Kaolid: a Lid-type Olfactory Interface to Present Retronasal Smell towards Beverage Flavor Augmentation

Daiki Mayumi[1], Yugo Nakamura[2], Yuki Matsuda[1], Shinya Misaki[1], Keiichi Yasumoto[1]
[1] Nara Institute of Science and Technology
Ikoma, Nara, Japan
[2] Kyushu University
Fukuoka, Fukuoka, Japan

ABSTRACT

In this paper, we introduce Kaolid, an olfactory interface that uses a lid mechanism to augment the flavor of beverages by delivering scents as retronasal smell. Kaolid aims to promote the consumption of healthier beverages by intensifying their perceived taste through the release of scents during drinking. The system features a compact olfactory display and an IMU sensor, triggering scents in response to drinking movements. It comes in two models: a straw-type for cold beverages and a cup-type for hot drinks. We tested the interface using sparkling and hot water and measured its efficacy in enhancing perceived sweetness when paired with scents. Results showed significant enhancements in all evaluation metrics (taste satisfaction, perceived sweetness, and preference) with the straw-type device. Notably, the perceived sweetness increased by an amount equivalent to about 2.88 grams of sugar when a retronasal smell was introduced compared to when no scent was present. This innovative interface holds promise in elevating the flavor of sugar-free drinks and could support those aiming to limit sugar consumption. Furthermore, this research contributes to the future of IoT systems for health support by harnessing the power of scent, opening avenues for novel approaches in sensory-driven well-being advancements.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**; *Redundancy*; Robotics; • **Networks** → Network reliability.

KEYWORDS

Olfactory device, Drinking activity recognition, Persuasive technology, Internet of things, Tasting change

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1 INTRODUCTION

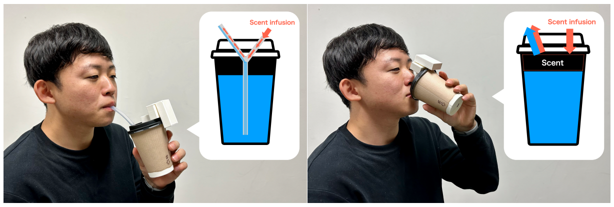
Sugar-sweetened beverages (SSB) have become the primary source of sugar in our diets. In developing countries, rising consumption patterns are linked with urbanization and economic growth, both of which have increased the availability and, consequently, the intake of SSBs [17, 26, 27, 34]. Habitual consumption of SSBs elevates the risk of obesity [12, 19, 30, 31], diabetes [12, 15], heart disease, and other cardiac conditions [18, 36]. Therefore, initiatives to curtail SSB intake are vital.

Various strategies have been suggested to counter these threats and assist individuals in reducing their consumption [14, 32]. These methods might momentarily persuade people to opt for beverages with lower sugar content. However, beverages with little or no sugar often lack appeal. Thus, a brief intervention might not be sustainable, possibly leading to a relapse into the habit of consuming sugary drinks. From a well-being standpoint, it is crucial to seek solutions that gradually decrease sugar content, as drastic reductions can cause emotional distress for individuals [11].

Recognizing that our sense of smell greatly influences our perception of taste [16, 24, 29], previous research has explored an olfactory interface designed to release a sweet scent during beverage consumption, thereby enhancing the perception of sweetness [20]. However, these studies indicate that merely presenting scents from a device is challenging in terms of enhancing taste satisfaction. We detect smells in two primary ways: "orthonasal smell" from the nostrils and "retronasal smell" from the mouth that travels through the nose. Each type of smell is processed differently in the brain [4, 13, 28]. Notably, retronasal smell, which contributes to the flavor of food and beverages, is intrinsically linked to our sense of taste [25]. Thus, our interface was revamped to highlight "retronasal smell," an scent closer linked to flavor.

In this paper, we introduce a lid-type olfactory device named "Kaolid"[1] that alters the taste of beverages by introducing scent information through the retronasal pathway during consumption. The Kaolid is available as both straw and cup-type configurations, each embedded with a compact olfactory device to facilitate retronasal smell detection, as depicted in Figure 1. To encourage water consumption, the Kaolid straw-type is designed for room temperature or cold water, while the cup-type is meant for plain hot water. The straw-type releases the scent into the straw's central tube, delivering it to the user's mouth as they drink. Conversely, the cup-type introduces the scent through the lid, offering an initial burst of scent at the onset of consumption.

[1] Derived from "Kaori," which means smell in Japanese.



(a) Straw-Type Device (b) Cup-Type Device

Figure 1: Overview of Kaolid ((a)Straw-type device, (b)Cup-type device)

This paper outlines the design and implementation of the Kaolid prototype system and presents findings from a study examining the influence of retronasal smell on taste perception.

