

Vocktail: A Virtual Cocktail for Pairing Digital Taste, Smell, and Color Sensations

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ABSTRACT

Similar to the concept of a cocktail or mocktail, we present Vocktail (a.k.a. Virtual Cocktail) - an interactive drinking utensil that digitally simulates multisensory flavor experiences. The Vocktail system utilizes three common sensory modalities, taste, smell, and visual (color), to create virtual flavors and augment the existing flavors of a beverage. The system is coupled with a mobile application that enables users to create customized virtual flavor sensations by configuring each of the stimuli via Bluetooth. The system consists of a cocktail glass that is seamlessly fused into a 3D printed structure, which holds the electronic control module, three scent cartridges, and three micro air-pumps. When a user drinks from the system, the visual (RGB light projected on the beverage), taste (electrical stimulation at the tip of the tongue), and smell stimuli (emitted by micro air-pumps) are combined to create a virtual flavor sensation, thus altering the flavor of the beverage. In summary, this paper discusses 1) technical details of the Vocktail system and 2) user experiments that investigate the influences of these multimodal stimuli on the perception of virtual flavors in terms of five primary tastes (i.e. salty, sweet, bitter, sour, and umami). Our results suggest that the combination of these stimuli delivers richer flavor experiences, as compared to separately simulating individual modalities, and indicates that the types of pairings that can be formed between smell and electric taste stimuli.

CCS CONCEPTS

•Human-centered computing → Mixed / augmented reality;

KEYWORDS

virtual taste, virtual flavor, digital taste, electric taste, virtual cocktail, vocktail

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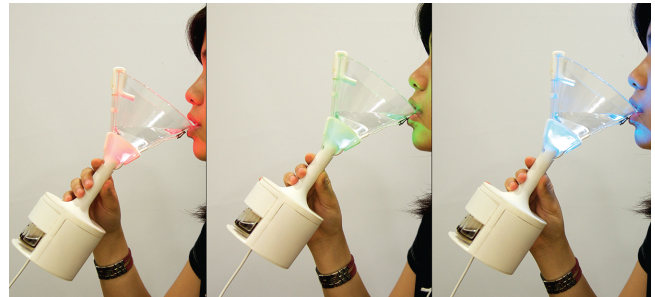


Figure 1: A participant interacts with the Vocktail system.

1 INTRODUCTION

People relish flavored beverages and use various drink mixers (or ingredients) to enhance, adjust, or create new flavor sensations (a.k.a. mixing). For example, the concepts of the cocktail and the mocktail, which are deeply associated with humans drinking culture, are all about mixing multiple ingredients or other beverages such as spirits, sodas, juices, syrups, and food colorings, despite their alcoholic or non-alcoholic natures. These various mixes of drinks alter different factors that influence the flavor of a beverage such as color, appearance, viscosity, as well as taste and smell sensations. Moreover, at present, the craft of mixing drinks to create different flavored beverages is also known as mixology [22].

In addition to mixing various drink recipes in the art of mixology, the concept of flavor-pairing (or food-pairing¹) studies intrinsic properties of different food ingredients and items to explore how they can be mixed together based on their key flavor components, or basic taste properties [1]. These concepts not only enhance the flavor of existing recipes but also assist in creating new nontraditional recipes. However, thus far, similar concepts cannot be experienced in the digital world due to the lack of digital techniques for augmenting the flavors of foods or beverages. Additionally, as individuals commonly find a particular flavor is not to their preference, there exists a need to develop digital technologies for customizing flavors.

To enable these interactions in the digital world, and to introduce flavor as a digitally controllable media, we have developed Vocktail (Virtual Cocktail). As shown in Figure 1, Vocktail is an interactive

¹<https://www.foodpairing.com/>

system capable of providing taste, smell, and visual stimuli to augment flavor experiences. The system has three main components: a cocktail glass, a 3D printed structure housing the electronics, and a mobile application. The cocktail glass is fused into the 3D printed structure to provide digital flavor augmentations. Since it takes the shape of a common glass, the system is portable and intuitive to use. The 3D printed structure has three modules to simulate different virtual flavor stimuli: 1) color using an RGB Light Emitting Diode (LED), 2) smell using micro air-pumps and scents in liquid state, and 3) taste through electrical stimulation at the tip of the tongue.

This system superimposes a new layer of virtual flavor on beverages, allowing users to experience virtual flavors just by drinking plain water. Additionally, they may also augment the flavors of existing beverages, such as soft drinks and fruit juices. The proposed method of Vocktail utilizes three concepts to simulate flavors:

- Color projected on beverage: upon seeing a glass of beverage we form a pre-taste perception in our mind based on the beverage's color, fizziness, temperature, and other physical attributes [12, 23, 29]
- Overlaying smell sensations: smells have a key role when perceiving and enjoying flavors [25]
- Digital taste simulation: controlled electrical pulses on the tip of the tongue to simulate saltiness, sourness, and bitterness while drinking the beverage [10, 18, 19]

Thus, users experience virtual flavors when they view the color-overlaid beverage, when they inhale the emitted scents and when their tongues are stimulated by the electric taste sensations during drinking (in addition to the original flavor of the beverage). The simultaneous perception of these stimuli creates augmented flavor sensations. This augmented flavor experience can be remotely controlled through a mobile app via Bluetooth, allowing users to have full control of their flavor creations.

