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RESEARCH ARTICLE

Aromug: A Mug-Type Olfactory Interface to Enhance the Sweetness Perception of Beverages

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This work involved human subjects or animals in its research. The authors confirm that all human/animal subject research procedures and protocols are exempt from review board approval.

ABSTRACT Sugary beverages are a significant contributor to sugar consumption, and their excessive consumption is associated with increased risks of elevated blood glucose levels and diabetes. Many individuals have a strong preference for sugary beverages and often find beverages with lower sugar content to be less satisfying. Attempts to switch to less sugary options are frequently short-lived, leading to a return to higher-sugar beverages. Recognizing that 75 – 95% of taste perception is influenced by scent, we investigated a scent-based approach to reduce sugar intake while preserving the perception of sweetness. This study introduces an olfactory interface in the form of a mug named "Aromug," designed to emit a sweet scent in sync with the drinking action. Aromug incorporates motion sensing and scent presentation functions to enhance the perceived sweetness of a beverage, thereby encouraging a gradual reduction in sugar intake. Our experiments, involving 33 participants, demonstrated that the combined scents of sugar-free coffee and chocolate increased the perception of sweetness ($p = 1.641 \times 10^{-2}$). The study also found that the simultaneous presentation of scent and visual cues improved taste satisfaction and sweetness perception. Additionally, we observed variations in sweetness preference related to age and frequency of coffee consumption. It was particularly observed that people in their 20s and those who frequently drink coffee tend to perceive the taste of beverages as sweeter. This suggests a potential for Aromug to customize the scent experience based on individual preferences, offering a novel way to encourage healthier beverage choices.

INDEX TERMS Olfaction, olfactory interfaces, olfactory display, scents, taste evaluation, smell, olfactory perception, behavior change support.

I. INTRODUCTION

The beverages we casually consume often contain a substantial amount of sugar. Particularly in developing countries, urbanization and beverage marketing have led to a dramatic increase in the consumption of sugary beverages [1], [2], [3]. As a result, the global diabetic population is on a notable rise annually [2]. Moreover, habitual sugar intake is known to lead to elevated blood glucose levels, increased risk of diabetes, and the accumulation of visceral fat contributing to metabolic syndrome [4], [5], [6].

To address the issue of excessive sugar consumption, several methods have been proposed to nudge individuals towards reducing their sugar intake [11], [12]. Through these

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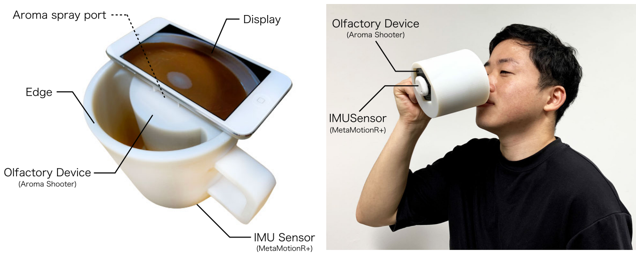
TABLE 1. Comparison with existing approaches related to our work.

Primary Taste Sensations	Nakamura [7]	Kaiji [8]	Ranasinghe [9]	Ranasinghe [10]	Our Proposed
Salty	✓	✓	✓	✓	
Sourness			✓	✓	
Bitterness				✓	
Sweetness					✓



(a) Appearance of Aromug (b) Image of Aromug usage

FIGURE 1. Aromug device appearance and examples of use.

methods, it is possible to promote the temporary selection of low-sugar beverages or the reduction of sugar use. However, for individuals habitually inclined towards consuming sugary beverages, low or no-sugar alternatives often result in a less satisfying taste experience. Consequently, the habit of choosing lower-sugar beverages does not persist, leading many to revert to their original routine of consuming sweet beverages. Therefore, there is a need for solutions that assist individuals in gradually reducing their sugar usage.

This study aims to maintain the sweetness of beverages while reducing sugar content by exploring interventions through olfactory and visual stimuli. It is recognized that 75 – 95% of taste perception is influenced by scent [13], [14], [15] and that sweet scents can amplify sweetness perception [16]. In our previous research [17], we proposed a system that amplifies sweetness and reduces sugar intake by synchronizing scent delivery with the action of drinking. In this paper, focusing on the everyday use of a mug cup, we propose "Aromug," a new mug-shaped olfactory interface by adding to our previous research new features including motion sensing and visual information display of the beverage (Figure 1). We examine the effectiveness of augmenting perceived sweetness through olfactory and visual stimuli.

Initially, an experiment was conducted to select effective scents for amplifying sweetness from a range of scents. Following this, an experiment was carried out to verify whether the selected scents assist in amplifying sweetness. Furthermore, by combining scent presentation and beverage visual display, the effect of augmenting perceived sweetness through olfactory and visual interventions was evaluated. Through a series of experiments, a combination of sugar-free coffee and chocolate scents was observed to potentially enhance sweetness perception. Additionally, differences in sweetness preference were noted depending on age and frequency of coffee consumption, and it was confirmed that specific scents tended to amplify the sweetness of coffee. Moreover, individuals who frequently consume coffee tend to perceive amplified sweetness with the combination of sugar-free coffee and scent. The presentation of both scent and visual cues was found to enhance taste satisfaction and sweetness more than scent alone. These results indicate the importance of scent interventions for reducing sugar intake and enhancing gustatory experiences.

II. RELATED WORKS

A. ENHANCING THE TASTE EXPERIENCE

In the field of Human-Computer Interaction (HCI), Human Food Interaction (HFI) [18], [19], [20] has attracted attention as a field that aims to enhance the dining experience through information technology. Various studies have been conducted to explore the use of information technology to augment the dining experience. These include approaches such as using Galvanic Taste Stimulation (GTS) from both inside and outside the oral cavity to enhance saltiness [7], [8], studies demonstrating the induction of different tastes by electrically stimulating the taste receptor system on the tongue [9], [10]. Furthermore, in existing HCI research, the focus has primarily been on visual elements, with methods proposed for manipulating the appearance and visual aspects of food. For instance, systems have been developed to control satiety by altering the quantity of food consumed using Head-Mounted Displays [21], [22]. Similarly, Projection Mapping techniques have been explored to change the visual aspects of food and the dining environment [23], [24]. These HFI research areas are expected to greatly contribute to enhancing the dining experience, providing new perspectives on food culture and health, and ultimately leading to significant changes in food-related habits and preferences. However, as shown in the Table 1, previous approaches have not established a method for amplifying the sweetness of taste, and have been limited to expanding other taste perceptions.