2 PRELIMINARY AND RESEARCH QUESTIONS

This section outlines the structure of the human nasal pathway and provides an overview of the types of odors humans can detect. We formulate research questions concerning effectively presenting smells that can modify taste.

2.1 Mechanism of the Human Sense of Smell

Figure 2 illustrates the olfactory mechanism and its two nasal pathways. Retronasal smell plays a pivotal role in determining the taste of food and beverages. This mechanism, essential for perceiving flavor, integrates both traditional olfaction and taste. It involves the sensation produced when odor molecules from food or drink travel through the nasal cavity during consumption. While the term "smell" often refers to "orthonasal smell"–the direct perception of odors entering the nose and passing through the nasal cavity–, the retronasal smell is equally vital for experiencing the taste of food and beverages [25].

2.2 Types of Scents Humans Can Detect

When designing an interface to enhance perceived sweetness, it is essential to understand which odors to choose and present. According to Castro et al.[5], 10 foundational categories represent core dimensions of odor perception. Table1 lists typical descriptors for the smells within these categories. For the purpose of our interface, we focused on carbonated and plain water, both non-sugary beverages with potential health benefits, as the primary beverages to augment sweetness. A review of the odor categories suggests that categories C3, C7, and C10 might be effective in boosting perceived sweetness. Based on empirical compatibility with carbonated and hot water, this study opted to introduce the scents of orange from category C10 and pineapple from category C3.

2.3 Research Questions

This study seeks to answer the following research questions:

- **RQ1** Can the introduction of fruity flavors through retronasal smell, using the proposed device's mechanism, enhance the perceived sweetness and overall flavor satisfaction?
- **RQ2** Do different scent categories have different sweetness enhancement effects?

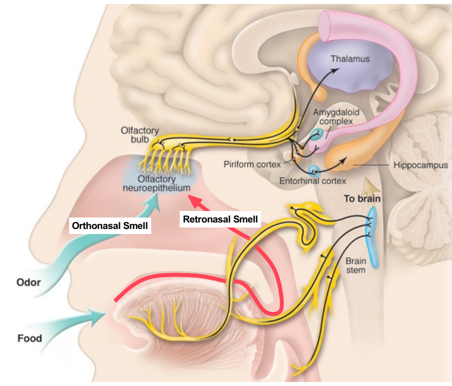


Figure 2: Olfactory mechanisms and two nasal pathways [7]

- **RQ3** How does the perceived sweetness intensity delivered by the proposed device compare to that of a standard sugar-sweetened beverage?

3 RELATED WORK

3.1 Alternatives to SSBs

Artificially sweetened beverages are gaining traction as substitutes to curb SSB intake. Although these beverages are becoming more prevalent in daily consumption, they haven't been notably successful in aiding weight loss. Fowler et al.[10] examined 3,682 adults over 7-8 years in the 1980s and found that increased consumption of artificially sweetened beverages was correlated with higher BMIs. Another study involving 103 adolescents replacing sugar-sweetened beverages with diet alternatives showed no BMI reduction after 25 weeks [9]. One potential reason is that both sugar and artificial sweeteners might stimulate human appetite [3].

100% fruit juice is also being considered as a potential SSB alternative. While often deemed healthy due to their nutrient content, some fruit juices can be as calorie-dense and sugary as SSBs, given the natural sugars present in fruits. Consuming fruit juices has been linked to weight gain [26] and an elevated risk of type 2 diabetes [2].

Conversely, water, being free of sugars and calories, is deemed the superior hydrating beverage. As the demand for water options grows, the emergence of various sparkling and flavored water types could help habitual SSB users switch to healthier options.

3.2 Olfactory Device Research

Recent years have witnessed the proposal of various olfactory devices and interactions employing them. Examples include head-mounted displays [21, 35] and neck-wearable devices [1, 8] designed for scent delivery. Wang et al. introduced an olfactory device which can be worn as a piercing, necklace, or face-mounted accessory [33], designed for convenient everyday use. Amores et al. showcased a necklace-style olfactory device, controllable via smartphone, which can modulate scent intensity and frequency based on biometric and contextual data [1]. Dobbelstein et al. introduced a wearable device for everyday scent notifications [8]. Meanwhile, Choi et al. developed 3D-printed glasses embedding a heating module within the frame, releasing scents when activated [6].