A user experiment was conducted to investigate the influences of these multimodal stimuli on the perception of virtual flavors in terms of five primary tastes (i.e. salty, sweet, bitter, sour, and umami). Four specific objectives were set to explore the users' perception of virtual flavors in terms of: 1) combining three modalities (visual, smell, and taste), 2) the influences that smell and electric taste have on one another, 3) how users perceive the complexity of a virtually flavored beverage, and 4) liking responses. We hypothesized that the influence of smell and electric taste on the combined flavor sensation can be better understood by comparing two distinct smells when they are paired with the same electric taste. Two electric taste modes, salty and sour, were chosen as these two sensations have higher accuracy through electrical stimulation according to previous studies [15, 19, 20]. The two choices of pairing smell with the electric taste, named as matching and non-matching, were based on the concept of flavor congruency [2, 21]. In our everyday life, we are accustomed to taste-smell pairs through our food experiences, explaining why we call some smells 'sweet' and others 'sour'. Similarly to the pairing concept that is based on basic taste attributes, for the matching smell, we pair the electric sour taste to a smell that is commonly associated with a sour taste, lime. As the non-matching smell for the sour taste mode, chocolate was chosen as it is a food item that is perceived as predominantly sweet or bitter, rather than sour. Similarly, for the electric salty taste, a savory

smell was chosen as the matching smell, and vanilla chocolate was selected as the non-matching smell.

In the following sections we present a review of related work on simulating taste and flavor sensations (Section 2), we describe the system components and implementation of the Vocktail (Section 3) and report the findings of our user experiments (Section 4). Finally, we present a detailed discussion before concluding the paper and proposing future opportunities of this technology (Section 5).

2 RELATED WORK

Ever since the invention of Sensorama [5], one of the earliest machines developed for multisensory interactions (immersion) including taste and smell sensations, both the popular press and the general public have been excited by the possibilities associated with the digitization of flavors (ranging from medical to entertainment and everyday well-being applications). Sensorama is a mechanical device which was considered as the personal cinema of the future when first introduced. It also has significant recognition in the history of virtual reality and interactive computer graphics technologies. However, progress in similar research has been tremendously slow. Simulating the sense of flavor and utilizing it as a digitally controllable medium are still two of the least explored areas within digital media technologies. This section reviews various existing approaches in related literature that focuses on simulating or augmenting flavor sensations.

Recently, there has been an active growth in interest towards researching the simulation of taste sensations in interactive systems. Ranasinghe et al. presented Digital Taste Interface to simulate primary taste sensations based on electrical and thermal stimulation of the human tongue [14, 20]. Based on their experimental results, sour, salty, bitter, and sweet (minor) tastes were simulated through electrical and thermal stimulation on the human tongue.

FunRasa is an interactive drinking platform which enhances drinking experiences by combining techniques of overlaying different colors on the beverage and stimulating the tongue using electrical pulses through a 3D printed straw. The authors also reported similar preliminary results where different participants perceived enhanced sourness, saltiness, and bitterness [17]. Similarly, Taste+ is a project where utensils, such as a spoon and a bottle, have been embedded with digital taste technology to augment the flavors of food and beverages, respectively [19]. Again, the perception of sour, bitter, and salty sensations was reported during these studies with varying levels of intensities and accuracies.

Alternatively, Nakamura et al. have demonstrated the use of electricity for augmented gustation [10]. They applied an electric current through isotonic drinks (which contain electrolytes) and food (vegetables, fruits, and cheese) to alter their taste perceptions. In this study, the main focus was to study the change of voltage levels required to augment the flavor sensations of food items. However, applying an electric current through isotonic drinks can elicit chemical reactions (through the process of electrolysis), which may be harmful in certain situations. They have also explored and measured the latency between presentation and perception using visual and electric taste stimuli [11].

Another example of using chemicals to actuate the sense of taste is TasteScreen [9]. The system, which is attached to the top of

the user's computer screen, holds 20 different chemical flavoring cartridges that can be mixed and sprayed onto the display. Once sprayed, the user may taste the dispensed flavors by licking the computer screen. However, this approach is questionable in three aspects: 1) the use of a computer screen as the delivery medium for chemicals may not always be possible as it may damage the screen, 2) it is not easy to interact with a display using the user's tongue, and 3) the suggested user behaviors may not be feasible since others may find licking their screens distasteful.

In recent research works, the future possibilities of smell simulation technologies and smell-based interactions are envisioned. "Smelling Screen" described a new olfactory display system that can be embedded into a display. The system has fans in four corners along with liquid-state smell sources. When required, the system emits the odors in directions controlled by the fans' airflow, which creates a virtual odor experience for the viewers [8].

In "Opportunities for Odor", Obrist et al. investigated the experiences of smell and emotions that connect to them from a future design perspective. They collected a total of 439 smell stories and categorized them into ten primary groups including smell-based memory, detection, social interactions, mood, and behaviors. Later, several implications were developed based on these categories to guide smell enhanced technology designs [13]. Some of these implications were smell-enhanced storytelling, reminders with a smell, sharing smells with family members, and smells combined with everyday objects and experiences.

Apart from the research works described above, several interactive systems explored other important sensory aspects, such as sound, temperature and vibration, during the consumption of a beverage. Straw User Interface, proposed by Hashimoto et al. [4], allows users to experience virtual drinking through an interactive system. The drinking experiences are generated by referencing pre-recorded data of actual sounds, pressures, and vibrations produced by drinking from a regular straw.

"Affecting Tumbler" [27] also focuses on altering the flavor perceptions of a beverage by applying thermal sensations on the skin around the nose to simulate skin temperature changes. User studies with this system suggested that the flavor richness and aftertaste strength were significantly improved by heating up the skin around the nasal region.