B. INFLUENCE OF SCENT ON TASTE PERCEPTION

It is often stated that 75 – 95% of human taste perception is influenced by scent, and generally, a substantial portion of what we recognize as "taste" is occupied by smell [13], [14], [15]. In other words, by controlling scent, there exists a possibility to alter a person's perception of taste.

Additionally, one might recall instances of experiencing a diminished or absent sense of taste during a cold with nasal congestion, or when pinching the nose while eating. These instances serve as commonplace evidence of the dependency of gustatory perception on olfaction. Moreover, the impact of olfaction on taste perception can be illustrated through the example of flavored syrups used in shaved ice desserts. Typical flavors, such as strawberry, lemon, and blue Hawaii, each offer distinct taste profiles despite having nearly identical values in sweetness, saltiness, bitterness, and sourness. This distinction in taste is manifested through the combination of visual and olfactory cues, such as the red color and strawberry scent representing the strawberry flavor. Through this example, it becomes evident how the differential presentation of visual and olfactory information can result in distinct taste experiences.

C. RESEARCH ON OLFACTORY DEVICE

In recent years, a variety of olfactory devices and the interactions utilizing them have been proposed. For instance, head-mounted displays that deliver scents in a wearable format have been developed [25], [26], as well as wearable devices that can be worn around the neck [27], [28]. In the study by Wang et al. [29], olfactory devices in the form of piercings, necklaces, and on-face wearables have been proposed. These proposed systems achieve a compact design conducive to daily use. The design integrates seamlessly into everyday life, allowing users to conveniently carry them daily. The societal acceptance, comfort, and the intensity of scent perceived by both wearers and observers of these systems have been evaluated. Additionally, development has been seen in the creation of necklace-type olfactory devices for daily use [27], [28], and 3D printed glasses with a heating module embedded at the ends of the frames for scent release [30]. Despite advancements in integrating olfactory interfaces into daily life, there has been no development to adapt to beverages such as a mug-type olfactory interface.

In this study, we focus on mugs commonly used for drinking beverages and aim to explore an olfactory interface with high receptivity that can blend seamlessly into daily life. Furthermore, we examine interactions for amplifying perceived sweetness through the proposed system while reducing sugar intake.

III. AROMUG: DESIGN AND IMPLEMENTATION

In this study, to reduce sugar content in beverages while enhancing the perceived sweetness through the presentation of scent, we introduce ‘‘Aromug.’’ In this section, we present use case scenarios for Aromug and describe the system design and implementation to realize these scenarios.

A. USECASE SCENARIO

We introduce use-case scenarios of how Aromug can be used in practice.

Taro, a 30-year-old office worker, usually has bread and milk coffee for breakfast before going to work (Figure 2A). Taro has a big sweet tooth, and he always puts milk and four sugar cubes in his hot coffee or tea. In the office, he drinks three cups of sweetened milk coffee, and after coming home from work, he drinks a beer with his meal. Before going to bed, he reads a book with a cup of milk tea (Figure 2B). Taro’s wife was concerned about her husband’s high blood sugar level and wanted him to reduce his sugar intake.

One day, when Taro’s blood glucose level got close to exceed the normal range during a physical examination, his wife gave him a ‘‘Aromug’’ as a gift (Figure 2C). Aromug is an olfactory interface in the form of a mug that presents a sweetness-enhancing scent when a drink is consumed. Taro decides to start a reduced-sugar lifestyle using the Aromug. He decided to use the Aromug whenever he drinks a beverage in his office. Taro wanted to know the effect of Aromug on sweetness amplification, so he poured hot coffee into Aromug. He then used the Aromug with a smaller amount of milk and sugar cubes than usual. As soon as he drank it, a sweet scent was emitted from the Aromug, and he enjoyed an unusual but sweet taste of milk coffee. At this time, Taro experienced a sense of satisfaction similar to that of the milk coffee he usually drinks (Figure 2D). Taro thought this might not be a problem even if he used less sugar. Taro liked the experience of drinking from the Aromug so much that he began pouring tea and milk coffee into it as well (Figure 2E). As Taro’s use of the Aromug increased, he began to enjoy reduced use of sugar. He began to develop the habit of drinking milk, coffee, and tea without sugar. A few weeks after using the Aromug, Taro sipped his regular sweetened coffee for the first time in a long time. At that time, Taro was surprised that he had been drinking such sweet coffee regularly. He was also reminded that too much sugar is not good for the body. A few months later, Taro began to choose less-sweetened drinks even without Aromug (Figure 2F).

B. OVERVIEW OF SYSTEM DESIGN

To accomplish the aforementioned use case scenario, we designed a mug-type olfactory interface for presenting scents, as shown in Figure 3, designated as Aromug. Aromug is a mug-shaped olfactory interface equipped with a motion-sensing functionality for the act of drinking and a correlated scent-presenting functionality initiated by the drinking action.

To efficiently deliver the scent to the human nostrils, we have integrated a scent-presenting device within the mug as depicted in Figure 3. The integration of the olfactory device within the mug enables a compact size while maintaining an appearance akin to an actual mug. For the prototype olfactory device, we employed the Aroma Shooter from Aromajoin Corporation.[1] Furthermore, as shown in Figure 3, an IMU sensor (MetaMotionR+: sensor: 100Hz quaternion three-axis accelerometer/gyroscope, dimensions: L29 $\times$ W18 $\times$ H6 mm, weight: 5.7 g)[2] is installed at the bottom of the mug.

C. DRINKING SENSING FUNCTION

For the recognition of drinking behavior and the estimation of remaining beverage volume, we use an IMU sensor

[1] https://aromajoin.com/products/aroma-shooter
[2] https://mbientlab.com/metamotionr/

FIGURE 2. The Aromug use case scenario.

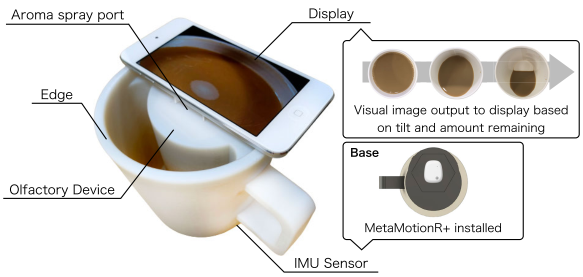


FIGURE 3. Design image of Aromug.