Table 1: 10 largest-valued descriptors for each of the 10 basis vectors obtained from non-negative matrix factorization. [5]

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Fragrant	Woody, Resinous	Fruity, Other Than Citrus	Sickening	Chemical	Minty, Peppermint	Sweet	Popcorn	Sickening	Lemon
Floral	Musty, Earthy, Moldy	Sweet	Putrid, Foul, Decayed	Etherish, Anaesthetic	Cool, Cooling	Vanilla	Burnt, Smoky	Garlic, Onion	Fruity, Citrus
Perfumery	Cedarwood	Fragrant	Rancid	Medicinal	Aromatic	Fragrant	Peanut Butter	Heavy	Fragrant
Sweet	Herbal, Green, Cut Grass	Aromatic	Sweaty	Disinfectant, Carbolic	Anise (Licorice)	Aromatic	Nutty (Walnut Etc)	Burnt, Smoky	Orange
Rose	Fragrant	Light	Sour, Vinegar	Sharp, Pungent, Acid	Fragrant	Chocolate	Oily, Fatty	Sulfidic	Light
Aromatic	Aromatic	Pineapple	Sharp, Pungent, Acid	Gasoline, Solvent	Medicinal	Malty	Almond	Sharp, Pungent, Acid	Sweet
Light	Light	Cherry (Berry)	Fecal (Like Manure)	Paint	Spicy	Almond	Heavy	Household Gas	Cool, Cooling
Cologne	Heavy	Strawberry	Sour Milk	Cleaning Fluid	Sweet	Caramel	Warm	Putrid, Foul, Decayed	Aromatic
Herbal, Green, Cut Grass	Spicy	Perfumery	Musty, Earthy, Moldy	Alcoholic	Eucaliptus	Light	Musty, Earthy, Moldy	Sewer	Herbal, Green, Cut Grass
Violets	Burnt, Smoky	Banana	Heavy	Turpentine (Pine Oil)	Camphor	Warm	Woody, Resinous	Burnt Rubber	Sharp, Pungent, Acid

It is recognized that 75-95% of human taste is driven by olfaction, with scents accounting for the majority of what’s typically perceived as “taste” [16, 24, 29]. Hence, manipulating scents might alter taste perceptions. Ranasinghe et al. [22, 23] created devices employing electrical stimuli, scents, and visual effects to enrich AR and VR drinking experiences, investigating the impact of each stimulus on taste. While they managed to elevate taste through multisensory interactions, pure sweetness amplification remained elusive. Moreover, their scent delivery method–via a tube inserted directly into the nose–wasn’t designed for daily use convenience. Our research group has also proposed a mug-type olfactory interface that amplifies sweetness through scent [20]. We conducted a demonstration test on 33 participants and confirmed that the perceived taste of sweetness was amplified by the scent, but taste satisfaction was not improved.

In essence, substituting SSBs with artificially sweetened beverages appears insufficient. Instead, promoting water consumption–devoid of sugars and calories–is more promising. Although scent-driven strategies have been investigated to amplify beverage sweetness, contemporary designs have mainly succeeded in enhancing sweetness but have not significantly elevated overall taste satisfaction. This research hinges on the variations in human nasal pathways and introduces a unique olfactory approach. Humans are known to possess two scent pathways: “orthonasal,” originating from the nose’s tip, and “retronasal,” emanating from the mouth and passing through the nose, with each being distinctly processed by the brain [4, 13, 28]. Notably, retronasal smell, which contribute to the flavors of food and beverages, have a robust correlation with our sense of taste [25]. In this paper, we detail the design and implementation of the Kaolid prototype—a device specifically tailored for retronasal smell presentation. We also present the results of a study that examines how retronasal smell influence beverage taste perceptions. Delving into these olfactory interfaces for health support promises to further research on IoT systems that augment and broaden the human sensory experience.

4 KAOLID: DESIGN AND IMPLEMENTATION

4.1 System Design

Our sense of taste is significantly shaped by our sense of smell, particularly the retronasal smell that characterize the flavors of food and beverages. With this knowledge, we aim to augment both the perceived sweetness and overall satisfaction of beverages by incorporating retronasal smell. For this purpose, we designed Kaolid, a device that recognizes drinking motions and emits targeted scents to modulate taste perception. The Kaolid system comprises a pneumatic pump and an associated circuitry that drives the pump, facilitating the generation of retronasal smell for the experiment.

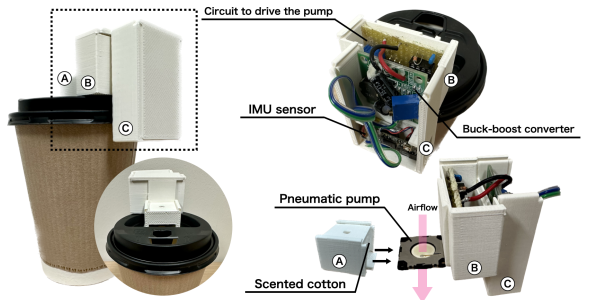


Figure 3: Device Design of Kaolid

We employed a pneumatic pump (MZB1001T02[2]) as the mechanism for scent injection. This pump operates by drawing air from one side and expelling it from the other. The chosen pump operates on the principle of a piezoelectric diaphragm pump, and by utilizing ultrasonic vibrations, it achieves high pressure and flow rates despite its compact and slim design.