Interesting research work that experimentally studied the phenomenon of colors affecting the flavor perception was conducted by Narumi et al. [12]. They describe an experiment with a pseudo-gustatory display based on the virtual color of a real drink. Here, a wireless LED module attached to the bottom of a transparent plastic cup is used to superimpose the virtual color of a customized drink. Studies with this methodology examined the cross-sensory effects of visual feedback and flavor interpretation of real drinks. The results from this suggested that different colors may induce a perception of different flavors, even with the same drink.

Similarly, there are a number of research works that have reported the influence of food and beverage colors on flavor perception [23, 24]. These studies are mainly concerned with exploring associations of food and beverage colors with the perception of flavors (such as lemon, banana, and the like) or basic taste sensations (such as sour, sweet, salty, bitter, and umami) and their intensity levels. These studies have assessed colors that people commonly

associate with specific taste sensations. For example, it has been found that green and yellow are commonly linked to sour sensations while red is linked to sweet sensations. They have also noticed slight differences in perceptions based on participants' culture and geographical region.

Also, several studies have highlighted that individuals usually have a preconception that brightly colored meals and beverages are more palatable, and that the color of the food and drink contributes to their decision of overall acceptability [3, 26]. People often get confused when they taste colorless solutions with different flavors simply due to the lack of color information.

These observations and phenomena underline the importance of multiple sensory modalities in flavor perception, in particular, the influences of color, taste, and smell modalities. Thus, primarily motivated by the aforementioned research works, we have developed Vocktail to simulate flavor sensations by digitally controlling three main modalities. Taste, smell, and color simulation technologies are merged into a single system to develop an interactive utensil where the users are able to craft various flavor stimuli using a mobile app. The key contributions of Vocktail system are:

- The ability to virtually create and experiment with flavors by digitally blending distinct color, taste, and smell stimuli.
- The ability to develop and experiment with flavors in order to assess their respective acceptance by consumers.
- The ability to craft and achieve digital controllability and repeatability of the virtual flavor sensations.
- The ability to implement virtual flavor experiences or interactions in day-to-day interactive systems.

3 SYSTEM DESCRIPTION

This section describes the implementation and technical details of the Vocktail system. As explained, the system has three modules to formulate virtual flavor stimuli: the color projection module, the smell module, and the taste simulating module. A Bluetooth Low Energy (BLE) enabled Bluno Nano² board is used as the master controller module to communicate with the mobile app. At present, the system is powered using a USB connection. The main components of the Vocktail system are displayed in Figure 2.

3.1 Color projection module

To project different colors on to the beverage, an RGB LED is attached to the bottom surface of the cocktail glass beneath a light diffusing layer (using a white colored diffuse-paper).

3.2 Smell module

The smell-releasing module is developed based on a simple airflow mechanism using micro-sized air-pumps and small medical grade polyurethane tubes. The module currently consists of three micro air-pumps connected to three smell chambers. Once activated, the smell molecules are released on the surface of the beverage, which is close to the user's nose when drinking (orthonasal olfaction). The main control module is capable of activating one or more air-pumps depending on the virtual flavor stimuli crafted on the mobile app. We also incorporate a mechanism to easily refill the

²<https://www.dfrobot.com/product-1122.html>

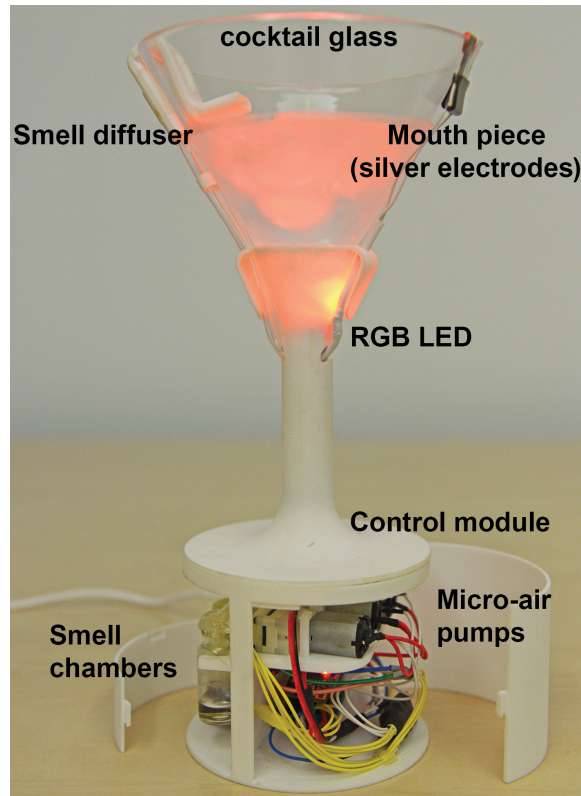


Figure 2: Different components of the Vocktail system. When a user drinks from the mouthpiece, controlled electrical pulses are applied through silver electrodes to simulate tastes. Smells are also released near the user's nose, while the colored light is projected onto the beverage.

scents inside the smell chambers similar to replacing cartridges in a printing device. To control the intensity of the smell stimuli, the Pulse-Width Modulation (PWM) technique is employed. This implementation has two distinct benefits: low power operation and relatively fast delivery of smell sensations. It has been observed that the average time required for smell molecules to travel from a smell chamber to the surface is approximately one second.

