Influence of Electric Taste, Smell, Color, and Thermal Sensory Modalities on the Liking and Mediated Emotions of Virtual Flavor Perception

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ABSTRACT

Little is known about the influence of various sensory modalities such as taste, smell, color, and thermal, towards perceiving simulated flavor sensations, let alone their influence on people's emotions and liking. Although flavor sensations are essential in our daily experiences and closely associated with our memories and emotions, the concept of flavor and the emotions caused by different sensory modalities are not thoroughly integrated into Virtual and Augmented Reality technologies. Hence, this paper presents 1) an interactive technology to simulate different flavor sensations by overlaying taste (via electrical stimulation on the tongue), smell (via micro air pumps), color (via RGB Lights), and thermal (via Peltier elements) sensations on plain water, and 2) a set of experiments to investigate a) the influence of different sensory modalities on the perception and liking of virtual flavors and b) varying emotions mediated through virtual flavor sensations. Our findings reveal that the participants perceived and liked various stimuli configurations and mostly associated them with positive emotions while highlighting important avenues for future research.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality**; **Systems and tools for interaction design**.

KEYWORDS

Human-Flavor Interaction; Virtual Flavor; Digital Gustation; Emotion; Mixed Reality; Virtual Reality; Emotional Flavor

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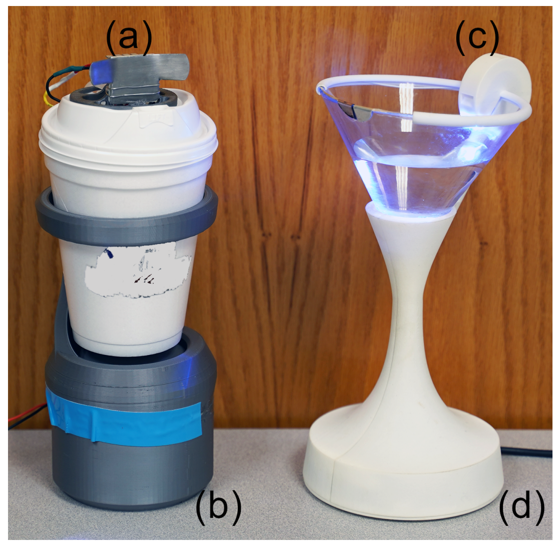

Figure 1: Two virtual flavor apparatus (Left: virtual coffee mug and Right: virtual beverage glass): (a) thermal and smell stimuli delivery, (b) & (d) electronic components and smell containers, (c) color and smell stimuli delivery.

1 INTRODUCTION

The concept of flavor is richly used in our everyday lives. Flavor is a multimodal sensation that is mainly determined by the taste and smell modalities [2]. Additional modalities such as color, texture, temperature, and sound also contribute towards the perception of flavor sensations. It is known that the flavors in our foods and beverages evoke vivid, colorful memories and emotions. Recent advancements in neurobiology and other related fields also reveal close associations of human olfaction and gustation with our memory and emotional responses [27]. Due to this entwined nature of flavor perception and emotional responses, flavors immediately remind us of a joyful holiday, being ill, or other past positive or negative memories. For example, we prefer to have a cup of tea or coffee when we are tired, eat candies when we are stressed, and sip a glass of lemonade on a hot summer day to relax - all these experiences are related to our emotions [25]. However, the contributions of various sensory modalities, including taste, smell, color, and thermal, towards flavor perception and the human emotions mediated through various modalities remain underexplored.

To study the effects of different sensory modalities on flavor perception, in this paper, we 1) present a novel approach to formulate flavor sensations by overlaying taste, smell, color, and thermal stimuli on plain water (i.e. Virtual Flavors), 2) investigate the influences of these multimodal stimuli on the perception of virtual flavors in terms of four primary taste sensations (i.e. salty, sweet, bitter, and sour), and 3) examine how different modalities affect participants emotions and liking towards a simulated flavor sensation.

As shown in Figure 1, we have developed two apparatuses, to deliver virtual flavor sensations: 1) a virtual beverage glass to simulate common beverages such as soft drinks by manipulating electric taste (electrical stimulation on the tongue via silver electrodes attached on the rim of the glass), smell (dispersed on the surface of the beverage via micro air pumps and liquid state essential oils), and color (projected on the beverage via RGB Light Emitting Diodes) sensations, and 2) a virtual coffee mug to simulate coffee beverage experience based on smell (dispersed on the surface of the beverage via micro air pumps and liquid state essential oils), and thermal (via Peltier elements attached on the disposable coffee mug) sensations. Our technology's working principle is to overlay different virtual stimuli (applying externally) when drinking from these two apparatus, enabling users to experience different virtual flavors.

Different sensory modalities are featured in two apparatus to simulate virtual beverage experiences. In virtual beverage glass, when a user drinks from the mouthpiece, colors are projected onto the beverage (visual), smells are released on the surface of the beverage (olfaction), and sour and salty sensations are applied via electrical stimulation (gustation) thus simulating common sensory modalities in everyday mixed drinks. Similarly, in the virtual coffee mug, virtual flavors are delivered through scents dispersed near the user's nose (olfaction) and thermal stimuli (hot and cold temperatures) near the user's upper lips (to simulate temperatures of coffee). Users' perception of single or combined stimuli creates virtual flavor sensations external to the plain water they consume using both apparatus, which is a novel aspect of this research.

A user experiment is conducted using both apparatus to apply different electric taste, smell, color, and thermal stimuli over plain water at room temperature. Participants were instructed to use both devices to consume virtually flavored water and provide their feedback on perceived virtual flavor sensations based on four primary taste sensations, their liking towards simulated sensations, and the emotions mediated through these flavor stimuli. Thus, key contributions of this paper are: 1) examining a wide range of digital stimuli configurations and specific changes in flavor perception with regards to four primary taste sensations salty, sour, bitter, and sweet, 2) studying participants' hedonic liking towards various stimuli configurations, 3) studying the emotions mediated through different stimuli configurations, and 4) introducing a novel approach to implement digital flavor experiences in future AR and VR technologies. Besides, the work presented in this paper contributes towards achieving the digital controllability of flavor sensations.

2 LITERATURE REVIEW

The perception of flavor is a multisensory experience that involves information from an individual or varying combinations of basic human senses (i.e., sight, sound, taste, smell, and touch) [2]. Even though the prior experiences and expectations are involved in flavor perception, it is commonly narrowed down to the intrinsic flavor components, which are the sensations of taste and smell [22]. The co-exposure of taste sensations (known as salty, sour, sweet, bitter, and umami) together with numerous smell sensations generally provide a wholesome sensory experience of the flavor [37]. Several prior works have explored the smell - taste interactions and their congruence in flavor perception; however, it remains uncertain how the overall flavor is perceived as a function of taste, smell, and other sensations [14, 29, 47, 50].