As depicted in Figure 3, we devised a mechanism to introduce scent from the lid’s top into the cup, aiming to facilitate the retronasal smell experience. In Figure 3 Ⓐ, we affixed a 3D-printed container on the lid’s top to house both the pneumatic pump and a cotton ball imbued with the scent.

In Figure 3, the container, crafted using a 3D printer, encases a pneumatic pump and its driving circuit. As illustrated in Figure 3Ⓑ and Ⓒ, the circuitry was designed for placement atop the lid to maintain a compact form factor. To operate the pneumatic pump, the power source voltage is elevated using a Buck-Boost Converter. Notably, the pump’s output pressure is contingent on its input voltage, and they share a proportional relationship. For this device, we set the pump’s input voltage at 15 V, resulting in an air pressure of roughly 1.6 kPa. This pressure setting ensures the scent reaches the user’s mouth. Aroma oil serves as the scent source, saturating the cotton housed in the container, from which the pneumatic pump releases the scent.

The device affixed to the cup is lightweight and compact, crafted using a 3D printer. It weighs in at approximately 100 g. Dimensionally, the attached container extends about 30mm upwards and has a depth of 10 mm. Though there are minor alterations, the overall weight and size remain relatively close to that of a standard cup, ensuring users enjoy a familiar experience.

4.2 Prototype of Kaolid

In this study, we devised both a straw-type and a cup-type device aimed at altering beverage taste by delivering scent to the mouth.

[2] https://www.murata.com/ja-jp/products/mechatronics/fluid/overview /lineup/microblower_mzb1001t02

Figure 4: Experiment Scene

Recognizing that beverages are typically consumed either cold or hot, our designs revolve around commonly used drinking tools: straws and cups.

We developed a straw-type device tailored for cold beverages and a cup-type device suited for hot beverages. Both are designed to convey scents to the mouth, enhancing perceived sweetness and improving taste satisfaction. The straw device, as illustrated in Figure 1(a), features a separate aperture in its center, channeling the scent directly into the straw and subsequently to the drinker's mouth. The cup-type device, depicted in Figure 1(b), positions a scent-injecting mechanism atop the cup, ensuring that as the user drinks, the scent is introduced to their palate.

5 EXPERIMENT

In this study, we conducted sensory evaluation experiments using the Kaolid prototype to examine the effect of various flavors on taste perception.The experiment involved 20 students in their 20s (average age = 23.5). All participants were in good health, presenting no symptoms of colds, fevers, or other ailments, and exhibited normal taste and smell abilities.

Different beverages were provided for each Kaolid prototype. The straw-type device, intended for cold beverages, was filled with unscented sparkling water. Conversely, the cup-type device, designed for hot drinks, was filled with plain hot water. For the scent component, orange and pineapple scents were chosen based on categories C3 and C10 from Table 1. These scents were determined to be compatible with sparkling and hot water, respectively, from ten distinct odors perceivable by humans [5]. After each test, participants completed a taste-related questionnaire. The questionnaire incorporated a 9-point hedonic scale where they evaluated perceived taste satisfaction, sweetness intensity, taste preference, and specific sweetness levels.

For the specific sweetness assessment, participants were presented with ten cups filled with varying sugar concentrations, as depicted in Figure 4. They were instructed to select the cup mirroring the sweetness they perceived during their drink test. The sugar water ranged from "1" (unsweetened water) to "9" (a sugar concentration of 11.3 g/100 ml, equivalent to typical carbonated drinks). Intermediate sugar water samples had evenly spaced sugar levels. A "10" rating was available for instances where participants felt the beverage surpassed the sweetness of a standard carbonated drink. This method enabled a comparison of perceived sweetness with Kaolid to actual sugar content.

This study received approval from the Ethics Committee affiliated with the author's institution (Approval number: 2020-I-16).

6 RESULTS

We began by aggregating the results for the scents used in this experiment (orange and pineapple). Subsequently, we conducted individual evaluations for each scent to discern differences in taste perceptions. Lastly, we presented the outcomes from the specific sweetness taste assessment.

6.1 RQ1: Influence of Retronasal Smell on Taste Sweetness and Satisfaction

The results for both the straw-type and cup-type devices are illustrated in Figure 5.

