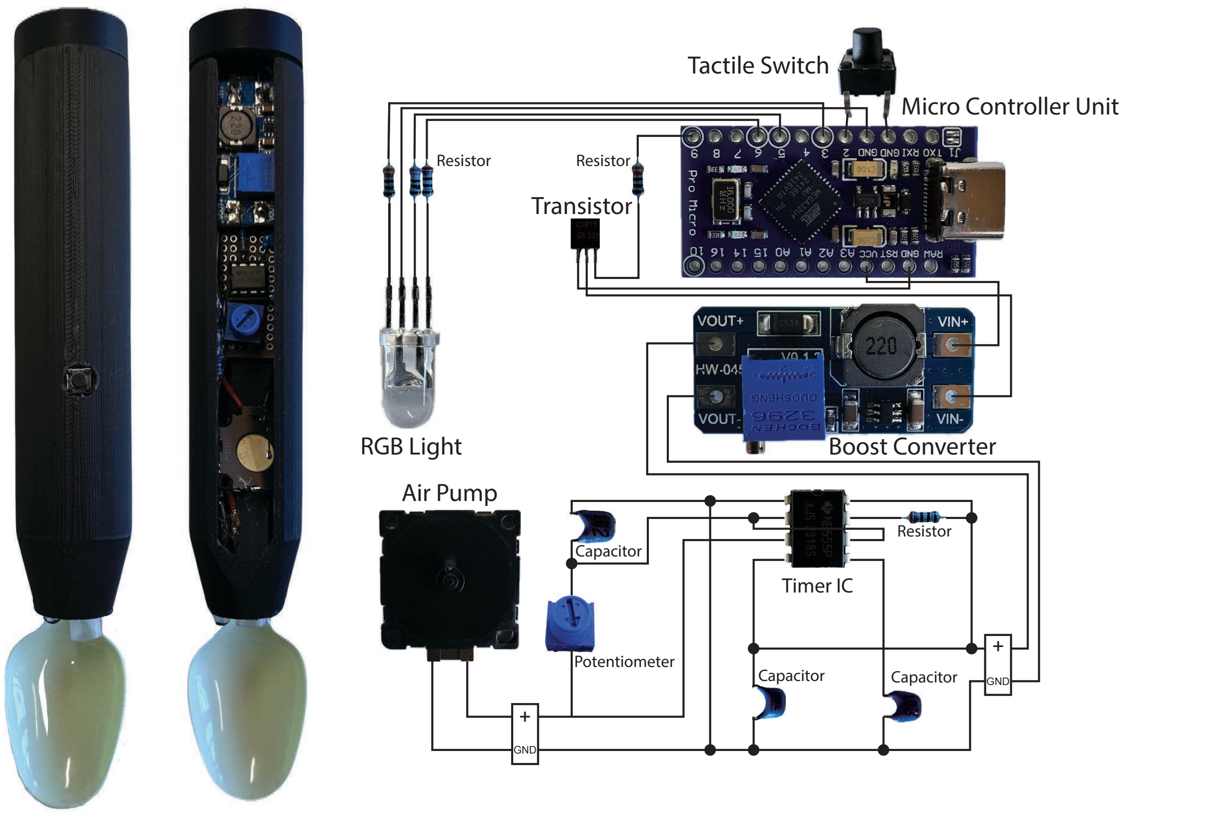

Figure 3: This is the system configuration of BubblEat. The left side illustrates the external design of the device, which was fabricated using a 3D printer. The right side presents the circuit diagram of the system.

2.3 Interaction Design for Food Experience

In the field of Human-Computer Interaction (HCI), various interaction designs have been explored to enhance taste perception and eating behavior. Regarding taste augmentation, research has investigated electrogustometry to enhance saltiness perception [21–23] and electrical stimulation of taste receptors to induce different taste sensations [11, 29, 30]. To modify the visual perception of food, systems have been proposed to manipulate portion size perception through visual augmentation to control satiety [25, 38], as well as projection mapping on food to alter the dining environment [13, 33]. Furthermore, behavioral intervention devices have been developed to promote healthy eating habits [10, 12, 14, 24, 41]. Furthermore, a device called a smoke bubble gun generates bubbles containing aromatic scents as a presentation effect before drinking a cocktail. The smoke bubble gun enhances the dining experience and demonstrates the validity of enclosing aromas within bubbles. This concept served as one inspiration for our approach. Our goal is to present retronasal smell that enhance the taste of food by creating small, cutlery-sized bubbles containing scents.