Apart from smell and taste sensations, the flavor perception is considerably influenced by the information from other sensory channels such as the vision, texture (mouthfeel), temperature, and the look and shape of eating or drinking utensils [9, 46]. Due to cross-modal interactions between colors and previous experiences with food and beverages, upon seeing them, we create a pre-perception of flavor in our mind based on their attributes such as color, presentation, fizziness, and temperature. Studies conducted on cross-sensory effects on visual stimuli and flavor interpretation (e.g., the interactive pseudo-gustatory display that superimposes virtual colors on to a drink [32]) highlight that different colors may induce different flavors regardless of the beverage presented.

In recent years, there has been a growing interest in the simulation of flavor sensations in VR, HCI [16] and consumer products [10]. Research works proposed by Ranasinghe et al. and Nakamura et al. demonstrate using controlled electrical stimuli to simulate primary taste sensations [30, 31, 38, 39, 41, 42]. In [41], the authors presented an experiment to study familiar and unfamiliar types of pairings that can be formed between smell and electric taste stimuli. The results highlight that matching smell - taste pairs increase the perception of single taste sensations (e.g., sour taste and lemon smell increase the perception of sour sensation) while non-matching pairs increase the perception of several taste sensations (e.g., sour taste with chocolate smell increases the perception of salty, sour, and sweet sensations). Additionally, Nakamura et al. applied electric current stimuli through isotonic drinks (which contains electrolytes) and food (vegetables, fruits, and cheese) to change their taste perceptions by varying voltage levels [30]. In [31], they have also measured the latency between presentation and perception using visual and electric taste stimuli.

Liking towards certain virtual flavor stimuli and mediated emotions from virtual flavor stimuli remain unexplored in VR and HCI research, especially when coupled with electric taste sensations. People's hedonic liking towards a flavor sensation is mainly based on its smell and taste sensory impressions. In addition, previous or repeated exposure, pleasant or unpleasant memories related to a specific flavor, ambience are also some of the factors affecting the liking towards a flavor sensation. As explained in [28], people also like certain flavors due to the number of calories associated with the food or drink. For example, although beverages such as beer and coffee taste bitter, people still develop higher preferences due to the calories consumed and smells released. This phenomenon is commonly known as the 'associative learning of flavors' where the liking responses are increased when the taste sensations are paired with smell sensations [11].

Flavors have a strong influence on people's emotions and vice versa - flavors can regulate and alter our emotions, at the same time,

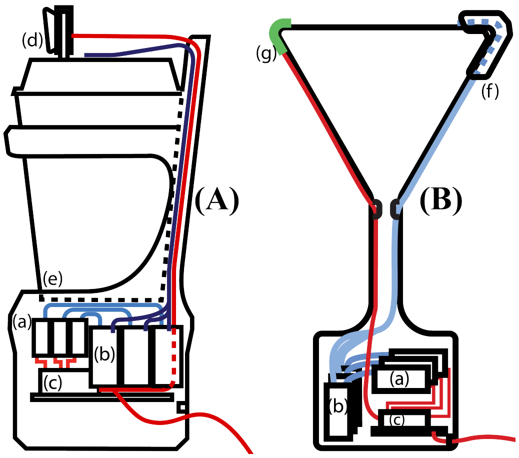

Figure 2: Different components of (A) virtual coffee mug, and (B) virtual beverage glass: (a) micro-air pumps, (b) smell containers, (c) main control module, (d) thermal module, (e) disposable coffee cup, (f) RGB color module and smell diffusing tube, and (g) electric taste module.

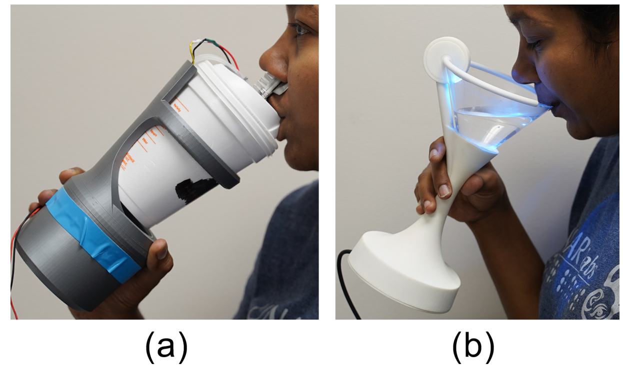

Figure 3: A participant interacts with the (a) virtual coffee mug, and (b) virtual beverage glass.

emotions can influence our food choices and appetite [3, 26, 26, 35]. However, in VR and HCI research, mediated emotions through flavor sensations are not studied in detail, let alone the influence of different flavor attributes towards people's emotions. Recently, Gayler et al. present an exploratory study on the relationship between the taste of 3D printed food and their emotional experiences [15]. Their findings indicate that the taste-emotional valence mapping (sweet as a positive and bitter as a negative emotion) extends into real-life scenarios, and the taste-emotional arousal mapping is proportional between each other (higher the taste higher the emotions).

Measuring emotions in an interactive system is uniquely challenging as people's emotions vary based on multiple factors, such as the context of use and difficulties in accurately verbalizing specific emotions. There exist many scales, such as Self-Assessment Manikin(SAM) [6], Emotion wheel [43], and EsSense Profile [33, 34], as well as many vocabulary terms to measure different emotional conditions. In this paper, we adopt the EsSense Profile to measure participants' emotions [19] as it is widely accepted in measuring emotions associated with foods and beverages, especially in sensory sciences and studies [17, 20].

3 APPARATUS DESIGN AND DEVELOPMENT

The working principle behind both virtual beverage glass and virtual coffee mug is the same. When a user takes a sip from either of these apparatus, the smell, taste, color, and thermal stimuli will be applied externally to enhance the base drink's flavors. The virtual beverage glass has three subsystems, as shown in Figure 2 (B): the RGB color projection module, the electric taste module, and the smell module. The virtual coffee mug has two subsystems, as illustrated in Figure 2 (A): the smell module and the thermal module. DFRobot's Arduino Bluno Nano [1] controls different subsystems in both apparatus. Various combinations of stimuli can be formulated and activated using a computer or a smartphone via Bluetooth.

3.1 The RGB color projection module

To simulate colored beverages, an RGB LED is attached to the virtual beverage glass (as in Figure 2 (B) (f)) that projects distinct colors based on different stimuli configuration.