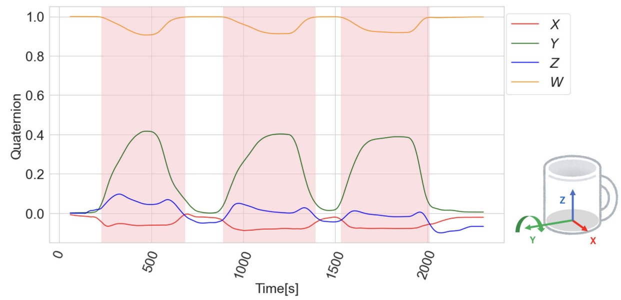


FIGURE 4. Example of IMU sensor data and emitting timing.

embedded on the base of our device. The sensor signals from the IMU are transmitted to a gateway device via Bluetooth Low Energy (BLE). The gateway device analyzes the IMU sensor signals to recognize drinking action and estimate the residual volume in the cup post-consumption.

1) DRINKING BEHAVIOR RECOGNITION

Aromug, using the IMU sensor on its base, identifies the interval from the user picking up the mug to finishing a sip, and activates the scent emission during this interval. Figure 4 depicts the relationship between the sensor data obtained from the IMU sensor located at the base during three sipping actions, and the emission timing (indicated in pink). This sensor data represents the change in posture (quaternion) relative to the mug placed on the desk. During the drinking action, changes can be observed in both the y-component and w-component of the quaternion. Due to the orientation of bringing the cup to the mouth, the rotational movement around the Y-axis during drinking action is reflected in the Y-component. The part marked in pink represents the continuous drinking action, during which Aromug emits the scent.

2) BASIC EVALUATION OF BEVERAGE RESIDUAL VOLUME ESTIMATION FUNCTION

a: OVERVIEW OF BEVERAGE RESIDUAL VOLUME ESTIMATION FUNCTION

During the drinking action, the attitude angle of the device is calculated from the acceleration signals and angular velocity signals obtained from the IMU sensor. Using these sensor signals, we estimate the remaining amount of beverage in the mug through machine learning. As depicted in Figure 5, the three sub-actions constituting a drinking action (picking up the mug, drinking, and putting down the mug) are recognized based on a threshold from the acceleration data and gyroscope sensor data. Furthermore, in this preliminary experiment, estimation is performed on the amount of liquid in Aromug when a sip of beverage is drunk from a state of 100g, this being the 80% of the maximum capacity that can be poured into Aromug. As shown in Figure 5, the IMU sensor data during drinking and the water amount in Aromug measured on a kitchen scale is indicated. The preliminary experiment was conducted with eight participants each performing the drinking action ten times, obtaining and analyzing 80 beverage sensing data instances.

b: FEATURES AND MODEL

The features used were derived from the acceleration sensor data and angular velocity data obtained from the IMU sensor during the drinking action. Additionally, acceleration and angular velocity were derived from the three axes of each sensor data. Therefore, we extracted the maximum, minimum, average, and variance from each sensor data's three axes, and the derived acceleration, and angular velocity. These extracted values were utilized as features in the model.

In this analysis, to estimate the remaining amount inside the Aromug using acceleration and angular velocity, supervised learning of regression models were applied to the

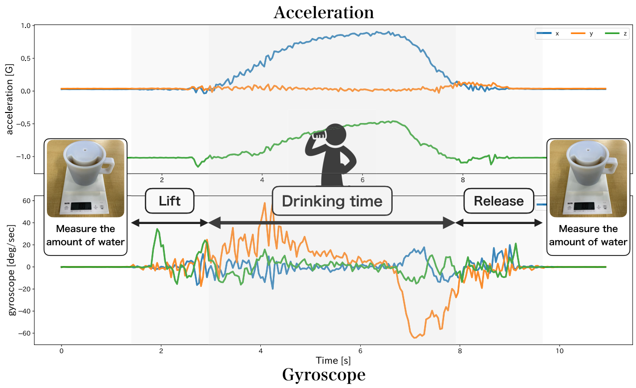


FIGURE 5. Identification of drinking timing by sensor data and timing of residual volume measurement.

TABLE 2. Residual volume estimation results in the cup.

Model	MAE	RMSE	R^2
Linear Regression	3.431	4.301	-0.931
Random Forest	4.450	5.443	-1.721
SVM	7.931	9.561	-11.85
Light GBM	**1.502**	1.772	0.542

features extracted as described above, with the actual remaining water amount as the target variable. Four regression models were adopted, namely, Linear Regression, Random Forest, SVM (Support Vector Machine), and LightGBM. The models were evaluated using Leave-one-person-out cross-validation, where each individual serves as the test set. The evaluation metrics employed were Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and the coefficient of determination (R^2).

c: PRE-EXPERIMENTAL RESULTS OF RESIDUAL VOLUME ESTIMATION

The prediction results of the remaining amount estimation model through machine learning are shown in Table 2. The results indicate that the model, when utilizing Light GBM, yielded an MAE of 1.502, making it the most accurate. Since the unit of MAE remains unchanged, the error is 1.502g. Given the average amount of drink per sip per participant is 18.5g, this error can be considered satisfactory. In this experiment, the initial value of the drink contained in the Aromug was set at 100g. In real-world scenarios, a model-independent of initial values is preferable. However, the features and the model used in this experiment demonstrated the feasibility of satisfactory remaining amount estimation, thus suggesting the potential of achieving satisfactory results even with different initial values.

D. SWEETNESS AMPLIFICATION FUNCTION BY PRESENTING SCENT AND VISUAL INFORMATION

1) APPROACH 1: EMITTING OF SCENT LINKED TO THE DRINKING ACTION

Aromug aims to amplify the perceived sweetness by precisely controlling the release of scent cues during the act of drinking.

(a) Device of Aroma Experiment (b) Device of Visual Experiment

FIGURE 6. Sweetness amplification through scent and visual intervention.

In Approach 1, the release of scent is synchronized with the drinking action. As depicted in Figure 6(a), an olfactory device is equipped within the mug to efficiently release scent towards the user's nose as they drink. The design ensures that the scent is released during the identified drinking action, courtesy of the beverage-sensing functionality. It is imperative here to select a scent that is anticipated to effectively augment the perception of sweetness for the experiment.

2) APPROACH 2: PRESENTATION OF VIDEO IMAGES AND SCENT LINKED TO THE DRINKING ACTION

As shown in Figure 3, a display is equipped on the upper part of the mug. The display outputs a simulated image of the beverage poured inside the mug, serving to enhance the user's drinking experience. The image displayed changes in real-time based on the beverage sensing, capturing the ongoing drinking action. In Approach 2, a synchronized display of imagery with the drinking action is combined with the scent release as described in Approach 1. As the user drinks, the scent is released in conjunction with simulated imagery of coffee flowing. The simulated imagery employs a lighter color than the actual iced coffee used, intending to evoke a sense of sweetness in the user. The scent is released while drinking is detected through the beverage sensing functionality, and dynamic control of the imagery is executed based on the sensor-detected tilt of the mug. By controlling the imagery in real-time, a drinking experience akin to handling an actual mug is accomplished.