3.3 Taste simulating module

To simulate different taste stimuli in the Vocktail system, we have incorporated the electric taste technology as explained in [16, 19]. A constant-current source is implemented to output controlled electrical pulses, which ensures that the electrical stimuli are not altered depending on the resistance of the user's tongue [7, 20]. Two silver electrodes (95% silver) are attached to the top rim of the cocktail glass as a mouthpiece. While drinking, this mouthpiece ensures that the user's tongue connects with the electrodes to correctly simulate electric taste sensations. Following settings are used to deliver three different electric tastes:

- Sour: magnitude of current: $180\mu\text{A}$, PWM duty cycle: 67%
- Salty: magnitude of current: $40\mu\text{A}$, PWM duty cycle: 20%
- Bitter: magnitude of current: $80\mu\text{A}$, PWM duty cycle: 43%

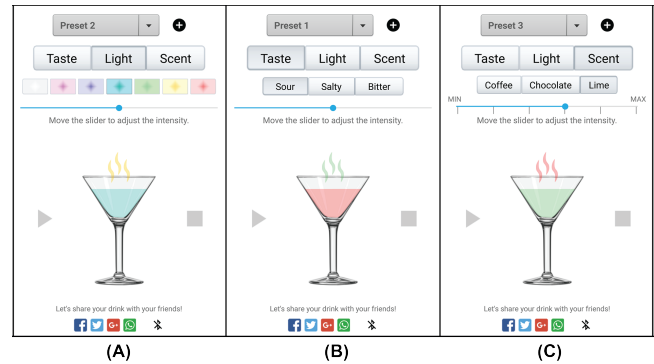


Figure 3: UI of the mobile app: (A) customize the projected color, (B) customize the electric taste, and (C) customize the smell sensations.

3.4 Mobile application

As shown in Figure 3, a mobile application has been developed that enables users to craft virtual flavors by remotely controlling the system's different stimuli and their relative intensity levels. Once the virtual flavor sensation is crafted, the flavor message is sent to the Vocktail system via Bluetooth. Play and stop buttons on the left and right sides of the UI are used to "play" and "stop" the virtual flavor in the system. Furthermore, the crafted virtual flavor sensations can be saved as presets or shared in social networks.

4 EXPERIMENTAL EVALUATION

To determine the effectiveness of this approach, we conducted a user experiment that investigates the influences of these multimodal stimuli on the perception of virtual flavors, when drinking plain water with regard to five primary tastes (i.e. salty, sweet, bitter, sour, and umami). We hypothesized that the participants will have an altered (enhanced or reduced) degree of flavor experience when overlaying virtual flavors on water due to crossmodal effects.

4.1 Participants

Participants were randomly chosen from the university staff and students, without any prior knowledge of the experiment. None of the participants were smokers and all were in good health with no taste or smell-related issues. They were instructed to not consume any foods or beverage that were excessively spicy, hot, cold, sweet or strong-flavored (e.g. coffee) at least one hour prior to the test. This instruction was to minimize factors that could possibly affect the sensitivity of their taste buds, or bias due to the lasting effects of previously consumed food or beverages. To minimize the perception bias, participants were also advised not to be too thirsty nor too full and drink sufficient amounts of water 15 minutes before the experiment.

4.2 Apparatus and stimuli configuration

As shown in Figure 4, the experiment was conducted in a quiet air-conditioned meeting room over four days for four different flavor pairings. The four different flavor pairing configurations were: 1) **Salty1** (electric salty taste + matching smell + blue), 2) **Salty2**

Stimuli	Salty1 and Salty2	Sour1 and Sour2
Taste	Electric salty	Electric sour
Color	Blue	Green
Matching smell	Squid ink ³	Lime ⁴
Non-matching smell	Vanilla ⁵ (with a hint of chocolate)	Chocolate ⁶

Table 1: The stimuli configurations.

(electric salty taste + non-matching smell + blue), 3) **Sour1** (electric sour taste + matching smell + green), and 4) **Sour2** (electric sour taste + non-matching smell + green). A summary of the stimuli configurations is presented in Table 1. Bottled water without any color, taste or smell characteristics was used throughout the experiment to ensure no interference with the stimuli of interest. Room lighting was adjusted to medium brightness to highlight the virtual color projection on the drink. The Vocktail system was cleaned with water and sanitized with 70% isopropyl alcohol after each participant and cleaned again with deionized water before the next volunteer.

For the controlled experiments, electric sour and electric salty tastes were selected as these two taste sensations were reported as dominant tastes during prior experiments in the electrical stimulation of tastes [10, 15]. Electric taste and color pairs (salty + blue and sour + green) were chosen to be matching stimuli combinations based on related literature [6]. Squid ink was used to provide a matching smell for the electric salty taste due to its savory characteristics, which remind participants of salty and umami tastes when received via orthonasal olfaction. In contrast, as people perceive the smell of vanilla with a hint of chocolate to be a sweeter sensation, this was used to provide the non-matching smell for the electric salty taste. Similarly, to deliver a matching smell with the electric sour taste, the essential oil of fresh lime was used, while the smell of chocolate was used as the non-matching pair with electric sour taste. All smell substances were in a liquid/semi-liquid state and were stored in separate chambers for the experiment.