3.2 The electric taste module

A constant-current source is developed in the virtual beverage glass to apply weak and controlled electrical pulses to the user's tongue while drinking, thus simulating sourness and saltiness as explained in [39, 40]. The constant-current source ensures that the electrical stimuli are not altered depending on the resistance of the user's tongue [21, 39]. Electrical stimuli are presented via two 95% silver electrodes attached to the rim of the virtual beverage glass. Electric sour and salty stimuli are formed as below:

- Sour: magnitude of current: 180μA, frequency: 800Hz
- Salty: magnitude of current: 40μA, frequency: 400Hz

3.3 The smell modules

The smell modules in both apparatus are implemented using three components: the micro air-pumps, smell containers that hold essential oils, and polyurethane tubes. Each air-pump can be actuated individually, forcing air into a specific smell container. Each container has essential oil-soaked cotton balls that acted as a medium to hold the particular scent consistently. In the virtual beverage glass, lemon and chocolate scents, as well as a spirit-like scent (prepared by mixing lime, cognac, and isopropyl alcohol), is used, while coffee, chocolate, and mint essential oils are used in the virtual coffee mug. The orthonasal olfaction approach is employed to deliver smell stimuli to the user's nose. The intensity of smell stimuli is regulated using a Pulse-Width Modulated (PWM) control algorithm to operate air-pumps in specific paces. All the essential oils are selected from Aftelier's chef's essence flavor products[2].

[1] https://www.dfrobot.com/product-1122.html

[2] https://www.aftelier.com/

3.4 The thermal module

In the virtual coffee mug, a Peltier element attached to a silver metal piece is used to apply controlled thermal stimuli on or near the user's upper lips and nose simulating hot or cold coffee experiences. A PWM control algorithm is implemented to manage the intensity of the thermal stimuli. The direction of the Peltier element (hot vs. cold) is controlled via a motor driver, which consumes approximately 7 Watts. A heat sink is attached to the Peltier module to extract the excessive heat generated on the Peltier element over time. Additional safety mechanisms are also implemented to confirm the temperatures applied are within a comfortable range.

4 EXPERIMENTAL SETUP AND EVALUATION

The primary purpose of the experiment presented in this paper was to investigate the influence of external sensory stimuli on participants' likeness and emotion-profile while consuming different virtual beverages, thus validating and supporting the concept of virtual flavor technology. The study presents two apparatus to simulate real-world experiences: 1) Virtual beverage glass that mimics the mocktail or cocktail glassware through which the liquid is visible. 2) Virtual coffee mug, which is to imitate a coffee mug or travel mug through which the liquid inside the cup is invisible.

4.1 Participants

A sample set of 30 healthy people were chosen for the study with both the apparatus. They consumed both virtual beverages and virtual coffee flavors. One participant was unable to return to consume the virtual coffee; therefore, the participant demographics are as follows. The experiment was conducted with 30 participants for the virtual beverage glass (17 male and 13 females) in the age range of 18-37 years (M = 26.42, SD= 4.8), and with 29 participants (17 males and 12 females) in the age range of 18- 40 years (M = 22.89, SD= 5.23) for the virtual coffee mug. They were instructed to refrain from consuming any food or beverages with heavy flavors such as coffee or spicy food an hour before the experiment. Furthermore, they were asked not to wear any cologne during the study and while attending their sessions to minimize external effects on the stimuli configurations. The participants gave their consent before the study, and each session took approximately 20 minutes to complete.

4.2 Stimuli configurations

The study was conducted in an air-conditioned research laboratory with minimum interference. A quiet, odor-free environment was maintained to ensure a controlled testing environment. None of the people entering the room were allowed to wear any fragrance products during the study. The minimum time gap between each participant was 30 minutes, which was adequate to reduce the lingering smells in the room. Bottled-water that is taste and odor-free was utilized to maintain the uniformity of the base drink, and avoiding any influence on the participants' flavor and emotion perceptions. The devices were sanitized using 70% isopropyl alcohol wipes before and after each testing session.

4.3 Virtual beverage glass

There were 11 different stimuli configurations in four different modalities for the virtual beverage glass, as described in Table 1.

Table 1: Stimuli configuration for virtual beverage glass.

Modality	Conditions		
Color	Red	Green	Yellow
Taste	Salt	Sour	
Smell	Lemon	Chocolate	Spirit
Combinations	Lemon + Sour + Yellow	Chocolate + Salt + Red	Spirit + Sour + Green

Table 2: Stimuli configuration for virtual coffee mug.

Modality	Conditions		
Smell	Coffee	Chocolate	Mint
Temperature	Hot	Cold	
Combinations	Hot + Coffee	Hot + Chocolate	Hot + Mint
	Cold + Coffee	Cold + Chocolate	Cold + Mint

Different stimuli configurations were selected based on prior work and to cover various combinations of visual, electric taste, smell, and thermal sensations. When choosing color stimuli, special attention was given to select natural colors from common food and beverages, in addition to the visibility of specific colors through plain water and glassware. For example, the blue color is not selected as it is less favored in food products. The color blue is considered an atypical food color as there are very few naturally occurring blue colored food [36]. Saltiness and sourness were selected as they are the two prominent taste sensations reported via electrical stimulation on the tongue [30, 39, 40]. Familiar smells such as lemon, chocolate, and spirit-like (alcohol-like) essential oils were used to formulate smell stimuli.

4.4 Virtual coffee mug

There were 11 different stimuli configurations in three different modalities for the virtual coffee mug, as described in Table 2. Familiar smells such as coffee, chocolate, and mint were used with hot and cold thermal sensations in the virtual coffee mug.

We have limited the number of possible conditions in the "combinations" category due to too many potential candidates. We noticed that participants were tired during our preliminary experiments due to repeated exposure when the experiment was too long. Furthermore, prolonged exposure, even with longer intervals between stimulus, generally results in sensory habituation (decreasing responsiveness to stimuli).

4.5 Experimental Method

During the study with virtual beverage glass, the participants were allowed to fill their apparatus with water as and when they needed between the different samples. For the virtual coffee mug, one water-filled cup was enough for a participant. Participants were informed that they are drinking plain water using both apparatus as per the Institutional Review Board (IRB) approval. The presentation order of different samples was counterbalanced to avoid the order bias. After each sample, participants were asked to complete a questionnaire to record perceived flavor sensations (in terms of four primary taste sensations), liking towards the stimuli (overall liking, smell liking, taste liking, color liking, and temperature liking), and emotions mediated through the stimuli.

The flavor sensations were recorded after each stimulus in terms of salty, sour, sweet, and bitter sensations on the JAR (Just about right) scale [22]. JAR Scale is commonly used to evaluate the appropriateness of the level of a particular attribute in a product using a five-point categorical scale ranging from 'much too little' to 'much too strong'. For example, the JAR scale determines whether a specific taste sensation is too high, too low, or just about right in a particular virtual flavor configuration. They have also rated the liking towards each stimulus on a 9-point hedonic scale, which ranges from 'extremely dislike' to 'extremely like' [22, 24].