3) BASIC EXPERIMENTATION FOR SCENT SELECTION

a: EXPERIMENT OVERVIEW

To investigate the influence of various scents on taste, we conducted a sensory evaluation experiment using the prototype of Aromug. Our objective was to narrow down effective scents for amplifying the sweetness of beverages from the numerous cartridges provided by Aromajoin Corporation.

In the initial experiment, seven students (all male) from our affiliated laboratory participated, with ages ranging from 20s to 30s. In this experiment, sugar-free iced coffee was used, and the combination of scent and beverage was evaluated. The selection of scents was made based on our judgment, focusing on sweet scents with the potential to amplify sweetness, from numerous cartridges provided by

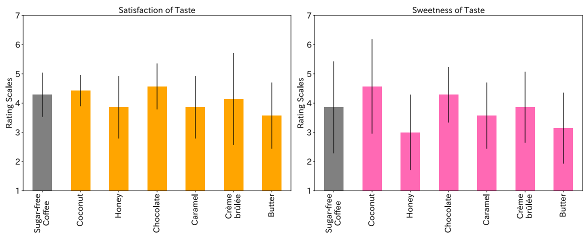


FIGURE 7. Pre-experiment result to decide scents.

Aromajoin Corporation.[3] Six scents were selected: coconut, beeswax, chocolate, caramel, crème brûlée, and butter. The questionnaire used in the experiment adopted a seven-point Likert scale, and participants evaluated the satisfaction of taste and the perceived sweetness when they drank the beverage.

b: RESULT

In Figure 7, the results of perceived taste satisfaction and sweetness of sugar-free iced coffee with different scents are shown. The evaluation for each scent is compared to the baseline of sugar-free iced coffee without any scent.

Based on the results of the experiment, the evaluations for both taste satisfaction and sweetness were slightly higher for coconut and chocolate scents compared to the baseline. It was observed that by infusing scents into the sugar-free coffee, the evaluations for sweetness tended to increase. From all the sweet scents that were selected for the initial aromatic experiment, among them, coconut and chocolate scents were the best performers compared to the baseline. From these experimental results, three scents (coconut, chocolate, and crème brûlée) were the candidates selected as potentially having a higher likelihood of perceived sweetness.

IV. USER STUDY

A. EXPERIMENTAL OBJECTIVES AND HYPOTHESES

So far, we have introduced the "Aromug," a device equipped with scent presentation and a beverage display, intervening in olfaction and vision. This device recognizes the user's drinking behavior in real-time and enhances the drinking experience through scent control and display visuals. In this chapter, we evaluate the validity and effectiveness of the proposed method based on the results of a user study aimed at revealing how Aromug alters the drinking experience and how it brings about changes in sweetness and taste. The evaluation here focuses on improving the drinking experience, rather than the accuracy of the beverage action sensing technology.

First, it is necessary to verify if there are scents that amplify the sweetness of taste. As mentioned in Section III-D3, we narrowed down scents that showed a tendency to amplify sweetness from a variety of scents. It is crucial to validate whether these scents are effective in enhancing the sweetness of taste.

H1: Taste sweetness is amplified by the presentation of scent when drinking beverages.

While proving H1 would confirm the possibility of amplifying the sweetness of the taste through scent, it is essential to verify whether further amplification of sweetness can be achieved by influencing not only the olfactory sense but also other sensory organs. Therefore, we proposed a second hypothesis.

H2: The visual and olfactory intervention of approach 2 amplifies the sweetness more than approach 1.

If these hypotheses are supported, it can be confirmed that the sweetness perceived can be amplified through interventions in both olfaction and vision. Motivated by this, a series of experiments were conducted to evaluate these hypotheses.

B. EXPERIMENT 1: EVALUATION EXPERIMENT OF H1

In this experiment, a sensory evaluation experiment was conducted using the prototype of Aromug shown in Figure 6(a) to investigate the effect of various scents on taste. Iced coffee was used in the experiment, and a survey was conducted to evaluate the taste of three different types of iced coffee with varying sugar content combined with various scents. At the time of the survey application, both oral and written explanations were provided regarding the purpose and methodology of this study as well as the ethical considerations for the survey participants. This study was conducted under the approval of the ethics committee of the organization to which the authors belong. (Approval number: 2020-I-16)

1) PARTICIPANTS OF EXPERIMENT 1

In Experiment 1, 33 individuals, consisting of university students and administrative staff (15 males and 18 females), participated, with ages ranging from their 20s to 50s (mean = 29.394, standard deviation = 10.503). Table 3 shows the distribution of participants in Experiment 1 by age, gender, and frequency of coffee consumption. The health condition of the participants was found to be unproblematic (with no symptoms such as colds or fever), and the experiments were conducted while their taste and olfactory senses were in normal condition.

2) OVERVIEW OF EXPERIMENT 1

In Experiment 1, three types of iced coffee with varying sugar content: sugar-free, trace-sugar, and ordinary, were prepared as base beverages. As demonstrated in Section III-D3, we conducted evaluation experiments using three types of scents (coconut, chocolate, and crème brûlée) which received higher evaluations in combination with iced coffee during the preliminary experiments. To prevent bias due to the order of smelling the scents, three experimental patterns with different order of scents were prepared and conducted, as shown in Table 4. Additionally, to prevent bias from the

[3] https://aromajoin.com/products/aroma-cartridge

TABLE 3. Information of participants.

Sex	Age		Frequency of drinking	
	20s	over 30s	Frequently	Rarely
Male	9	6	8	7
Female	11	7	8	10

TABLE 4. Type of experiment 1.

	Group1	Group2	Group3
C1	Sugar-free Coffee	Sugar-free Coffee	Sugar-free Coffee
C2	Sugar-free+Coconut	Sugar-free+Chocolate	Sugar-free+Crème brûlée
C3	Sugar-free+Chocolate	Sugar-free+Crème brûlée	Sugar-free+Coconut
C4	Sugar-free+Crème brûlée	Sugar-free+Coconut	Sugar-free+Chocolate
C5	Trace-sugar Coffee	Trace-sugar Coffee	Trace-sugar Coffee
C6	Trace-sugar+Coconut	Trace-sugar+Chocolate	Trace-sugar+Crème brûlée
C7	Trace-sugar+Chocolate	Trace-sugar+Crème brûlée	Trace-sugar+Coconut
C8	Trace-sugar+Crème brûlée	Trace-sugar+Coconut	Trace-sugar+Chocolate
C9	Ordinary Coffee	Ordinary Coffee	Ordinary Coffee

scents, a 5-minute rest period was provided between each stimulus, during which participants were allowed to drink water. After each trial, participants were asked to respond to a questionnaire regarding the taste test.