4.3 Experimental method

Twenty-one participants (17 male and 4 female), aged between 18 and 33 (mean = 26.7, $M = 26$, $SD = 3.7$) were recruited to evaluate flavor pairing configurations for the electric salty taste (i.e.: Salty1 and Salty2). Twenty participants (16 male and 4 female), aged between 18 and 33 (mean = 26.6, $M = 26$, $SD = 3.8$) were recruited to evaluate the flavor pairing configurations for the electric sour taste (i.e.: Sour1 and Sour2). In each session, participants tasted the drink four times from the Vocktail system, each time corresponding to a different combination of stimuli. These four sets were: 1) water with LED only (**LED set**), 2) water with an electric taste only (**Electric taste set**), 3) water with a smell only (**Smell set**), and 4) water with LED + Taste + Smell (**Combined set**). The participants spent approximately 10 seconds tasting each set, enough time for them to take two sips of water. In the Smell set and Combined set, the air



Figure 4: Experimental setup: a participant is experiencing the Vocktail system.

pump was activated for 10 seconds. After tasting each set, participants answered one of the four sections of the questionnaire. Once all four sets had been completed, they were combined to provide one complete survey for the respective flavor pairing configuration (electric taste + color + smell). The order of different flavor pairing configurations and above-mentioned stimuli sets was randomized to ensure there was no order bias.

Demographic information of the participants, complexity and the intensity of perceived taste sensations, along with hedonic data were collected using the online questionnaire. Complexity of the virtual flavors was measured using the question “How complex is this drink flavor? (whether you perceive many or few taste sensations)”. Participants were asked to rate their answer on a continuous 5-point scale, with marker words at two ends: 1(simple), 5 (complex).

The participants’ perceptions of the basic taste attributes of each set of stimuli were evaluated using a rate-all-that-apply (RATA [28]) test with a 5-point Likert scale. This included the following keywords: “Not at all”, “Weak”, “Moderate”, “Strong”, “Very strong”. The attributes in the RATA questions were five basic tastes: “Salty”, “Sweet”, “Bitter”, “Sour”, “Umami”. While this simple list of words might not capture a full profile of the virtual flavor (may include attributes relating to the smells), the simplification helps to decrease training time as all participants were familiar with these terms. Furthermore, liking scores were measured using a 7-point Likert scale, including the following keywords: “Dislike strongly”, “Dislike moderately”, “Dislike slightly”, “Neither like nor dislike”, “Like slightly”, “Like moderately”, “Like strongly”.

4.4 Data analysis

All data collected (on 5-point or 7-point scales) was normalized and visualized the average mean scores for each configuration. A one-way MANOVA was applied to analyze the results of RATA data for intensity of primary tastes perceived in four stimuli sets of each flavor pairing configuration. The results revealed differences among perceived taste when different flavor configurations were employed. The five dependent variables were normalized scores of five primary taste sensations, while the independent variable was a stimulus which comprised of four groups: LED, Electric taste, Smell, and Combined. If MANOVA produced a significant p-value, lower than 0.05, it was then followed by a separate one-way repeated-measures

³<https://www.muji.com.hk/en/product/4547315283736>

⁴<https://www.aftelier.com/Lime-Chef-s-Essence-p/chefs-lime.htm>

⁵<http://www.bakeking.com.sg/products/flavours-colours/bake-king-vanilla-essence>

⁶<https://www.aftelier.com/Chocolate-Chef-s-Essence-p/chefs-chocolate.htm>

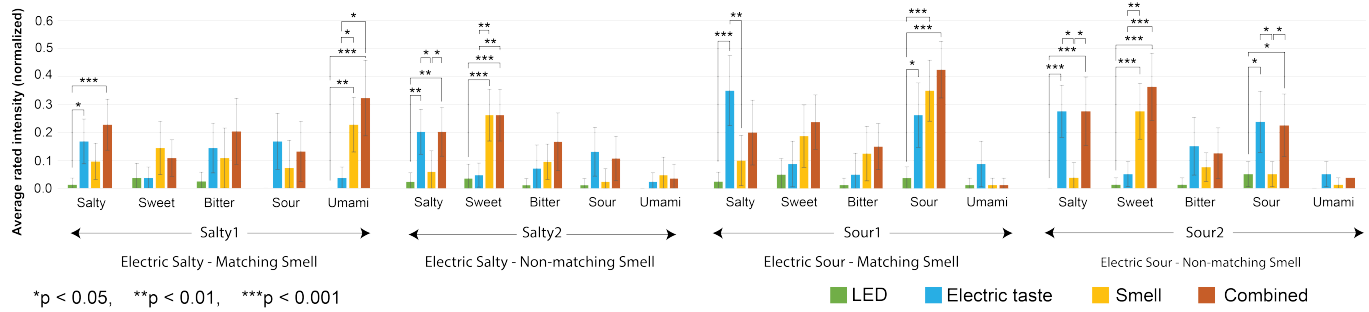


Figure 5: Average intensity scores of primary taste attributes for four different flavor pairing configurations (Error bars represent 95% CI)

ANOVA for each dependent variable, using a Bonferroni-corrected alpha level of 0.01. Additionally, for each statistically significant ANOVA result, pairwise comparisons were performed to examine which sets of stimuli contributed to the difference, together with mean score analysis to find an effect on primary taste sensations.

Complexity scores of four stimuli sets were compared using a one-way repeated measured ANOVA with Greenhouse-Geisser correction to evaluate whether users perceived a richer flavor experience. If a significant difference was detected (alpha level 0.05), post-hoc tests using Bonferroni correction for pairwise comparison were executed to reveal which sets of stimuli significantly differed from the other.

Liking scores were evaluated using a one-way repeated measured ANOVA with Greenhouse-Geisser correction to evaluate users' hedonic ratings on each set of stimuli. Post-hoc tests using Bonferroni correction were employed to detect the different pairs when there was an overall significance reported in ANOVA.