For the straw-type device, the introduction of retronasal smell generally improved both taste satisfaction and perceived sweetness. Taste satisfaction saw a median score increase of one point, suggesting the scent delivery method, the beverage, and the chosen scent collectively enhanced taste perception. The middle 50% of participants' scores fell between the first (Q1) and third quartiles (Q3), indicating consistent satisfaction. Perceived sweetness scores indicate the device consistently boosted sweetness for most, with exceptions. No significant improvement in overall taste preference.

The cup-type device demonstrated an overall trend of improved sweetness perception with retronasal smell presentation. The data indicates consistent sweetness enhancement for the majority of participants. However, certain outliers suggest that while some found the sweetness amplified significantly, others didn't observe a substantial change. For taste satisfaction, the data indicates improved average taste perception, but overall consistency in enhancement was lacking. Taste preference results showed a potential decline in evaluations with the introduction of retronasal smell. The distribution of these results suggest that while the cup-type device boosted sweetness perception, further improvements might be necessary to consistently enhance taste satisfaction and preference.

To compare evaluations based on scent presence, we used the Wilcoxon signed-rank test, appropriate for assessing significant differences between two related sample sets. Test results, summarized in Table 2, revealed significant differences in all evaluation aspects for the straw-type device. For the cup-type device, significant differences were primarily observed in sweetness perception. In conclusion, in response to RQ1, our lid-type olfactory device, Kaolid, successfully introduces retronasal smell that amplify perceived sweetness and improve taste satisfaction.

6.2 RQ2: Effect of Scent Category on Taste Sweetness

We examined the influence of different scents, specifically orange and pineapple, on taste perception.

6.2.1 Result of Using Orange Scent. The outcomes from experiments using the orange scent are presented in Figure 6.

For the straw-type device, adding the orange scent generally heightened both taste satisfaction and perceived sweetness. Taste

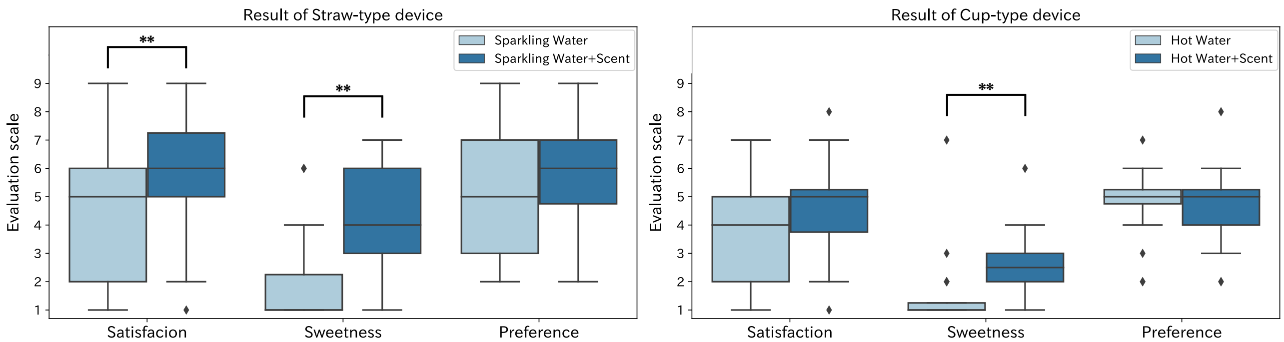


Figure 5: Overall result (Left:Straw-type,Right:Cup-type)

Table 2: Test results for each evaluation item

	Two pairs to compare	P-value	Significant Difference ($p \leq 0.05$)
Straw-type Device	Taste Satisfaction(Sparkling water)& Taste Satisfaction(Sparkling water+Scent)	1.130×10^{-3}	✓
	Taste Sweetness(Sparkling water)& Taste Sweetness(Sparkling water+Scent)	2.728×10^{-4}	✓
	Taste Preference(Sparkling water)& Taste Preference(Sparkling water+Scent)	1.533×10^{-1}	-
Cup-type Device	Taste Satisfaction(Hot water)& Taste Satisfaction(Hot water+Scent)	6.636×10^{-2}	-
	Taste Sweetness(Hot water)& Taste Sweetness(Hot water+Scent)	3.293×10^{-3}	✓
	Taste Preference(Hot water)& Taste Preference(Hot water+Scent)	7.238×10^{-1}	-

satisfaction, for instance, saw an increase in both the median and minimum scores, implying a more harmonious pairing of the orange scent with the carbonated water. Similarly, sweetness perception scores, both median and minimum, improved, suggesting a consistent perceived sweetness enhancement using the orange scent. However, while adding the orange scent indicated a narrower range of taste preference scores, the maximum score decreased, indicating challenges in improving overall taste preference.