3) RESULTS OF EXPERIMENT1 (H1)

The first hypothesis was that "by presenting scent when drinking the beverage, the perceived sweetness will be amplified."

Figure 8 shows the average ratings and standard deviation results for all participants. C1 to C9 correspond to the scents listed in group 1 of Table 4. Here, the combinations of coffee and various scents are evaluated with respect to the respective coffee without scent as a baseline. Regarding taste satisfaction, none of the scents enhanced the ratings above the baseline when added to the respective base coffee. Regarding perceived sweetness, compared to sugar-free coffee without scent, the addition of coconut, chocolate, and crème brûlée scents resulted in higher ratings than the baseline. The amplification of perceived sweetness was confirmed when combining sugar-free coffee with sweet scents. However, for the trace-sugar coffee, the addition of scents resulted in ratings that were almost identical to the baseline, and results equivalent to the perceived sweetness of ordinary coffee were not obtained.

Following, the Wilcoxon Signed-Rank Test commonly used for correspondence testing between two sets of samples, was used to quantitatively compare the ratings of various scent combinations that exceeded the baseline in sweetness evaluation. The test results for the combinations of sugar-free coffee and various scents are summarized in Table 5. According to the test results, a significant difference was observed in the combination of sugar-free coffee and chocolate when compared to the baseline of sugar-free coffee without scent. This aligns with the initial experiment where chocolate scent received the highest sweetness evaluation.

To visualize the bias in opinions, the distribution of survey results obtained on a 7-point Likert scale is shown in Figure 9. The top graph shows the distribution regarding taste

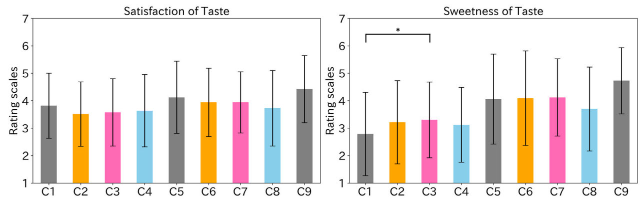


FIGURE 8. Result of experiment 1 (all of participants).

TABLE 5. Test results for the sweetness of sugar-free coffee in experiment 1.

Two pairs to compare	P-value	Significant Difference ($p \leq 0.05$)
Sugar-free Coffee & Sugar-free+Coconut	9.758×10^{-2}	-
Sugar-free Coffee & Sugar-free+Chocolate	1.641×10^{-2}	✓
Sugar-free Coffee & Sugar-free+Crème brûlée	9.508×10^{-2}	-

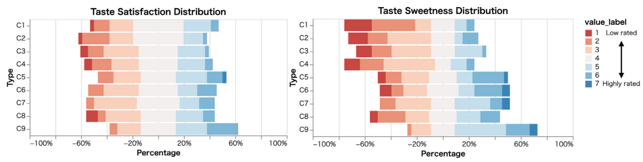


FIGURE 9. Overall analysis results distribution for experiment 1 (Top: satisfaction, bottom: sweetness).

satisfaction, while the bottom graph shows the distribution regarding perceived sweetness. Closer to 1 indicates lower ratings, and closer to 7 indicates higher ratings.

In terms of taste satisfaction, no significant bias was observed in the distribution, and individual preferences were sporadically seen in the data. Concerning perceived sweetness, many people rated sugar-free coffee with low scores of 1 or 2; however, the proportion of individuals giving low scores of 1 or 2 tended to decrease when scent was added. When chocolate was added to trace-sugar coffee, the number of ratings at 5 increased compared to the baseline, leading to a tendency for higher sweetness ratings against the baseline. On the other hand, no significant difference in sweetness was observed for trace-sugar coffee, even when scent was added as the ratings did not change significantly from the baseline.

For a more detailed analysis of the results, the following will show the analysis separated by user attributes.

4) ANALYSIS RESULTS BY USER ATTRIBUTES

a: ANALYSIS RESULTS BY AGE

In order to evaluate taste perceptions based on age differences, participants were divided into two groups, "20s" (20 people) and "30 and over" (13 people), for analysis. The mean and standard deviation results for taste satisfaction and sweetness perceptions are shown in Figure 10 and Figure 11.

Regarding taste satisfaction, there were hardly any scents that led to higher evaluations compared to the baseline. In the case of those aged 30 and over, the combination of trace-sugar coffee and chocolate was rated higher than the baseline, but not significantly so, and there was no change compared to the evaluation of all participants. As shown in Figure 11,

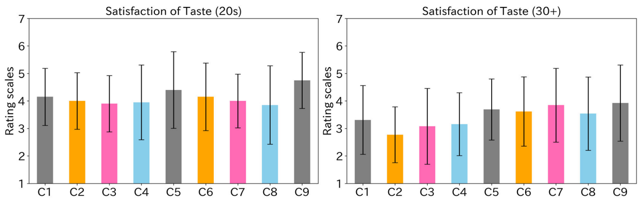


FIGURE 10. Results for taste satisfaction in experiment 1 (by age).

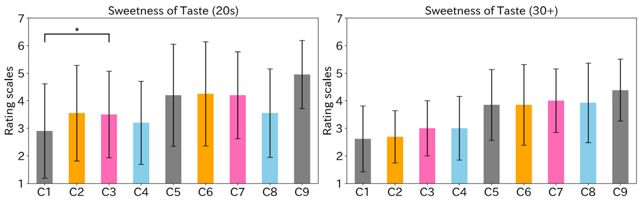


FIGURE 11. Results for taste sweetness in experiment 1 (by age).

TABLE 6. Test results for the sweetness of Sugar-free coffee by age for experiment 1.

	Two pairs to compare	P-value	Significant Difference (p ≤0.05)
20s	Sugar-free Coffee & Sugar-free+Coconut	8.918×10^{-2}	-
	Sugar-free Coffee & Sugar-free+Chocolate	3.222×10^{-2}	✓
	Sugar-free Coffee & Sugar-free+Crème brûlée	2.557×10^{-1}	-
over 30s	Sugar-free Coffee & Sugar-free+Coconut	7.477×10^{-1}	-
	Sugar-free Coffee & Sugar-free+Chocolate	2.482×10^{-1}	-
	Sugar-free Coffee & Sugar-free+Crème brûlée	2.059×10^{-1}	-

concerning sweetness, changes were observed between those in their 20s and those aged 30 and over. Both groups rated chocolate and crème brûlée higher when paired with sugar-free coffee. However, in the 20s group, the combination of sugar-free coffee and coconut scent was rated highest compared to the baseline. Although variations were seen in sweetness evaluation due to scent based on age groups, a common trend of amplifying sweetness was confirmed.