Previous studies have explored the development of olfactory devices and various approaches to taste augmentation. However, challenges remain in developing effective methods for delivering retronasal smell during food consumption. This study proposes a novel interaction design that enhances taste experiences by generating bubbles on cutlery, using both visual and olfactory stimuli. In this paper, we present the design and implementation of *BubblEat*, a prototype device capable of delivering retronasal smell. Additionally, we report findings on the optimal viscosity of bubble solutions to ensure stable bubble formation during aroma presentation.

3 Prototyping BubblEat: Interactive Cutlery for Presenting Retronasal Smell

This study proposes *BubblEat*, an interactive cutlery-type device that introduces a novel method for presenting retronasal smell using bubbles. The device generates scented bubbles on a spoon, which burst inside the mouth to deliver retronasal smell. Additionally, it incorporates RGB lighting to alter the color of food, creating an interactive experience that enhances the user's taste perception.

3.1 Hardware Design

BubblEat is designed to enhance taste experiences by integrating visual and olfactory interactions. This section describes its hardware components. *BubblEat* consists of the following key components (Figure 3):

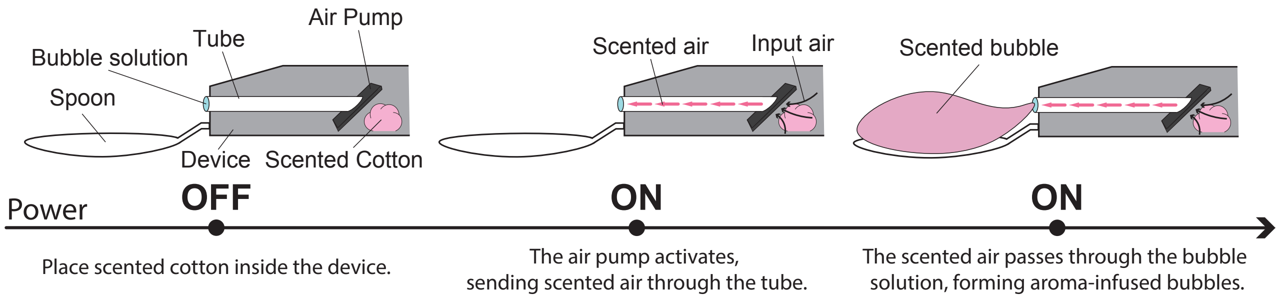

Figure 4: The mechanism of scented bubble generation.

- Air pump: Supplies air to generate bubbles. The pump delivers air through a tube to the bubble solution at the tip, forming scented bubbles.
- RGB lighting: Adds visual effects by illuminating the bubbles with color, altering the perceived impression of food through visual stimuli.
- Microcontroller: Controls the entire device, managing button operations, the air pump, and RGB lighting.
- Olfactory device control circuit: Includes a voltage booster to drive the air pump. The microcontroller activates the voltage booster by the input of a tactile switch.
- Enclosure design: The internal circuitry is housed in a 3D-printed casing sized like standard cutlery, with a slot for attaching a regular spoon, ensuring everyday usability.

The device is designed to be easily attachable to existing cutlery, maintaining a compact and lightweight form factor for everyday use. By aligning its size with standard cutlery, *BubblEat* eliminates the need for additional equipment, allowing seamless integration into daily eating environments.

3.2 Bubble Generation Mechanism

The core functionality of *BubblEat* is to provide visual and olfactory stimulation through bubble generation, enhancing the taste experience. This section details two key aspects of the bubble generation process: foam liquid composition and the integration of the olfactory device with the RGB lighting.

3.2.1 Foam Liquid for Bubble Generation. The foundation of the bubble generation mechanism consists of an air pump-connected tube and a specially formulated foam liquid. The tube tip is dipped into the bubble solution to coat it with the solution. At the tip of the tube, a thin layer of foam liquid is maintained, which expands into an uniform bubble when air is supplied by the pump. In this prototype device, the bubble solution was manually applied to the tube tip. In the future, we aim to implement an automatic mechanism that dispenses the bubble solution from an integrated tank within the device. The foam liquid is optimized to ensure stable bubble formation. The tip of the tube has a micro-textured surface, allowing the foam liquid to adhere securely and expand without premature rupture due to air pressure. To maintain bubble stability, the liquid contains food-safe ingredients, including glycerin, which helps adjust its viscosity. Since the foam liquid meets food safety standards, the device can be used safely in everyday dining situations, ensuring a comfortable and reliable user experience.