4.5 Results

As presented in Figures 5, 6, and 7, we analyzed the results based on four specific objectives: 1) perception of virtual flavors combining three modalities (visual, smell, and taste), 2) the influences that smells and electric taste have on each other, 3) complexity of a virtual flavor, and 4) liking of a virtual flavor.

4.6 Perceived taste attributes in four different flavor pairing configurations

Salty1 (as in Figure 5): There was a significant difference among the four stimuli sets when five primary taste attribute scores were grouped together for Salty1 configuration, Wilk's lambda = 0.34, $F(15, 210) = 6.627$, $p < 0.0005$, $\eta_p^2 = 0.300$. Separate ANOVAs were performed on each taste attribute, with a Bonferroni corrected alpha-level of 0.01. There was a significant difference among four stimuli for salty taste, ($F(3, 80) = 7.098$, $p < 0.0005$), and umami taste, ($F(3, 80) = 13.014$, $p < 0.0005$). For salty taste, the LED set had the lowest salty score ($M = 0.012$), and it was significantly lower than the Electric salty set ($M = 0.167$), $p = 0.014$, and the Combined set ($M = 0.226$), $p < 0.0005$. For umami taste, the Combined set had the highest score ($M = 0.321$), and it was significantly higher than the Electric salty set ($M = 0.036$), $p < 0.0005$, and LED ($M = 0.00$), $p < 0.0005$. The umami score in the Smell set ($M = 0.226$) was

significantly higher than the Electric salty set, $p = 0.013$ and the LED set, $p = 0.002$. Although there was no significant difference in the salty and umami tastes between the Smell set and Combined set, the intensities of these two tastes in the Combined set were higher than in the Smell set or the the Electric salty set. The bitterness score was higher in the Combined set compared to the Electric salty set and the Smell set too.

Salty2 (as in Figure 5): In Salty2 configuration, there was a significant difference among the four stimuli sets, Wilk's lambda = 0.438, $F(15, 210) = 4.881$, $p < 0.0005$, $\eta_p^2 = 0.240$. Separate ANOVAs with alpha-level of 0.01 revealed that there were significant differences for salty, $F(3, 80) = 6.570$, $p = 0.001$, and sweet tastes, $F(3, 80) = 11.540$, $p < 0.0005$. Specifically, the Electric salt set had a significantly higher score of salty ($M = 0.202$) than the LED set ($M = 0.024$), $p = 0.005$, and higher than the Smell set ($M = 0.060$), $p = 0.043$. The Combined set ($M = 0.202$) was significantly higher than the LED set, $p = 0.005$, and the Smell set, $p = 0.043$. For the sweet taste, the Smell set ($M = 0.262$) was significantly higher than both the LED set ($M = 0.036$), $p < 0.0005$ and the Electric salty set ($M = 0.048$), $p = 0.001$. The Combined set had a mean score of 0.262 for sweetness, and was significantly higher than the LED set, $p < 0.0005$, and higher than the Electric salty set, $p = 0.001$. It could be observed that the salty taste in the the Combined set was contributed to by the Electric salty, while the sweet taste in the Combined set was mainly due to the smell. It should also be noted that bitter taste in the Combined set was increased as compared to bitter taste in both the Smell set and Electric salty set. The bitter taste in the Smell set could be attributed to bitterness associated with the chocolate smell. However, it was interesting that this bitter taste was more profound when all three stimuli combined.

Sour1 (as in Figure 5): In Sour1, there were significant differences among the four stimuli sets when five basic tastes were considered together, Wilk's lambda = 0.373, $F(15, 199) = 5.604$, $p < 0.0005$, $\eta_p^2 = 0.280$. Individual ANOVAs were performed at alpha level of 0.01 and revealed that there were significant differences in two dependent variables which were salty, $F(3, 76) = 7.922$, $p < 0.0005$, and sour tastes, $F(3, 76) = 11.714$, $p < 0.0005$. The salty taste reported in the Electric sour set ($M = 0.350$) was significantly saltier than in both the LED set ($M = 0.025$), $p < 0.0005$ and the Smell set ($M = 0.100$), $p = 0.004$. The sour taste reported in the LED set ($M = 0.037$) was significantly lower than the sour taste reported in 1) the Electric sour set ($M = 0.262$), $p = 0.011$, 2) the Smell set ($M =$

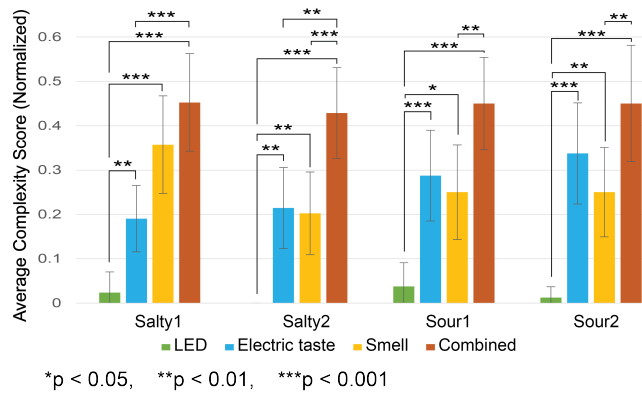


Figure 6: Complexity scores of different sets of stimuli in four different flavor pairing configurations (Error bars represent 95% CI)

0.350), $p < 0.0005$, and 3) the Combined set ($M = 0.425$), $p < 0.0005$. The taste profile of the Combined set was very similar to the Smell set, with the sour taste being the most dominant. At the same time, salty, sweet, and sour tastes in the Combined set were higher than in the Smell set. Although the differences were not significant, they suggested the effects of overlaid color and electric tastes in virtual flavor perception.