Moreover, for each stimulus, participants were asked to check all the emotions that they can relate to on the check-all-that-apply (CATA) scale [1, 34]. As described in [13], the CATA approach is considered one of the quick and straightforward methods to gather the participants' emotions towards the flavor combinations while requiring little cognitive effort as they select all that applies related to a particular stimulus. Thus, the CATA scale was incorporated to evaluate participants' emotions, and the list of emotions was provided based on the EsSence Profile following [18]. Composite positive and negative emotion scores were created by taking the sum of the positive emotions and the negative emotions, as shown in [34]. We employed a similar questionnaire format to record participants' feedback keeping both studies consistent.

5 RESULTS

The main findings of the user experiment using two apparatus (virtual beverage glass and virtual coffee mug) are discussed in this section. Participants' responses concerning different virtual flavor stimuli and mediated emotions are recorded in a similar manner employing both apparatus, while the virtual beverage glass provided feedback on the overall liking, smell liking, taste liking, and color liking and the virtual coffee mug provided feedback on overall liking, smell liking, taste liking and temperature liking based on different modalities included in each apparatus. In each condition, repeated measures ANOVA were conducted to determine significant differences based on p-values < 0.05 and conducted follow up post hoc analysis where necessary.

5.1 Results: Virtual Beverage Glass

5.1.1 Grouping the Virtual Beverage Glass Modalities: The stimulus combinations for the virtual beverage were combined into four different modality groups. The groups are as follows, color (containing the red, green, and yellow color stimuli), electric taste (containing the salty and sour stimuli), smells (lemon, chocolate, and spirit stimuli), and combination (containing yellow+sour+lemon, chocolate+salted+red, and spirit+sour+green). These groups were chosen because the stimulus conditions within the groups share a key feature in common. For example, in the color condition, the virtual beverage conditions only contained coloring, no electric taste stimulation and no additional smell.

First, the within-group differences are assessed. The differences in overall liking, smell liking, taste liking, and temperature liking are compared within the different groupings of the stimuli. Repeated measures ANOVAs were conducted to test if there were differences in liking within the groups. This was done to ensure that the members of each group were not different so that the scores within the groups could be collapsed. There were no differences within the groups of smell liking and taste liking (p's > .05). For overall liking, there was no difference within the color, electric taste, and combination groups. There was a significant difference in overall liking within the smell group $F(2, 60) = 5.41$, $p = .007$, $\eta^2 = .091$. Tukey's post-hoc analyses revealed that the spirit smell is overall liked less than both the lemon smell ($p = .015$) and the chocolate smell ($p = .018$).

Similarly, the differences in the perception of individual sensations of salty, sour, sweet, and bitter are compared within each grouping (i.e., color, electric taste, smells, and combination) of the stimulus combinations. Repeated measures ANOVAs were conducted to test if there were differences in the perception of these sensations within their respective groups. There were no differences within groups for the perception of salt, sweet, or bitter. For the perception of sour, there were significant differences within the smell group $F(2, 60) = 4.76$, $p = .0012$, $\eta^2 = .03$, and the combination group $F(2, 60) = 4.44$, $p = .016$, $\eta^2 = .049$. Within the smell group, the spirit smell elicited stronger sensations of sour as compared to both the lemon ($p = .02$) and the chocolate ($p = .034$) smell. In the combination group, the lemon+sour+yellow combination was significantly perceived as more sour compared to the chocolate+salted+red combination ($p = .012$).

5.1.2 Comparing the Virtual Beverage Groups in Terms of Taste: Here, the perception of different virtual flavor stimuli groupings (color, electric taste, smell, and combination) was evaluated in the virtual beverage in terms of four primary taste sensations: salty, sour, sweet, and bitter. Initial inspection of data reveals differences for salty, sour, and bitter sensations (Figure 4). A repeated measure ANOVA revealed a significant difference for the perception of salty, $F(3, 90) = 8.96$, $p < .001$, $\eta^2 = .092$. Tukey's post-hoc comparisons reveal that the electric taste and the combination groups are not different from each other ($p > .05$) and are both greater than the color and smell groups ($p < .05$). Significant differences in the perception of sour were found, $F(3, 90) = 14.3$, $p < .001$, $\eta^2 = .12$. Like the salty perception, the electric taste and the combination groups were higher in sour than the color and smell groups ($p < .05$). There were also significant differences found in the perception of bitter $F(3, 90) = 9.94$, $p = <.001$, $\eta^2 = .077$. Again, the perception of bitter was greater in the electric taste group and the combination group as compared to the color and smell group $p < .05$). There was no significant difference between the groups for the perception of sweetness. Overall, the electric taste group and the combination group showed higher flavor sensations.

5.1.3 Comparing the Virtual Beverage Groups in Terms of Liking: Participants' overall liking, smell liking, taste liking, and temperature liking of the different groupings are compared to understand how the different types of stimuli configurations affect the liking towards virtual beverages. Initial inspection of the data suggests a general liking for the color group compared to the combination group (Figure 5). A repeated-measures ANOVA show a significant effect of stimulus group on overall liking ($F(3, 90) = 5.82$, $p < .001$, η^2

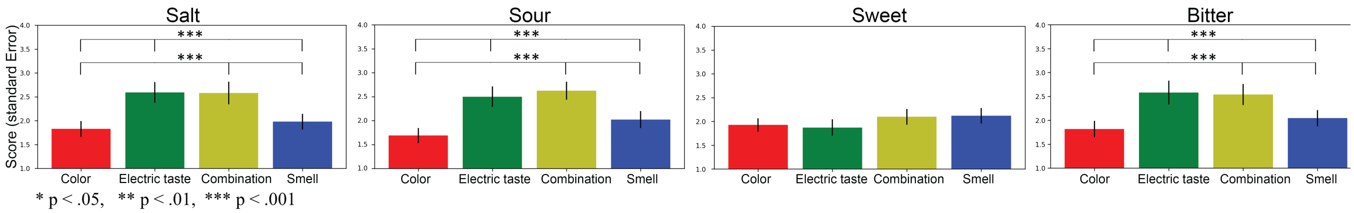

Figure 4: Average intensity scores of different stimuli groups in terms of primary taste sensations reported from the virtual beverage glass (error bars represent standard error).