Continuing on, the Wilcoxon Signed-Rank Test was used to quantitatively compare the ratings of sugar-free coffee and various scent combinations that exceeded the baseline. The test results of the combinations of sugar-free coffee and various scents, segmented by age, are summarized in Table 6. As a result of the test, a significant difference was confirmed in the combination of sugar-free coffee and chocolate scent in the 20s group. Evaluating by age showed that the combination of sugar-free coffee and chocolate scent was effective in amplifying sweetness in the 20s group. Moreover, individuals aged 30 and over tended to rate sweetness lower compared to those in their 20s, though no significant difference was observed in ratings. As a result, analyzing by age revealed that the trend of amplifying sweetness was stronger in individuals in their 20s compared to those aged 30 and over.

b: ANALYSIS RESULTS BY FREQUENCY OF COFFEE DRINKING

To evaluate taste perception based on the frequency of coffee consumption, participants were divided into two groups: those who "drink frequently" (16 people) and those who "drink rarely" (17 people). The group that "drinks frequently" consisted of individuals who chose 5 or higher on a 7-point Likert scale questionnaire item. The mean and standard deviation results for taste satisfaction and sweetness are shown in Figure 12 and Figure 13.

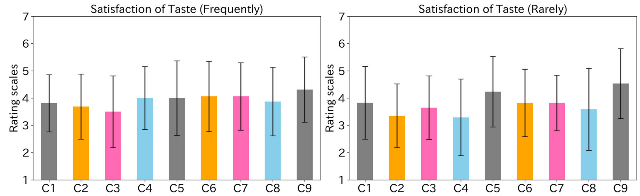


FIGURE 12. Results for taste satisfaction in experiment 1 (by frequency of drinking).

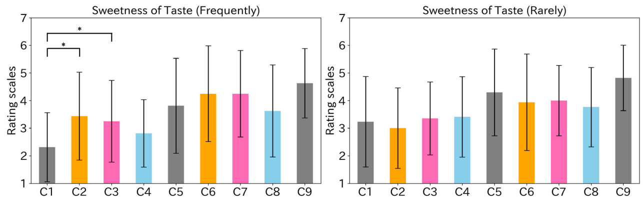


FIGURE 13. Results for taste sweetness in experiment 1 (by frequency of drinking).

Regarding taste satisfaction, hardly any scents were identified that led to higher evaluations than the baseline. However, for the group that drinks coffee frequently, there was hardly any difference in evaluations between the scent-added and baseline conditions. On the other hand, in the group that drink coffee rarely, the evaluations for when scents were added tended to be lower than the baseline.

Concerning sweetness, the results differed based on the frequency of coffee consumption. Those who drink coffee frequently tended to rate the combination of sugar-free coffee and scent higher. Moreover, in the group that drinks coffee frequently, the evaluation of the combination of sugar-free coffee and scent was similar to that of trace-sugar coffee alone. The evaluation of the combination of trace-sugar coffee and scent was also similar to that of very sweet coffee alone. However, for those who drink coffee rarely, adding a scent did not tend to enhance the perception of sweetness.

Continuing, the Wilcoxon Signed-Rank Test was used to quantitatively compare the evaluations of sugar-free coffee and various scent combinations that exceeded the baseline. The test results for the combinations based on coffee drinking frequency are summarized in Table 7. Based on the test results, significant differences were observed in the combination of sugar-free coffee with coconut and chocolate scents for the group that drinks coffee frequently. As shown in Table 8, there was no significant difference in evaluations between sugar-free coffee combined with coconut and trace-sugar coffee alone. Similarly, there was no significant difference in evaluations between trace-sugar coffee combined with coconut and chocolate and very sweet coffee alone. This means that despite different sugar levels,

TABLE 7. Test results for the sweetness of Sugar-free coffee by frequency of drinking for experiment 1.

	Two pairs to compare	P-value	Significant Difference (p ≤0.05)
Frequently	Sugar-free Coffee & Sugar-free+Coconut	1.111×10^{-2}	✓
	Sugar-free Coffee & Sugar-free+Chocolate	1.112×10^{-2}	✓
	Sugar-free Coffee & Sugar-free+Crème brûlée	1.237×10^{-1}	-
Rarely	Sugar-free Coffee & Sugar-free+Coconut	5.211×10^{-1}	-
	Sugar-free Coffee & Sugar-free+Chocolate	6.077×10^{-1}	-
	Sugar-free Coffee & Sugar-free+Crème brûlée	4.169×10^{-1}	-

TABLE 8. Test results for sweetness by frequency of drinking in experiment 1 (frequency of drinking).

Two pairs to compare	P-value	Significant Difference (p ≤0.05)
Sugar-free+Coconut Trace-sugar Coffee	1.769×10^{-1}	-
Sugar-free+Chocolate Trace-sugar Coffee	4.573×10^{-2}	✓
Sugar-free+Crème brûlée Trace-sugar Coffee	2.055×10^{-2}	✓
Trace-sugar+Coconut Ordinary Coffee	4.037×10^{-1}	-
Trace-sugar+Chocolate Ordinary Coffee	3.881×10^{-1}	-
Trace-sugar+Crème brûlée Ordinary Coffee	2.025×10^{-2}	✓

the scent amplified sweetness, resulting in no difference in evaluations. As a result, analyzing by coffee drinking frequency showed that those who drink coffee frequently had a stronger tendency for sweetness amplification than those who don't.

After verifying the hypothesis, it was confirmed that presenting scent when drinking beverages tends to amplify the perception of sweetness. These results suggest that while sweetness amplification was observed with only olfactory intervention, further sweetness amplification is possible by stimulating other sensory organs. In the next section, in addition to olfactory intervention, the effect of visual intervention on sweetness perception was investigated.

C. EXPERIMENT 2: EVALUATION EXPERIMENT OF H2

In this study, we conducted sensory evaluation experiments using the prototype of Aromug as shown in Figure 6(b) to investigate the impact of visual stimuli on taste perception. The experiments utilized iced coffee, and a survey was conducted to evaluate the taste of three different types of iced coffee with varying sugar levels, in combination with olfactory and visual interventions.