With the cup-type device, there was a noticeable inclination towards heightened taste satisfaction and sweetness when the scent of orange was introduced. Both the minimum and maximum scores for taste satisfaction improved, suggesting an overall positive response to the orange scent when paired with plain hot water. Similarly, sweetness perception saw a rise in scores, with the median score improving notably. However, taste preference showed a wider range of scores, suggesting varied individual responses to the orange scent.

6.2.2 Result of Using Pineapple Scent. The outcomes from experiments using the pineapple scent are detailed in Figure 7.

With the straw-type device, evaluations across all categories leaned towards lower scores compared to those using the orange scent. This suggests that the combination of carbonated water and pineapple scent was less favored than its orange counterpart. However, there were some participants who rated the pineapple scent positively in terms of both taste satisfaction and sweetness.

For the cup-type device, the results for pineapple scent were similar to the overall outcomes. While there was a trend of enhanced sweetness perception, significant improvements in taste satisfaction were lacking. This suggests that while the cup-type device can amplify perceived sweetness, elevating overall taste satisfaction remains challenging.

In conclusion to RQ2, the results indicate that the pairing of carbonated water and the scent of oranges significantly amplified perceived sweetness. On the other hand, plain hot water, when paired with the scent of pineapples, also showed enhanced sweetness. This underscores the interplay between specific scent categories and beverage types in influencing sweetness perception.

6.3 RQ3: Quantitative Evaluation of Sweetness Enhancement by Kaolid

The results assessing the specific degree of perceived sweetness are illustrated in Figure 8. The sugar content of standard carbonated beverages is denoted by a red line, while that of commercial flavored water is marked by an orange line. From the findings, when using the straw-type device with carbonated water, the introduction of a scent led to an average sweetness enhancement of roughly 2 scale units. Considering that each unit on this scale corresponds to a sugar content of 1.44g/100ml, a median-based comparison indicates that the straw-type device facilitated a sweetness enhancement equivalent to around 2.88g. A median score of 3 in the participants' evaluations suggests that presenting the retronasal smell indeed amplified the perceived sweetness. Notably, there were high scores of 6 and 9, hinting that for certain participants, the device was especially successful in intensifying sweetness perception. Regarding the cup-type device, which was paired with plain hot water, it demonstrated a similar trend of sweetness enhancement, albeit not as pronounced as the straw-type. Some participants felt that the cup-type device rendered beverages sweeter than conventional carbonated drinks. These findings suggest that Kaolid can be instrumental in magnifying sweetness perception, potentially assisting in lowering sugar consumption.

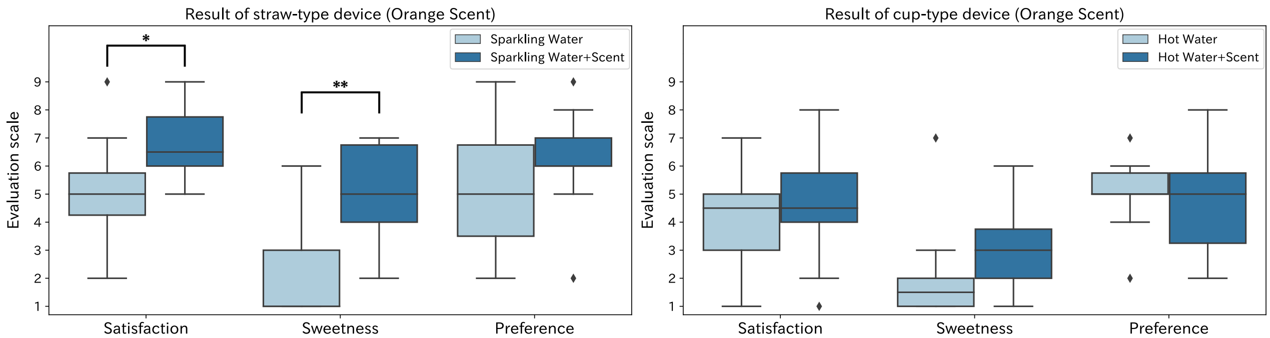


Figure 6: Result using orange scent (Left:Straw-type,Right:Cup-type)