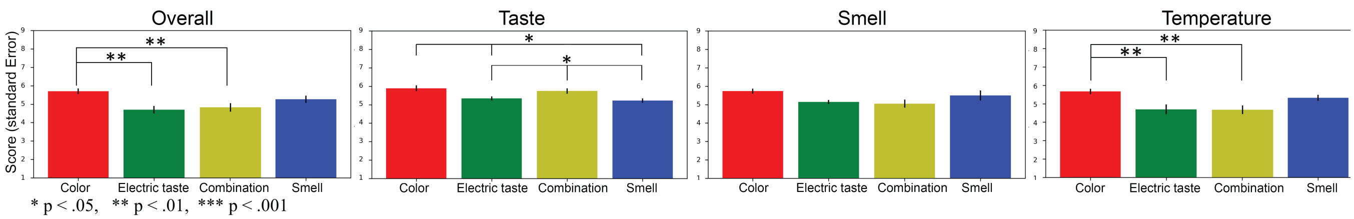

Figure 5: Average liking scores of different stimuli groups using virtual beverage glass (error bars represent standard error).

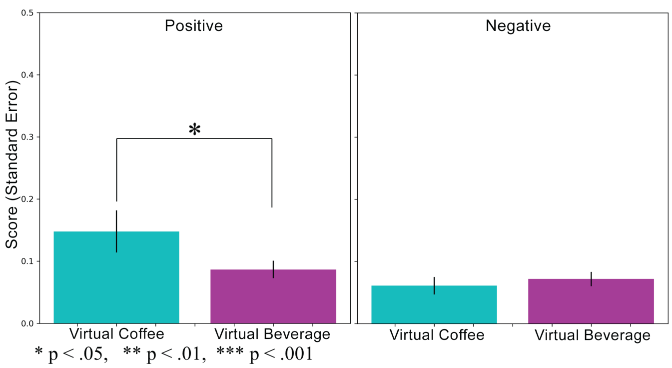

Figure 6: Positive vs. negative emotions perceived by the participants (error bars represent standard error).

= .10), taste liking ($F(3, 90) = 8.00$, $p < .001$, $\eta^2 = .12$), and temperature liking ($F(3, 90) = 5.69$, $p < .001$, $\eta^2 = .11$). Tukey's post-hoc analyses showed that participants overall liked the color group more than both the electric taste group (p = .002) and the combination group (p = .008). Participants' liked the taste of the color and the combination more than both electric taste and smell groups (p's < .05). Finally, participants liked the temperature of the color group more than the electric taste (p = .006) and the combination group (p = .004). There was no difference in how the participants liked the smell of the groups (p = .055). Overall, participants liked the color group the most but also enjoyed the taste of the combination group. It is surprising to detect significant differences in thermal-based liking when using the virtual beverage glass where there are no additional thermal stimuli applied. This can be due to specific color and other stimuli combinations and merits future explorations.

5.1.4 Emotion responses and associations with virtual flavor stimuli in Virtual Beverage Glass: Figure 7 depicts the various emotions mediated by different virtual flavor stimuli delivered via the virtual beverage glass on the correspondence analysis factor map. The axes revealed 45.16% of the variance in the data. The F1 axis accounts for positive (affectionate) and negative (disgusted) emotions while the F2 axis illustrates the emotions related to energy and extends between the positive (energetic) and negative (aggressive) emotions.

The elicited emotions from color stimuli were related to comforting emotions such as 'peaceful', 'pleasant', and 'friendly'. Among the electric taste sensations, salty was closely related to 'interested' and 'eager' emotions. The sour taste was not particularly related to a specific emotion; however, it was on the lines of a 'boring' emotion. The smell of Chocolate was closely associated with a lot of positive emotions like 'friendly', 'calm', 'polite', 'steady', and 'understanding'. The Lemon smell did not have a close association with any specific emotion. The participants associated the spirit smell with a 'daring' emotion, which was interesting. Following a similar trend, the participants reported different mediated emotions when combined stimuli of color, taste, and smell were provided. For example, the Spirit smell was associated with 'daring' emotion, and when combined with the Sour taste and Green color, the participants felt 'active'. On the contrary, the combined stimuli of Lemon + Sour + Yellow, which was intended to imitate a lemonade-like experience were related to 'guilty' and 'worried' emotions.

5.2 Results: Virtual coffee mug

5.2.1 Grouping the Virtual Coffee Mug Modalities: In the same way that there were groupings created a priori for the virtual beverage, groupings for the virtual coffee were created. They are as follows: flavor (chocolate, mint, and coffee flavorings only), hot flavor (hot temperate + chocolate, hot temperature + mint, and hot temperature + mint), cold flavor (cold temperate + chocolate, cold temperature + mint, and cold temperature + mint), hot temperature, cold temperature, and no stimulation.

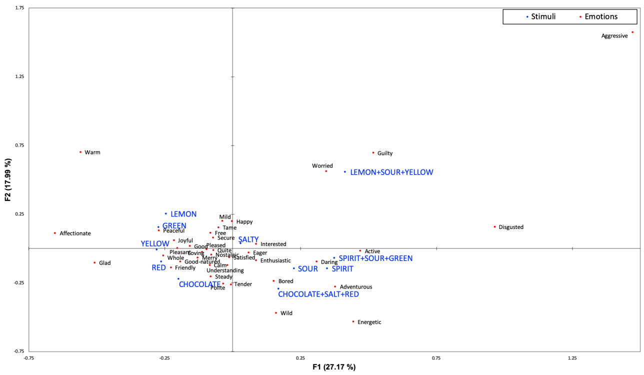

Figure 7: Elicited emotions from the virtual beverage glass[3]

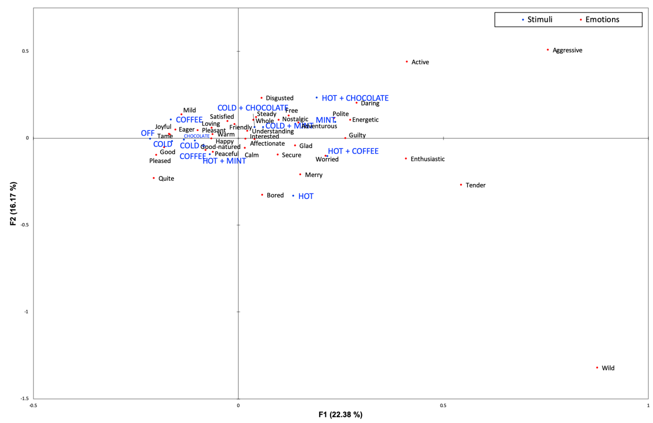

Figure 8: Elicited emotions from the virtual coffee mug[3]

The groups, flavor, hot flavor, and cold flavor were examined for within-group differences regarding the primary sensations (salty, sour, sweet, and bitter) and liking scores (overall, taste, smell, and temperature). Initial inspection of the data suggests that overall there are few (if any) differences within the group. Repeated measures ANOVAs confirmed this. Within respective groups, there was no difference in terms of the primary sensations (p > .05), and for the liking scores, there was only one difference. There was a significant effect of smell liking within the hot flavor group, F(2, 54) = 4.06, p = 0.023, η^2 = .062. The hot+coffee stimulus had greater smell liking than the hot+mint (p = .022). Other than participants liking the smell of the coffee when paired with a hot temperature more than the smell of the mint, there were no differences within the groups.