1) PARTICIPANTS OF EXPERIMENT 2

In Experiment 2, 15 students from the laboratory (aged between 20s and 30s) participated. There were no health concerns with the participants (no symptoms like cold or fever), and the experiments were conducted under normal conditions of taste and olfaction.

2) OVERVIEW OF EXPERIMENT 2

In Experiment 2, three types of iced coffee with different sugar levels - sugar-free, trace-sugar, and ordinary, were prepared as base beverages, and chocolate scent was used for the olfactory part. The experiments were conducted in three patterns: no intervention, olfaction only intervention, and olfaction and visual intervention. For the visual intervention, a display was installed at the top of the mug, projecting a simulated coffee image. The survey conducted in all

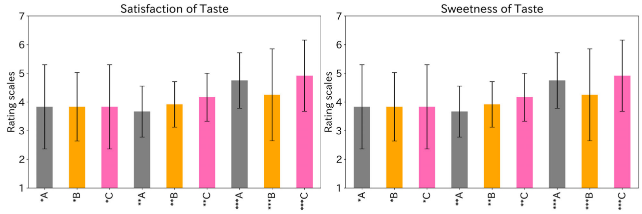


FIGURE 14. Results of experiment 2 (A: No intervention, B: Scent, C: Scent + visual).

the experiments adopted a 7-point Likert scale, where participants evaluated the satisfaction and sweetness of taste upon consumption.

3) RESULTS OF EXPERIMENT 2 (H2)

The second hypothesis was that "Approach 2, with visual and olfactory stimuli, amplifies sweetness more than Approach 1."

The mean values and standard deviations of taste satisfaction and sweetness ratings due to visual intervention are shown in Figure 14. "A" represents no intervention, "B" represents olfaction only intervention, and "C" represents olfaction and visual intervention. Regarding taste satisfaction, there was a tendency for increased satisfaction when visual effects intervention was used compared with only olfaction intervention. In the scent effect experiment, there was no tendency for taste satisfaction to improve with olfaction only intervention, however, a tendency for taste satisfaction to improve was observed with visual intervention. Similarly, for taste sweetness, there was a tendency for sweetness to be amplified with visual effects compared to olfaction only intervention. In other words, visual effects were confirmed to significantly enhance the user's beverage experience, affecting satisfaction and sweetness amplification.

Upon verification of the hypothesis, it was observed that interventions in the visual aspect, compared to when only olfaction was intervened, had stronger tendencies for enhancing taste satisfaction and sweetness amplification. This implies that intervention in other sensory organs is crucial for realizing taste enhancement, as was confirmed through this exploration.

V. DISCUSSION

Thus far, by verifying H1 and H2, we have demonstrated that Aromug is effective in amplifying the sweetness of taste through interventions in olfaction and vision. This also showcased the potential to support behavioral changes aimed at reducing sugar intake in the future. In this chapter, we will discuss the findings obtained from this study and deliberate on further experimental designs that could possibly enhance sweetness amplification.

A. USABILITY STATUS AND ISSUES (H1)

Participants have left comments on their experience when using Aromug.

"When I drank it, I could smell the scent and it felt sweeter. It was a strange experience."

It was observed that the sweet scent influenced the perceived amplification of sweetness. In this regard, many found the taste to be sweeter than usual, however, there were not ample opinions regarding the satisfaction with Aromug. Several factors could account for this. Below is an actual comment from a participant:

"I reacted to the sound during the scent emission and thought I had to drink during that time."

This implies that the olfactory device used emitted a noticeable sound while dispensing the scent. The proposed device utilizes an air pressure pump to emit the scent, which may cause initial users to get surprised by the unfamiliar noise compared to regular drinking experiences, potentially leading to a decrease in satisfaction. To address this issue, future work will focus on exploring mechanisms to reduce the noise generated during scent emission, aiming to enhance user comfort and alleviate concerns about the device. Another factor could be that the effect of working on olfaction alone did not render satisfaction. This suggested the need to investigate the impact of visual interventions on taste satisfaction, not just olfactory. From other participants' comments we hear:

"There was no unpleasant scent, and there was no issue with the amount of scent dispensed. However, it was scary not knowing what kind of scent would come out when using it for the first time."

This comment underlines the necessity to the initial use anxiety during the first scent emission.

Additionally, in the evaluation of taste sweetness, a significant difference was observed when trace-sugar coffee was augmented with chocolate scent, but no significant difference was noted with other scents. While individual preferences for scents vary, it became clear that there is a need to explore scents other than chocolate that generally amplify sweetness. In conducting long-term experiments, providing a variety of scents can aid in sustaining user engagement. Therefore, there's a necessity to further explore scents effective in enhancing sweetness amplification.

1) DIFFERENCES IN PREFERENCE TENDENCIES BY USER ATTRIBUTES

a: CONSIDERATIONS ANALYZED BY AGE

Regarding taste satisfaction, there was no difference in evaluation between the group in their 20s and those over 30, and there was no variance in evaluation across all participants. However, there was a difference in evaluations regarding the sweetness of taste between groups. In the group in their 20s, the evaluation increased when a coconut scent was added, whereas in the group over 30, there was a tendency for higher evaluations when a crème brûlée scent was added. This suggests a change in how scents are perceived with age, possibly influenced by the decline in olfactory function with aging. In fact, it is generally known that the ability to identify scents varies with age [31], [32]. Furthermore, research by Wysocki and Gilbert [33] reported that olfactory decline is seen in males in their 20s and females in their 40s. Also, differences in preferred foods between older individuals and younger groups have been confirmed [34], showing varied food preferences due to age differences. Similar results were obtained in this experiment as well.

b: CONSIDERATIONS ANALYZED BY FREQUENCY OF DRINKING

Participants who frequently drink coffee left the following comment:

"The taste of coffee is weak. I wanted to taste coffee extracted from beans."

People who drink coffee frequently felt that the coffee used in this experiment was weak in taste, tending to give lower evaluations to the sweetness baseline of sugar-free coffee. In this experiment, pod-bottled coffee was used, suggesting that the richness and depth inherent to coffee influenced the taste perception. In the future, it will be necessary to conduct experiments with richer and more robust coffee, and evaluate accordingly. Additionally, scent perception varies with temperature and humidity, generally evaporating easier at room temperature, and with increasing temperature, more scent molecules disperse into the air. This experiment used iced coffee as the beverage, but there is a need to conduct experiments with warm beverages, which are generally easier to scent, to evaluate taste satisfaction and sweetness perception.

Also, those who frequently drink coffee tended to rate the coconut scent higher compared to other scents. This suggests that the preference for crème brûlée scent and coconut scent varies with the frequency of drinking, and in the future, this knowledge could inform scent selection according to individual attributes.