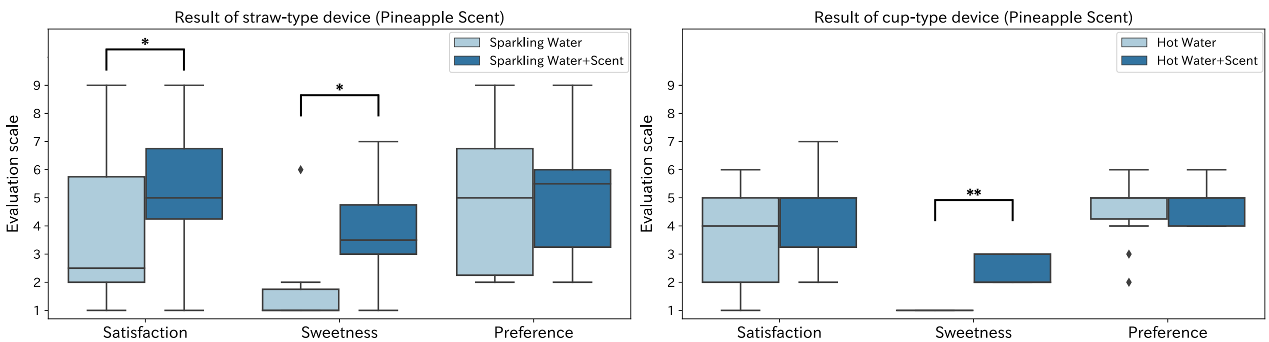


Figure 7: Result using pineapple scent (Left:Straw-type,Right:Cup-type)

7 DISCUSSION AND LIMITATION

7.1 RQ1: Kaolid's Enhancement of Taste Satisfaction and Sweetness through Retronasal Smell

Taste evaluations using the straw-type device indicated an upward trend in ratings for both taste satisfaction and perceived sweetness. These outcomes suggest an enhancement in taste satisfaction that had not been achieved with traditional orthonasal smell presentation methods. Many users perceived a notably sweeter taste with the straw-type device compared to the orthonasal approach. This matches the idea that retronasal smell, molded by olfaction, is key in taste judgment. Thus, it is evident that the scent delivery via the straw-type device was effective.

For the cup-type device, the introduction of a scent mainly led to heightened perceptions of sweetness rather than overall taste satisfaction. This may hint that the design of the cup-type device wasn't optimal for conveying retronasal smell. However, it is essential to note that all participants in this study were in their twenties. Future studies should account for demographic factors like age and gender. The potential of the cup-type device to elevate beverage experiences warrants further exploration. During the experiments, some participants expressed initial reservations about using an unfamiliar device. Yet, as they discerned notable taste alterations throughout the procedure, their intrigue seemed to outweigh their initial hesitancy.

Concerning taste variations, the straw-type device appeared more dynamic to users than the cup-type. One participant remarked, *"The taste alteration was more pronounced since the beverage was sparkling water"*, while another observed, *"The straw seemed to convey the smell directly into the mouth, ensuring no flavor was lost, which led to a more distinct taste change."* Regarding the cup-type device, a different participant noted, *"Although the change in taste felt more vivid with the straw-type, I preferred the mouthfeel delivered by the cup-type."* Such feedback underscores that the direct scent delivery through the straw-type device made it easier for users to detect taste changes. In our study, the process of injecting scented air directly into participants' mouths surprisingly didn't diminish their satisfaction. This might be attributed to the choice of carbonated water, which inherently contains air bubbles, thus making the scent injection process feel less intrusive. However, some participants found the straw device more intuitive and comfortable for drinking than the cup-type, likely because they're accustomed to the direct pathway a straw provides.

7.2 RQ2: Taste Sweetness Variation Based on Scent Category

For the straw-type device, the introduction of the orange scent consistently led to heightened ratings in both taste satisfaction and perceived sweetness when compared to the general results. Both the median and minimum values for these evaluations showed notable improvement with the orange scent. These observations suggest that the combination of carbonated water and the orange

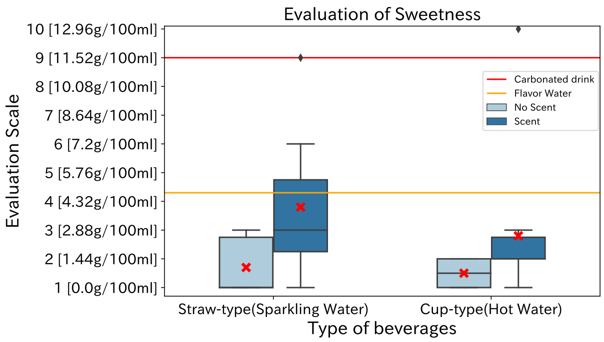


Figure 8: Result of Sweetness Evaluation

scent might be particularly synergistic with the straw-type device. Conversely, when the pineapple scent was introduced, all evaluation metrics tended to be lower than those recorded with the orange scent. There was also a pronounced variability in the data across evaluation categories, highlighting a strong divergence in individual preferences among participants. From these findings, and considering the patterns in the data, the orange scent appears to be more universally favored when paired with sparkling water. Scents for this experiment were chosen from a palette that humans can typically differentiate. Future research can further refine the choice of scents by focusing on those within the orange scent category, aiming to find those that best complement sparkling water.