5.2.2 Comparing the Virtual Coffee Mug Groups in Terms of Taste: The virtual coffee mug groups (flavor, hot flavor, cold flavor, hot temperature, cold temperature, and no stimulation) were compared in terms of the primary sensations: salty, sour, sweet, and bitter. Repeated measures ANOVAs show no significant difference (p's > .05) between the groups in any of the primary sensations suggesting that the different stimulus components did not alter the primary sensations. However, it should be noted that the participants rated the groups low on each of the sensations. There is likely a floor effect here, where no significant difference can be found because the current virtual coffee mug device does not produce adequate levels of the flavor sensations.

5.2.3 Comparing the Virtual Beverage Groups in Terms of Liking: Similarly, the virtual coffee mug groups were compared in terms of overall liking, taste liking, smell liking, and temperature liking. Repeated measures ANOVAs show no significant difference (p's > .05) between the groups for these liking scores. On average, the liking scores were above the midpoint, suggesting that participants liked the virtual coffee. This is likely due to the device not creating strong enough of a difference in the sensations.

5.2.4 Emotion responses and associations with virtual flavor stimuli in Virtual Coffee Mug: Figure 8 depicts the various emotions elicited by different virtual flavor stimuli delivered via the virtual coffee mug on the correspondence analysis factor map. The axes explain 38.54% of the variability in the data. The F1 axis displays the emotions related to 'disgusted' and 'bored', while the F2 axis extends between positive (good) and negative (guilty) emotions.

As explained, there is a diverse range of emotions elicited when delivering virtual flavor sensations from both apparatus. The emotions elicited from the virtual coffee mug were closely attached to different stimuli when compared to emotions elicited using the virtual beverage glass. It is interesting to notice that the hot stimuli were not enjoyed when delivered to the participants as it was related to 'bored' emotion. However, when combined with smells, the participants' responses were varied. For example, hot + chocolate stimuli were associated with 'daring' emotion, while hot + coffee was related to 'worried' emotion. A possible reason for this can be the overheated Peltier element, which could be optimized in future studies. On the contrary, hot + mint stimuli were associated with 'peaceful' emotion.

The cold stimulus was associated with several emotion clusters when simulated alone or in combinations. The cold stimulus was related to 'good' and 'pleased' emotions, while cold + coffee was related to 'good', 'good-natured', 'peaceful' emotions. Similarly, cold + chocolate stimuli were perceived to be rich in 'understanding', 'interesting' and 'friendly' emotions, and cold + mint stimuli were closely associated with 'whole', 'nostalgic', 'steady', and 'free' emotions. The mint smell only stimulus was associated with 'polite' and 'adventurous' emotions. A similar trend was observed with coffee and chocolate smell stimuli, which were associated with 'mild', 'loving', 'joyful', 'pleasant', and 'warm' emotions. Almost all the stimuli given in the virtual coffee mug were related to positive emotions, which ultimately represents a good user experience with not only the apparatus but also virtual flavor sensations.

The positive and negative composite scores are compared between the stimulus groups for the virtual coffee mug (flavor, hot flavor, cold flavor, hot temperature, cold temperature, and no stimulation). There was no significant difference between the groups for either positive emotion (F(3, 81) = 2.19, p = .096, η^2 = .04), or negative emotion (F(3, 81) = 1.90, p = .136, η^2 = .04). Scores for both positive and negative emotions were low; thus, it is likely that drinking from the virtual coffee mug did not evoke a strong enough emotional response on it's own.

[3]See supplemental material for larger image

5.3 Results: Comparison Between the Virtual coffee mug and Virtual beverage glass:

The virtual beverage and the virtual coffee apparatus were compared to understand differences in how participants liked and rated the two different apparatus as well as their emotional response to it. Initial inspection of the ratings for the primary senses, bitter, sweet, sour, and salt, show differences between the virtual beverage and the virtual coffee experiences. Independent samples T-tests reveal that the participants overall rated the virtual beverage higher than the virtual coffee on bitter ($t(58) = 2.78$, $p = 0.007$, $d = .71$), sweet ($t(58) = 2.13$, $p = 0.001$, $d = .55$), sour ($t(58) = 3.41$, $p = 0.001$, $d = .88$), and salt ($t(58) = 3.91$, $p < .001$, $d = 1.01$). These results show that participants felt that the virtual beverage had stronger flavors than the virtual coffee in every way. Overall, the data seems to show that participants liked the virtual beverage more than the virtual coffee. Independent samples T-tests show greater overall liking ($t(58) = 2.30$, $p = 0.025$, $d = .60$) and temperature liking ($t(58) = 2.30$, $p = 0.034$, $d = .56$). There was no significant difference for neither the taste nor the smell liking. It is likely that the participants liked the stronger flavor profiles of the virtual beverage glass.

The participants' positive and negative emotion composite scores are compared between the two apparatuses (Figure 6). Independent samples t-tests show that there are no differences between virtual beverage and the virtual coffee for both positive emotions ($t(58) = 1.70$, $p = 0.093$, $d = .44$), and negative emotions ($t(58) = .60$, $p = 0.554$, $d = .15$). Exploring the Cohen's d effect size for positive emotions, there is an evidence of a medium effect for positive emotions where the virtual beverage elicited higher positive emotions than the virtual coffee.

6 DISCUSSION AND CONCLUSION

The results of our user experiment with both apparatus revealed that the participants 1) perceived various flavor sensations when presented with different stimuli configurations, 2) generally liked different virtual flavor sensations, 3) distinguished different basic taste sensations as per the stimuli, and 4) associated different emotions for virtual flavor sensations. One significant finding that validates our approach is that the participants have liked all of the stimuli configurations, in general, and some more than others. This finding is encouraging as the way virtual flavor components are delivered differs from a traditional drinking experience where the volatile aromatic compounds are released retronasally through mastication inside the mouth. In our approach, smells are released orthonasally while the electric taste is only applied to the tip of the tongue, and thermal stimuli only applied to the outer lips.

Our approach of delivering flavor sensations and their specific combinations is novel and a first-time experience for all the participants, this might have an influence on their liking scores. The "Neophic effect" or the fear of trying new things in the controlled experiment could have affected the liking scores perceived for each stimulus and apparatus. Furthermore, 1) the two apparatus developed is a little heavier and different from everyday utensils, and 2) the stimuli configurations are not calibrated towards individual preferences may also negatively affect participants' responses.