In this study, we conducted an analysis based on attributes such as age and coffee consumption frequency. In the future, we can gain a more detailed understanding of the effects of Aromug through experiments that incorporate individual preferences for aroma and taste.

B. USABILITY STATUS AND ISSUES (H2)

The intervention through vision, as opposed to scent alone, confirmed a tendency for improved taste satisfaction and sweetness amplification. This shows the influence of visual cues on taste, suggesting that visual stimuli contributed to improving taste satisfaction and sweetness. Visual information is a crucial source for predicting food flavor, which might explain the improved taste satisfaction and sweetness. These results align with past studies [35], [36], proving the effectiveness of visual intervention for enhancing human taste perception.

On the other hand, a comment from a participant was noted:

"I unconsciously close my eyes when drinking, so I don't look at the display."

From this comment, it is clear that there's a difference in drinking habits among users, with some keeping their eyes open while drinking and others not. For those who close their eyes while drinking, evaluating the taste would solely rely on olfactory intervention, hence there is a need to explore more effective ways of presenting olfactory information.

For example, changing the way olfactory information is presented may potentially improve taste sweetness and satisfaction. There are two types of olfactory intervention: "Orthonasal smell," which is the scent that wafts to the nose, and "Retronasal smell," which is the scent of the food that enters the mouth and exits through the nose. In this study, only orthonasal olfactory intervention was explored, but there's potential that intervening with retronasal smell could alter the taste experience.

C. LIMITATIONS AND FUTURE WORK

1) SWEETNESS AMPLIFICATION METHOD

Through experimentation, we have demonstrated thus far that Aromug is a promising approach for enhancing perceived sweetness. However, there are several limitations. Firstly, while the augmentation of sweetness through the use of scents was confirmed, the variety of scents effective in enhancing sweetness are limited. Hence, further investigation into scents effective for augmenting sweetness is desirable. As the perception of scents varies among users, having a broader selection of scents effective in enhancing sweetness would be ideal. In relation to this, there is a need to explore beverages to be used with Aromug. In this experiment, coffee was used as the beverage, but the types of scents effective in enhancing sweetness may change with different beverages. Therefore, it is necessary to conduct experiments using other beverages, such as tea which has potential to lower the onset risk of diabetes [37], to verify if the trend of enhanced sweetness is observed outside of coffee. The use of various types of beverages in this study can potentially provide a more comprehensive understanding of the applicability of Aromug.

Another limitation lies in our olfactory approach. Until now, our group has been focusing on the development of a mug-shaped olfactory device that augments perceived sweetness by presenting a sweet scent while drinking, capitalizing on the fact that a large part of what is recognized as "taste" is dominated by scent. However, the existing approach only encompasses the presentation of orthonasal smell (scent perceived through the nostrils), lacking the delivery of retronasal smell (scent perceived through the mouth to the nose), which might not be a sufficient design to promote taste alteration. Humans have two nasal pathways to perceive scents: the orthonasal and retronasal smells. It has been shown that olfactory information from orthonasal and retronasal smells is processed differently in the brain [38], [39], [40]. Specifically, the retronasal smell, which contributes to the flavor of food and beverages, has a strong association with taste [41]. The current proposed system affects the "orthonasal smell" perceived through the nostrils. Therefore, there is a need to design a method of scent presentation that affects the "retronasal smell". Designing a device that acts on retronasal smell and evaluating its impact on taste perception could be a promising research task for the future.

2) DRINKING SENSING FUNCTION

The current system is designed to continuously emit scents while the user is holding the mug. However, it is necessary to verify in the future at which timing the emission of scents would maximize taste alteration. While drinking a beverage, the mouth is open, and the nasal pathway is closed. This means that as soon as the user moves the mug away from their mouth, the nose opens, and the scent is inhaled, suggesting that presenting the scent at the timing when the user finishes drinking may be sufficient to perceive the sweetness. Moreover, optimizing the timing of scent emission could reduce the consumption of flavoring agents while maintaining the same taste perception for the user.

Aromug features functionalities for logging user beverage data, such as residual volume estimation within the cup, beverage type identification, and sugar level estimation of the beverage. In this analysis, an IMU sensor attached to Aromug was utilized for a basic evaluation of the residual volume estimation function. Moving forward, it will be necessary to implement the beverage type identification and sugar level estimation functions. For instance, there are studies like those utilizing smartphone vibrations for beverage type and concentration estimation [42], and others employing electrical impedance spectroscopy to estimate the water volume in the cup, beverage type, and sugar level in the beverage [43]. In the future, considerations will be made towards these methods, and features for estimating the type and sugar content of the beverage poured into the cup will be added. Additionally, as the visual effect experiment only featured a simple display on the top of the mug, there will be designs for devices that can expand the beverage experience, such as controlling the display based on user beverage sensing.

VI. CONCLUSION

In this study, we proposed Aromug and presented experimental results exploring the optimal scent for amplifying the sweetness of iced coffee for 33 subjects. Additionally, the experimental results for sweetness amplification perceived through visual stimuli were presented for 15 subjects. The results demonstrated that adding scent to iced coffee significantly enhances the perception of sweetness. Particularly for sugar-free coffee, the addition of a chocolate scent confirmed an amplification of perceived sweetness. Variations were observed in taste perception according to user attributes, providing insights for future context-aware scent presentation based on user attributes. The presentation of scent along with visuals tended to enhance taste satisfaction and perceived sweetness more than presenting scent alone. Furthermore, long-term studies investigating the changes in sugar intake with the proposed device can be expected to provide valuable insights into this field by exploring its potential as a tool for promoting dietary improvements.

By conducting experiments with 33 subjects and analyzing by user attributes, sufficient results, such as differences in preference tendencies between groups, were obtained in the current system. However, the existing approach is limited to presenting orthonasal smell, missing out on presenting retronasal smell, which indicates a limitation in prompting taste alterations. There is a need to consider approaches towards retronasal smell for extending taste perception. Designing devices that act on retronasal smell and conducting taste evaluations in the future will verify the potential for taste extension through retronasal smell.

Furthermore, as one of the beverage sensing functions equipped in Aromug, the residual volume estimation function in the cup was evaluated. As a result, the volume estimation error was found to be 1.502g, achieving satisfactory results. Currently, it only covers residual volume estimation in the cup, but implementing beverage type identification and sugar level estimation functions will be necessary for logging of healthy beverage consumption. By exploring inventive scent presentation and designing devices to enhance user beverage experiences in the future, we aim to actualize behavioral modifications towards reducing sugar intake among users, which is the objective of this research.

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