Sour2 (as in Figure 5): In Sour2, there was a significant difference among the four stimuli sets when five basic tastes were considered together, Wilk's lambda = 0.336, $F(15, 199) = 6.443$, $p < 0.0005$, $\eta_p^2 = 0.305$. Separate ANOVAs were further carried out at alpha level 0.01 and found that there were significant differences in salty taste, $F(3, 76) = 12.764$, $p < 0.0005$, sweet taste, $F(3, 76) = 16.476$, $p < 0.005$, and sour taste, $F(3, 76) = 5.913$, $p = 0.001$. The salty taste in the Combined set and the Electric sour set was similar ($M = 0.275$), but significantly higher than 1) the LED set ($M = 0.000$), $p < 0.0005$, and 2) the Smell set ($M = 0.038$), $p = 0.001$. The Combined set ($M = 0.363$) was significantly sweeter than the LED set ($M = 0.013$), $p < 0.0005$, and higher than the Electric sour set ($M = 0.050$), $p < 0.0005$. The Smell set ($M = 0.275$) was significantly sweeter than 1) the LED set, $p < 0.0005$, and 2) the Electric sour set, $p = 0.002$. For sour taste, the Electric sour ($M = 0.237$) was the highest, and significantly higher than in 1) the LED set ($M = 0.050$), $p = 0.017$, and in 2) the Smell set ($M = 0.050$), $p = 0.017$. The sour taste reported in the Combined set ($M = 0.225$) was significantly higher than in 1) the LED set, $p = 0.032$, and in 2) the Smell set, $p = 0.032$. It could be deduced that the electric sour taste has a major contribution to simulate saltiness and sourness in the Combined set, while sweetness was mainly due to the smell sensation.

4.7 Complexity

As reported in Figure 6, complexity of the virtual flavor perceived in the LED set had the lowest score, significantly lower than the other three sets. This result was expected as the LED light's intensity was lower when projected onto the plain water. This is in agreement with data presented in Section 4.6, as the LED set always received the lowest taste intensity scores.

In Salty1, a one-way repeated measures ANOVA with Greenhouse-Geisser correction revealed that there was a significant difference among the complexity scores of the four stimuli sets, $F(2.548, 50.955) = 26.585$, $p < 0.0005$. Post-hoc test using Bonferroni correction disclosed that the Combined set had a significantly higher complexity score compared to the Electric salty taste ($p < 0.0005$) and the LED ($p < 0.0005$). No significant difference was found between the Combined set and the Smell set, $p = 0.621$. This result could be due to the nature of the squid ink's smell, which was made from many different ingredients.

In Salty2, a one-way repeated measures ANOVA revealed that there was a significant difference among the complexity scores of the four stimuli sets, $F(2.597, 51.953) = 28.268$, $p < 0.0005$. The Combined set had significantly higher complexity ratings than the other three sets: 1) LED set ($p < 0.0005$), 2) Electric Salty set ($p = 0.002$), and 3) Smell set ($p < 0.0005$).

In Sour1, ANOVA results revealed that complexity scores differed significantly among the four stimuli sets, $F(2.672, 50.0774) = 19.937$, $p < 0.0005$. Post-hoc tests using Bonferroni correction showed that the complexity of taste in the LED set ($M = 0.038$, $SD = 0.027$) was significantly lower than in 1) the Electric sour set ($M = 0.288$, $SD = 0.052$), $p < 0.0005$, 2) the Smell set ($M = 0.250$, $SD = 0.054$), $p = 0.015$, and 3) the Combined set ($M = 0.450$, $SD = 0.053$), $p < 0.0005$. The Combined set was significantly more complex in terms of taste perception than the Smell set, $p = 0.005$. There was no significant difference among the Combined and the Electric sour sets, $p = 0.069$.

In Sour2, a one-way repeated measures ANOVA with Greenhouse-Geisser correction revealed that there was a significant difference among the complexity scores of the four stimuli sets, $F(2.407, 45.731) = 21.761$, $p < 0.0005$. Post-hoc tests using Bonferroni correction revealed that there was a significant difference between the LED set ($M = 0.013$, $SD = 0.056$) and the other three sets, all with $p < 0.005$. Similarly, a significant difference was also observed between the Smell set and the Combined set. It further revealed that the complexity of the Combined set ($M = 0.45$, $SD = 0.300$) was significantly higher when compared to the Smell set ($M = 0.25$, $SD = 0.229$), $p = 0.001$. There was no significant difference between the Combined and Electric sour sets ($M = 0.338$, $SD = 0.260$), $p = 0.211$.

Overall, in all four flavor pairing configurations, the Combined set had a significantly higher complexity score than the other three sets. This result proves that the simultaneous effect of three stimuli could create rich multisensory flavor experiences, hence, suggesting the potential of designing exciting virtual flavors by manipulating and combining these stimuli together.

4.8 Liking

As in Figure 7, liking scores for the LED sets in four pairing configurations received an average liking score of 0.5 (i.e. "Neither like nor dislike"). This response was expected as the LED set contained only the color stimuli on plain water, which was neutral and would not evoke a pronounced preference from the users. Hence, the liking for LED set could be considered as the baseline for this analysis and the comparison of other scores against the LED set could reveal the drive for hedonic responses from participants.