The responses received for sweet taste was evaluated to be weak in that there were no differences between the groups via the stimuli delivered from the virtual beverage glass. As expected, there was an increased sensation of salt, bitter, and sour for the electric taste group, especially compared to the color group. This was also true for the combination group, which included an electric taste component. The responses were low for the color and smell group. This may indicate that a large factor for altering taste is the electric taste component, or that the smells provided were not strong enough. It also shows further opportunities to optimize the stimuli configurations to achieve the expected 'just about right' perception for all the stimuli. Interestingly, the color and smell groups were liked more in terms of overall liking suggestions. In contrast, the electric taste and combination groups had a stronger flavor profile, however, with lower liking scores for the flavors. Regardless, participants liked all of the flavor combinations for the virtual beverage.

A better replication of coffee would enable a better assessment of the emotional effects of different coffee flavors and temperatures. One method to increase the flavor intensity would be to introduce a taste input to occur with the smell. While it is true that there is an existing taste-smell association, and odor may be enough to elicit flavor perception [12], taste and smell combinations can increase the intensity of both the smell and the taste when presented together [5]. Also, the way that an odor is presented can alter the impact that the odor has on a flavor sensation. When an odor is presented retronasally (in a consumed solution), it is more identifiable than if presented oronasally [45]. The ability to precisely adjust the tastes, smells, and temperatures of the beverages give this research the unique ability to investigate precisely how these different modalities play a part in an overall flavor experience. Another way to improve the virtual coffee would be to improve the cup design to better replicate a coffee cup (more realistic coffee cup shape may cause the participants to perceive more significant flavor sensations). The beverage vessel can impact the taste of the beverage itself [23]. The shape, color, and texture can affect the smell, sweetness, and perceived acidity of the coffee [7, 8, 48].

The elicited emotions from different virtual flavor sensations were generally positive. It is also observed that the emotions reported from the virtual beverage glass were recognized as calm, peaceful, and pleasant emotions while from the virtual coffee mug were identified as energetic, happy, and merry. These emotions are generally associated with soft drinks and coffee in our everyday lives [4, 49]. None of the stimuli were related to disgust or anger. These findings confirmed that the participants enjoyed most of the stimuli configurations. Future research should also focus on even more smell and color sensations, developing seamless apparatus, and various base drinks instead of plain water. When comparing the two apparatuses, a few key points should be noted. First, the virtual beverage elicited stronger taste sensations than the virtual coffee. Second, participants liked the virtual beverage more than the virtual coffee. It is likely that there was not a strong enough flavor sensation for the virtual coffee. People typically expect that coffee has a relatively strong flavor and drinks more similar to the virtual beverages can have less flavor and still be considered acceptable. Finally, there was a trend for the virtual beverage to elicit greater positive emotions than the coffee. This may be due to a larger discrepancy between the virtual coffee's expected flavor and the actual flavor. A disconnect between what an individual expects and experiences may lead to less positive emotions [44].

REFERENCES

[1] G Ares and SR Jaeger. 2015. Check-all-that-apply (CATA) questions with consumers in practice: experimental considerations and impact on outcome. In *Rapid sensory profiling techniques*. Elsevier, 227–245.

[2] Malika Auvray and Charles Spence. 2008. The multisensory perception of flavor. *Consciousness and cognition* 17, 3 (2008), 1016–1031.

[3] Jessica Bennett, Geoffrey Greene, and Donna Schwartz-Barcott. 2013. Perceptions of emotional eating behavior. A qualitative study of college students. *Appetite* 60 (2013), 187–192.

[4] Natnicha Bhumiratana, Mona Wolf, IV Chambers, Koushik Adhikari, et al. 2019. Coffee Drinking and Emotions: Are There Key Sensory Drivers for Emotions? *Beverages* 5, 2 (2019), 27.

[5] S Bonnans and AC Noble. 1993. Effect of sweetener type and of sweetener and acid levels on temporal perception of sweetness, sourness and fruitiness. *Chemical senses* 18, 3 (1993), 273–283.

[6] Margaret M Bradley and Peter J Lang. 1994. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry* 25, 1 (1994), 49–59.

[7] Fabiana M Carvalho, Valentina Moksunova, and Charles Spence. 2020. Cup texture influences taste and tactile judgments in the evaluation of specialty coffee. *Food Quality and Preference* 81 (2020), 103841.

[8] Fabiana M Carvalho and Charles Spence. 2018. The shape of the cup influences aroma, taste, and hedonic judgements of specialty coffee. *Food quality and preference* 68 (2018), 315–321.

[9] Mabel M Chan and Catherine Kane-Martinelli. 1997. The effect of color on perceived flavor intensity and acceptance of foods by young adults and elderly adults. *Journal of the Academy of Nutrition and Dietetics* 97, 6 (1997), 657.

[10] The Right Cup. accessed August 30, 2020. . https://www.therightcup.com/

[11] Jan De Houwer, Sarah Thomas, and Frank Baeyens. 2001. Association learning of likes and dislikes: A review of 25 years of research on human evaluative conditioning. *Psychological bulletin* 127, 6 (2001), 853.

[12] Jeannine Delwiche. 2004. The impact of perceptual interactions on perceived flavor. *Food Quality and preference* 15, 2 (2004), 137–146.

[13] Lauren Dooley, Young-seung Lee, and Jean-François Meullenet. 2010. The application of check-all-that-apply (CATA) consumer profiling to preference mapping of vanilla ice cream and its comparison to classical external preference mapping. *Food quality and preference* 21, 4 (2010), 394–401.

[14] Robin Fondberg, Johan N Lundström, Maria Blöchl, Mats J Olsson, and Janina Seubert. 2018. Multisensory flavor perception: The relationship between congruency, pleasantness, and odor referral to the mouth. *Appetite* 125 (2018), 244–252.

[15] Tom Gayler, Corina Sas, and Vaiva Kalnikaite. 2019. Taste Your Emotions: An Exploration of the Relationship Between Taste and Emotional Experience for HCI. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (San Diego, CA, USA) *(DIS '19)*. ACM, New York, NY, USA, 1279–1291. https://doi.org/10.1145/3322276.3322336

[16] Daniel Harley, Alexander Verni, Mackenzie Willis, Ashley Ng, Lucas Bozzo, and Ali Mazalek. 2018. Sensory vr: Smelling, touching, and eating virtual reality. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*. 386–397.

[17] Alisa Kanjanakorn and Jeehyun Lee. 2017. Examining emotions and comparing the EsSense Profile® and the Coffee Drinking Experience in coffee drinkers in the natural environment. *Food quality and preference* 56 (2017), 69–79.