3.2.2 Olfactory Device and RGB Light. The olfactory device and RGB lighting play a crucial role in stimulating both smell and vision through bubble generation, enhancing the overall dining experience. In this system, the olfactory device infuses the bubbles with aroma during their formation, effectively delivering retronasal smell during eating. As shown in Figure 4, inside the device, a cotton pad infused with aroma oil is placed, allowing air from the air pump to pass through and carry the scent into the bubbles. Users can change the aroma oil to customize the scent according to their preferences, enabling a personalized flavor experience.

The mechanism is designed to effectively trap the aroma within the bubbles as they form, ensuring that the scent is released naturally the moment the bubbles burst inside the mouth. As illustrated in Figure 5, the process consists of three phases. In Phase 1, the user picks up their desired food using the spoon. In Phase 2, they press a button to generate scented bubbles on the spoon. Users can control the size of the bubbles according to their preference. In Phase 3, they bring the food to their mouth, where the bubbles burst, releasing the aroma inside the oral cavity and presenting retronasal smell. This process creates an illusion of taste, allowing the brain to perceive a different flavor profile. Through this sequence, users can experience food flavors from a new perspective.

Moreover, the combination of the olfactory device and RGB lighting does more than provide sensory stimuli—it reshapes the perception of flavor and ingredients. As illustrated in Figure 6, the RGB lighting synchronizes with the olfactory stimuli, not only enriching the user's eating experience but also reinforcing and altering flavor perception through visual cues. In fact, color plays a crucial role in taste perception [3, 8, 16, 35], and this device leverages that effect to help users accurately identify scents. For example, when presenting the scent of strawberries alone, users may not immediately recognize it as such. However, incorporating the color red can enhance recognition, increasing the likelihood that users perceive the scent as that of strawberries. The selected color is reflected in the bubbles, adding a new sensory dimension to the dining experience. This visual enhancement, combined with olfactory stimulation, further shapes taste perception and the overall impression of food. The interaction between vision and smell is a key factor in offering users a novel dining experience. By integrating these sensory interactions, the system enhances the immersive nature of eating, fostering deeper engagement with food.

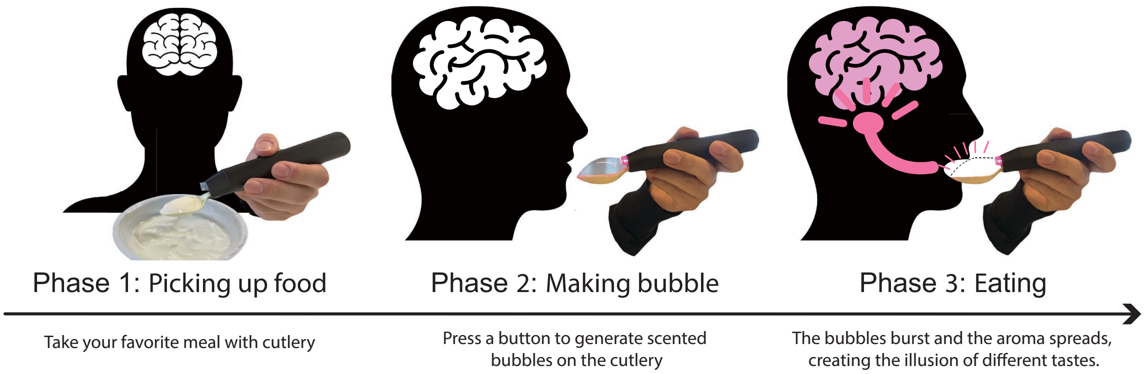

Figure 5: This diagram illustrates how to use BubblEat and the method of presenting retronasal smell.

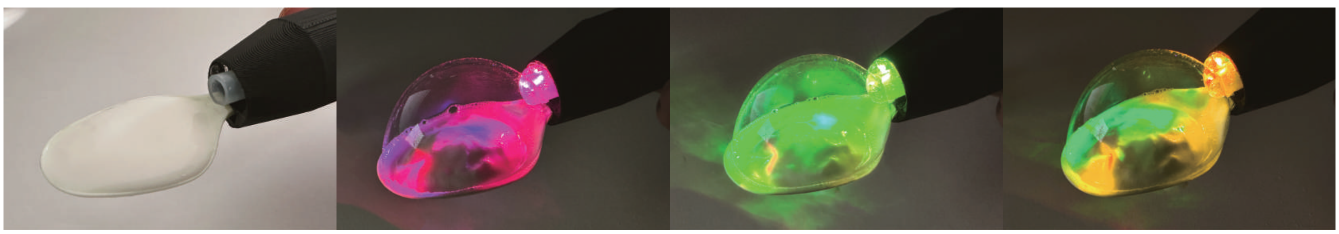

Figure 6: Yogurt is placed on a spoon, and the color of the cutlery and meal changes using RGB light, changing the impression of the meal based on color information.