In Salty1, it was observed that liking score decreased in both the Smell set and the Combined set as compared to the LED set

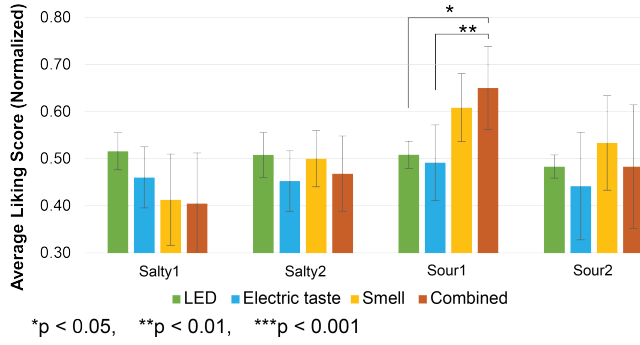


Figure 7: Liking scores of different sets of stimuli in four different flavor pairing configurations (Error bars represent 95% CI)

(although no significant difference was found). This may be due to the participants' unfamiliarity to the savory smell, squid ink. Some participants noted that they did not expect this type of smell in a beverage, hence they rated a low liking score. Familiarity and congruency between overlaid flavor and the food item could affect users' preference, as also reported in [21].

In Sour1, a significant difference in liking scores was found using a one-way repeated measures ANOVA, $F(2.284, 43.395) = 6.874$, $p = 0.002$. Post-hoc tests with Bonferroni correction revealed that the liking score of the Combined set ($M = 0.650$) was significantly higher than 1) the Electric sour set ($M = 0.492$), $p = 0.009$, and 2) the LED set ($M = 0.509$), $p = 0.047$. No significant difference was found between the Smell set and other sets. This result highlighted that combining electric sour taste with a matching smell and matching color could significantly increase users' liking. When all stimuli are in harmony and relevant to users, it is easier for users to relate to their familiar flavor sensations.

In Salty2 and Sour2, the non-matching smell was paired with the electric taste. Here, the liking scores of the four stimuli were similar, with the liking score of electric taste being slightly lower than the other three stimuli. This result is expected as some users were startled by the electrical stimulation.

5 DISCUSSION AND CONCLUSION

Experimental results of the Vocktail system revealed that interactions between color, smell, and taste modalities influenced the perception of virtual flavor sensations. Together with the complexity results, we showed that there was indeed a synergic interaction of smell and electric taste as a combined virtual flavor, rather than when they were perceived separately and discretely. This finding is promising as the way virtual flavor components are delivered is contrasting from a traditional drinking experience where the aromatic volatile compounds are released retronasally through mastication inside the mouth. In Vocktail, the smell stimuli is released orthonasally while the electric taste is only applied to the tip of the tongue. Although some participants noted the disconnection between the smell and the water in the Smell set, this effect was not observed in their rated score for the Combined set. Hence, the electric taste, together with the overlaid color, helped to convey a seamless flavor experience to the participants.

Interesting findings were observed when two contrasting smells were paired with electric taste and color stimuli. In the matching smell conditions of Salty1 and Sour1, the taste profile of the Combined set had no significant difference to the Smell set in terms of five basic tastes, but the intensity levels of all taste sensations were increased. It emphasized that the Combined set's taste profile was a cumulative effect of three modalities, visual, electric taste, and smell. This indicated that there was a consonance in taste perception between blue color, electric salty and squid ink smell, and similarly between green color, electric sour and lime smell. On the other hand, in non-matching smell conditions, a significant difference was found between the Combined and Smell sets. For example, in Salty2, the perceived saltiness in the Combined set was significantly higher than the salty scores in both the Smell and LED sets. This result suggested that the electric salty taste could alter the perception of the smell and contributed to the combined virtual flavor experience. In Sour2, the Combined set had a significantly higher score in saltiness and sourness when compared to both Smell and LED sets, which further confirmed that the addition of the electric sour taste augmented the virtual flavor experience.

It could be seen that two types of interaction between visual, electric taste and smell stimuli can be observed. The first is of a harmonic type where preferable taste sensations (coupling qualities) were enhanced, while undesirable tastes (non-coupling qualities) were reduced. Although the difference was not significant, it can be observed that the green light, electric sour and lime smell gave a combined virtual flavor that was higher in both sour and sweet scores when compared to the Smell set alone, and lower in saltiness compared to the Electric sour taste alone. In Salty1, the taste profiles of the Combined set and Smell set had similar patterns, with the Combined set having generally higher scores (with the exception of sweetness). The addition of the electric salty and blue light magnified the intensity of the tastes as noticed in the Smell set. The other type of interaction that can be observed is that of a contrasting stimuli combination, where electric taste and smell are not naturally paired. Here, the combined flavors were perceived to have all taste attributes from both electric taste and smell. Similarly, as highlighted, participants perceived stronger taste sensations when multisensory stimuli were blended together.

In conclusion, we have presented a novel interactive media system, Vocktail, that digitally simulates multisensory flavor experiences. We have also conducted an experiment to investigate the influences of digital taste, color, and smell modalities on the perception of virtual flavors. The results from our experimental pairing of virtual flavors revealed interesting interactions between different modalities as well as stimuli. In the future, it would be interesting to further explore the long-term influences of smell sensations when pairing with electric taste stimuli and vice versa. It is also possible that the pairing of electric taste with novel, unfamiliar smell and color stimuli may open up future opportunities in crafting novel flavor experiences.

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