[18] Silvia C King and Herbert L Meiselman. 2010. Development of a method to measure consumer emotions associated with foods. *Food Quality and Preference* 21, 2 (2010), 168–177.

[19] Silvia C King, Herbert L Meiselman, and B Thomas Carr. 2010. Measuring emotions associated with foods in consumer testing. *Food Quality and Preference* 21, 8 (2010), 1114–1116.

[20] Silvia C King, Herbert L Meiselman, and B Thomas Carr. 2013. Measuring emotions associated with foods: Important elements of questionnaire and test design. *Food Quality and Preference* 28, 1 (2013), 8–16.

[21] I Lackovic and Zoran Stare. 2007. Low-frequency dielectric properties of the oral mucosa. In *13th International Conference on Electrical Bioimpedance and the 8th Conference on Electrical Impedance Tomography*. Springer, 154–157.

[22] Harry T Lawless and Hildegarde Heymann. 2010. *Sensory evaluation of food: principles and practices*. Springer Science & Business Media.

[23] Sarah Lefebvre and Marissa Orlowski. 2019. Can, cup, or bottle? The influence of beverage vessel on taste and willingness to pay. *International Journal of Hospitality Management* 76 (2019), 194–205.

[24] Juyun Lim and Tomomi Fujimaru. 2010. Evaluation of the labeled hedonic scale under different experimental conditions. *Food quality and preference* 21, 5 (2010), 521–530.

[25] Michael Macht. 2008. How emotions affect eating: a five-way model. *Appetite* 50, 1 (2008), 1–11.

[26] Michael Macht and Gwenda Simons. 2011. Emotional eating. In *Emotion regulation and well-being*. Springer, 281–295.

[27] María Isabel Miranda. 2012. Taste and odor recognition memory: the emotional flavor of life. 23, 5-6 (2012), 481–499.

[28] Sirous Mobini, Lucy C Chambers, and Martin R Yeomans. 2007. Effects of hunger state on flavour pleasantness conditioning at home: flavour–nutrient learning vs. flavour–flavour learning. *Appetite* 48, 1 (2007), 20–28.

[29] Claire Murphy and William S Cain. 1980. Taste and olfaction: independence vs interaction. *Physiology & Behavior* 24, 3 (1980), 601–605.

[30] Hiromi Nakamura and Homei Miyashita. 2011. Augmented gustation using electricity. In *Proceedings of the 2nd augmented human international conference*. ACM, 34.

[31] Hiromi Nakamura and Homei Miyashita. 2012. Development and evaluation of interactive system for synchronizing electric taste and visual content. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 517–520.

[32] Takuji Narumi, Munehiko Sato, Tomohiro Tanikawa, and Michitaka Hirose. 2010. Evaluating cross-sensory perception of superimposing virtual color onto real drink: toward realization of pseudo-gustatory displays. In *Proceedings of the 1st Augmented Human International Conference*. ACM, 18.

[33] Michael A Nestrud, Herbert L Meiselman, Silvia C King, Larry L Lesher, and Armand V Cardello. 2016. Development of EsSense25, a shorter version of the EsSense Profile®. *Food Quality and Preference* 48 (2016), 107–117.

[34] M Ng, C Chaya, and J Hort. 2013. Beyond liking: Comparing the measurement of emotional response using EsSense Profile and consumer defined check-all-that-apply methodologies. *Food Quality and Preference* 28, 1 (2013), 193–205.

[35] Corinna Noel and Robin Dando. 2015. The effect of emotional state on taste perception. *Appetite* 95 (2015), 89–95.

[36] Maija Paakki, Mari Sandell, and Anu Hopia. 2016. Consumer's reactions to natural, atypically colored foods: An investigation using blue potatoes. *Journal of sensory studies* 31, 1 (2016), 78–89.

[37] John Prescott. 2015. Multisensory processes in flavour perception and their influence on food choice. *Current Opinion in Food Science* 3 (2015), 47–52.

[38] Nimesha Ranasinghe, Adrian Cheok, Ryohei Nakatsu, and Ellen Yi-Luen Do. 2013. Simulating the sensation of taste for immersive experiences. In *Proceedings of the 2013 ACM international workshop on Immersive media experiences*. 29–34.

[39] Nimesha Ranasinghe and Ellen Yi-Luen Do. 2017. Digital lollipop: Studying electrical stimulation on the human tongue to simulate taste sensations. *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM)* 13, 1 (2017), 5.

[40] Nimesha Ranasinghe, Ryohei Nakatsu, Hideaki Nii, and Ponnampalam Gopalakrishnakone. 2012. Tongue mounted interface for digitally actuating the sense of taste. In *2012 16th International Symposium on Wearable Computers*. IEEE, 80–87.

[41] Nimesha Ranasinghe, Thi Ngoc Tram Nguyen, Yan Liangkun, Lien-Ya Lin, David Tolley, and Ellen Yi-Luen Do. 2017. Vocktail: A virtual cocktail for pairing digital taste, smell, and color sensations. In *Proceedings of the 25th ACM international conference on Multimedia*. ACM, 1139–1147.

[42] Nimesha Ranasinghe, David Tolley, Thi Ngoc Tram Nguyen, Liangkun Yan, Barry Chew, and Ellen Yi-Luen Do. 2019. Augmented Flavours: Modulation of Flavour Experiences Through Electric Taste Augmentation. *Food Research International* 117 (2019), 60–68.

[43] Vera Sacharin, Katja Schlegel, and Klaus R Scherer. 2012. Geneva emotion wheel rating study. (2012).

[44] Hendrik NJ Schifferstein. 2001. Effects of product beliefs on product perception and liking. In *Food, people and society*. Springer, 73–96.

[45] Dana M Small and Marilyn K Jones-Gotman. 2001. Neural substrates of taste/smell interaction and flavor in the human brain. *Chemical Senses* 26, 8 (2001), 1034.

[46] Charles Spence. 2011. Mouth-watering: the influence of environmental and cognitive factors on salivation and gustatory/flavor perception. *Journal of Texture Studies* 42, 2 (2011), 157–171.

[47] Charles Spence. 2017. Multisensory flavour perception. *Flavour: From Food to Perception* (2017), 373–394.

[48] Charles Spence and Fabiana M Carvalho. 2019. Assessing the influence of the coffee cup on the multisensory tasting experience. *Food quality and preference* (2019).

[49] Hannelize van Zyl. 2016. Emotion in Beverages. In *Emotion Measurement*. Elsevier, 473–499.

[50] Mark T Wallace. 2015. Multisensory perception: the building of flavor representations. *Current Biology* 25, 20 (2015), R986–R988.