4 Experiment

This experiment investigates the effect of bubble solution viscosity on the stability of bubbles generated by our device. The goal is to identify the optimal viscosity conditions that ensure stable and long-lasting bubbles, thereby enhancing the consistency of retronasal smell presentation and improving olfactory stimulation.

4.1 Experimental Design

To evaluate how viscosity influences bubble duration and stability, five different bubble solutions were prepared by adding varying amounts of glycerin to a base solution consisting of surfactant and distilled water in a fixed ratio. Glycerin was used as a viscosity modifier to assess bubble characteristics under different viscosity conditions. As the independent variable, glycerin was added in 25g increments to 100g of the base solution, creating five different viscosity levels. Each condition was tested in 10 trials. The evaluation metrics included bubble duration (seconds) and bubble generation success rate (%), both of which were used to assess bubble quality.

4.2 Experimental Procedure

First, the bubble solutions were prepared by mixing glycerin with the base solution at predetermined ratios to create five different viscosity levels. Each bubble solution was then applied to the tip of the tube in a fixed amount, followed by the injection of a controlled airflow to generate bubbles. During the experiment, the input voltage to the air pump was set to 15V, and the air pressure was maintained at approximately 1.6 kPa[1].

[1]https://www.murata.com/en-us/products/mechatronics/fluid/overview/lineup/microblower_mzb1001t02

Table 1: Relationship between foam liquid viscosity and foam generation probability

	Base liquid (100g)	wt. % of Glycerin in Solution			
		25	50	75	100
Probability of success	0%	0%	90%	50%	30%

4.3 Results

The experimental results are shown in Table 1. The findings indicate that bubbles could not be generated using the base solution alone, nor with the addition of 25g glycerin. In contrast, when 50g glycerin was added, bubbles formed successfully in 90% of the trials. This suggests that while surfactant alone lacks sufficient bubble retention capability, an appropriate viscosity level enhances bubble stability. Once generated, the bubbles remained stable for over 60 seconds. When they did burst, it occurred during expansion, preventing precise time measurement. However, when the glycerin concentration exceeded 75g, the success rate decreased, likely due to excessive viscosity hindering bubble formation. These results suggest that the optimal bubble solution composition for *BubblEat* is 50g glycerin, balancing viscosity for consistent bubble generation.

5 Discussion

This study proposed *BubblEat*, a novel aroma delivery device that utilizes bubbles to present retronasal smell during meals. Unlike conventional aroma presentation techniques, which primarily target orthonasal smell, *BubblEat* enables the effective delivery of retronasal smell in dining contexts, potentially influencing the perception of food flavors and taste. Additionally, this study conducted a foundational investigation into the stability of bubble formation, evaluating how viscosity affects bubble durability and generation success rate. The following sections discuss the significance of *BubblEat* and its comparison with existing methods, as well as the role of viscosity analysis within this study.

5.1 Significance of *BubblEat* and Comparison with Existing Methods

BubblEat introduces a novel approach to aroma delivery by utilizing bubbles as a medium, offering an experience distinct from conventional scent presentation methods. Most existing techniques focus on delivering orthonasal smell, while no established device has effectively achieved retronasal smell presentation for taste modulation. In contrast, *BubblEat* integrates retronasal smell into the dining experience by embedding scented bubbles as part of the meal.

Furthermore, the device combines visual elements with olfactory stimulation, leveraging the interaction between smell and sight to enhance the eating experience. The bubbles themselves contribute to the aesthetic appeal of the meal, while the integration of RGB lighting further reinforces the visual impression of food and tableware. This multisensory approach has the potential to alter taste perception and create new forms of interaction distinct from traditional aroma presentation techniques.

5.2 Role of Viscosity Analysis in This Study

Ensuring reliable bubble formation is crucial for maximizing the effectiveness of *BubblEat*. This study examined the relationship between bubble solution viscosity and bubble stability, providing essential baseline data for optimizing the device's performance. The results revealed that excessive viscosity reduces the success rate of bubble formation, while low viscosity leads to rapid bubble collapse. In particular, the bubble solution with 50g of glycerin added to 100g of the base solution was suggested to have the optimal balance. However, this viscosity analysis serves as foundational research for bubble stability rather than the core focus of the study. The primary objective remains to enhance the dining experience through retronasal smell presentation.