In the context of the cup-type device, the introduction of the orange scent showed a tendency to amplify perceived sweetness. However, the taste satisfaction remained largely unchanged in comparison to evaluations without any scent. Consistent with the overarching findings, participants' taste preferences seemed to decline upon the introduction of the scent. Conversely, with the introduction of the pineapple scent, while there was a perceptible amplification in the sweetness of the taste, other metrics like taste satisfaction, preference, or the overall taste experience remained largely unchanged. This suggests that the current design of the cup-type device primarily accentuates sweetness, irrespective of the specific scent introduced, and struggles to enhance overall taste satisfaction. This may indicate challenges in effectively delivering the retronasal smell experience.

7.3 RQ3: Evaluating Kaolid's Sweetness as a Substitute for SSBs

The Kaolid's ability to induce perceived sweetness was quantitatively assessed. The straw-type device managed to amplify the perceived sweetness equivalent to an average of 2.88g of sugar. On the other hand, the cup-type device achieved a sweetness amplification corresponding to an average of 1.5g of sugar. While this does not equate to the sweetness levels of sugar-sweetened beverages (SSBs), it demonstrates the potential to enhance sweetness perception in unsweetened drinks purely through the introduction of scents. Although the current iteration of the device primarily relies on olfactory stimulation via scents, future designs may incorporate visual stimuli, such as LED light cues, to bolster sweetness perception through multimodal interactions.

The cup-type device, though less effective than its straw-type counterpart, also demonstrated a potential to increase perceived sweetness. It is worth noting that participants in this study were all in their 20s. Subsequent research will expand the participant pool to include middle-aged and elderly individuals, aiming to offer a more comprehensive quantitative assessment of sweetness perception across age groups.

7.4 Future Work

In this experiment, carbonated water was used as the beverage for the straw-type device. However, it is necessary to conduct similar experiments on other beverages to demonstrate its effectiveness. Previous research, apart from carbonated water, has also used plain water and found that both the perceived sweetness and satisfaction were significantly amplified when compared to cases without any scent. By conducting experiments with other sugar-free healthy beverages like tea and coffee, the potential uses of Kaolid can be significantly expanded. Additionally, in this experiment, we used hot water for the cup-type device. There's a need to experiment with other warm beverages as well. To determine whether the cup-type device was able to reproduce the retronasal smell, further exploration of beverages and scent is necessary.

The number of participants in this experiment was 20. In the evaluation of the straw-type device, a significant difference was confirmed in both taste satisfaction and perceived sweetness. For the cup-type device, a significant difference was confirmed only in the perceived sweetness. Even with a small number of participants, the significant difference was established. In the future, by increasing the number of participants and considering factors like age and gender, we aim to demonstrate the effectiveness of Kaolid for various demographic groups and design a more versatile device. Furthermore, in this experiment, subjects' scent preferences were not considered. However, analyzing subjects' scent preferences will allow a valid evaluation of this device in the future.

Our proposed device is currently a prototype, and we acknowledge that several improvements could enhance its real-world applicability. For example, we could improve the aesthetics and portability of the device to make it easier to use and carry. In terms of limitations, the device currently only supports a limited range of scents, which may not cover all the possible flavors a user might want to experience. In future work, we plan to expand the range of supported scents and refine the technology based on user feedback. Moreover, not only olfactory interventions but also visual interventions, such as using LEDs to change the color of the liquid, will be introduced, aiming for a device that further augments sensory experiences. And also in the conducted experiment, we powered the device directly from a main supply. However, for real-world applications, we envision equipping the device with an internal rechargeable lithium polymer battery. We aim to design a device that can provide a full day's use with a single daily charge.

8 CONCLUSION

The experiment demonstrated that Kaolid significantly enhanced both taste satisfaction and perceived sweetness compared to scenarios without any scent introduction. Specifically, the findings indicated a notable increase in taste satisfaction and sweetness for the straw-type device, while the cup-type device mainly showed a distinct enhancement in perceived sweetness. As IoT continues to influence various facets of our everyday life, a novel interface like Kaolid, which harnesses sensory enhancements using scent, could pave the way for delving into the next frontier of IoT possibilities. To further validate Kaolid's effectiveness, upcoming experiments will factor in participant variables such as age and gender.

The scent-based analysis suggests that optimal scents might differ depending on the beverage. While orange and pineapple scents were employed in this study, it is essential to explore compatible scents for beverages, considering the 10 odor groups humans can detect. Although the straw-type device seems to have achieved retronasal smell, the same might not be true for the cup-type device. Future research should aim to design an IoT device capable of delivering retronasal smell in hot water and other warm beverages.

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