6 Limitations and Future Work

This study developed *BubblEat*, a device that presents retronasal smell during meals, establishing a technical foundation for effective retronasal smell delivery. However, several limitations remain, guiding future research directions.

6.1 Impact of Retronasal Smell on Taste Perception

We investigated the design of *BubblEat* and the stability of bubble formation but did not evaluate the impact of olfactory presentation on taste perception. Future research will investigate how BubblEat's retronasal smell influences the dining experience. Specifically, we plan to quantitatively assess how different scents and visual elements affect taste perception, aiming to clarify the interaction between olfaction, vision, and taste.

In this study, we focused on smooth, white foods such as yogurt. However, when using bubbles to deliver retronasal smell by placing them on food, the shape and texture of the food can affect the stability of the bubbles—some surfaces may prevent proper adhesion, while others may cause the bubbles to burst prematurely. Investigating how different food characteristics influence bubble adherence and stability will be essential for broadening the range of applicable food types in future research.

6.2 Enhancing Usability and User Experience

Further improvements are needed in the bubble generation method. This study enhanced bubble stability by adjusting glycerin concentration, but other additives, such as syrup, may further improve bubble longevity. However, increasing the viscosity to create more durable bubbles can also affect the taste of the food. For instance, the addition of syrup introduces sweetness, which may interfere with the intended flavor experience. It is therefore important to select additives, such as gelatin, that enhance bubble strength while minimizing any impact on taste. Additionally, future research should explore approaches that ensure the bubbles are made from safe, health-conscious materials that do not compromise the overall dining experience. Additionally, this prototype device requires manual application of the bubble solution to the tube tip. In the future, we plan to develop an automated mechanism that forms a bubble film at the tube tip using a built-in solution tank. This improvement aims to enhance the device's usability by streamlining bubble formation, reducing user effort, and ensuring consistent quality. Automating this process will make the device more practical and convenient for everyday dining.

Usability-focused research will also be essential in assessing BubblEat's practicality and ease of use. Future work will evaluate the intuitiveness of the bubble generation process, the ease of aroma replacement, and the overall operability of the device to enhance its usability during meals. Furthermore, we will examine user enjoyment, satisfaction, and the perceived novelty, analyzing the synergistic effects of visual and olfactory stimulation on the overall dining experience.

6.3 Future Directions and Applications

Through further research, we aim to clarify how *BubblEat* influences taste perception and food experiences, providing concrete insights for improving the device. In the long run, we will explore its applicability in various dining scenarios, such as restaurants and home settings, considering its potential as a tool for promoting healthier food choices. For instance, we plan to investigate how olfactory stimulation can enhance the perception of low-sugar or reduced-sodium foods, encouraging healthier eating habits without compromising taste. Beyond traditional dining experiences, BubblEat opens new avenues for sensory rehabilitation, culinary education, and experimental gastronomy. It may serve as a tool for individuals with taste or olfactory impairments, helping to restore or enhance their sensory experiences. Additionally, its potential for interactive culinary training could provide new learning methods in food education and professional gastronomy. Furthermore, this research contributes to human-computer interaction (HCI) by expanding the design space of olfactory interfaces. Future work will explore the integration of BubblEat with digital interfaces, adaptive scent delivery systems, and augmented reality (AR)-based dining experiences. These advancements could allow for personalized olfactory interactions, dynamically adjusting scent presentation based on user preferences or specific meal contexts.

BubblEat introduces new possibilities for olfactory-based interaction design, offering a novel approach to enhancing dining experiences. Future research will focus on practical evaluations to validate the real-world effectiveness of retronasal smell presentation, ultimately improving BubblEat's usability and impact while expanding its applications beyond conventional dining.

7 Conclusion

This study proposed *BubblEat*, a novel aroma delivery device that reliably produces bubbles to present retronasal smell during meals, demonstrating its potential to enhance the dining experience. To address the limitations of conventional aroma presentation techniques, we designed and developed a bubble generation mechanism that enables the stable delivery of scented bubbles. The integration of olfactory stimulation into dining experiences, which was challenging with existing technologies, opens new possibilities in the field of Human-Food Interaction, providing a foundation for further research and applications. *BubblEat* introduces a new direction in interaction design centered on olfaction, paving the way for innovations that influence eating experiences and health-related behaviors.

Acknowledgments

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