Taste Your Emotions: An Exploration of the Relationship between Taste and Emotional Experience for HCI

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ABSTRACT
Taste offers unexplored opportunities for novel user experiences in HCI, however it is difficult to design for. While most lab research has shown basic tastes are consistently associated with positive or negative emotional experiences, the value of these mappings for user experience is less explored. In this paper we leverage 3D food printing technologies to report an experimental study investigating the relationship between taste and emotional experience for use in HCI. We present four real-life inspired scenarios: product rating, sports match results, experiential vignettes, and website usability, to explore the understanding and expression of emotional meaning through tastes. Our findings extend previous emotion mappings for sweet and bitter tastes to applied scenarios. We also draw out fresh insights into the role of taste, flavor, and embodiment in experience design, reflecting on the role of 3D food printing in supporting taste interfaces.

Author Keywords
Taste, Emotion, User Experience, 3D Printed Food

CSS Concepts
• **Human-centered computing~Empirical studies in HCI** • Human-centered computing~Interaction devices

INTRODUCTION
I am sat in front of a website designed by a colleague. I navigate around it with some trouble, the design needs quite a bit more work. As I try to use it, I am growing increasingly frustrated but when I try to explain my experience to my colleague, I struggle to find the words. Thinking hard about how to describe my experience, I sit back and absent-mindedly pick up a mug, drinking the last drops of coffee. Suddenly in my mouth there is a dry, tingling experience, the same I had using the website. I call my colleague over and say "That is it! The website you designed is bitter, but bland too, like old coffee, a low-quality experience, but quite weak, like I only just noticed it." I go make a fresh coffee for us both to make-up for my *very* honest feedback.

Figure 1. The nūfood printer during the printing phase (droplets of printed material can be seen in the bath on left)

This scenario illustrates how taste can be a powerful tool to express and communicate experience. The mouthful of cold coffee provides an unsatisfactory feeling, as the bitter taste creates an unpleasant sensation in the mouth. This embodied taste experience juxtaposed with the website usage could help better understand user experience. The potential use of taste for research arises through the embodied nature of taste experience and its potential to trigger associated affective and temporal experiences [31]. Initial work in HCI [28,47] and findings from psychology [20,35,49,54] show specific relationships between basic tastes and emotions, explored mostly in lab-based contexts. Thus, we know little about how these relationships or the mapping between tastes and emotions, extend to a real-life context.

Unlike visual, auditory or haptic interfaces, taste-based interfaces have been considerably less explored due to the challenges of digitally stimulating taste sensations [32]. Taste is a chemical sensation, normally relying on contact between stimuli and the body, as opposed to light, sound, or heat which can be sensed at a distance. Taste (the sensation of sweet, sour, bitter, salty, and umami) is often confused with flavor but is in fact only part of flavor experience [44], which is more complex and multisensory. Working with taste therefore is challenging due to the need to control the other aspects of flavor experience. We argue that the advent of 3D printing food technologies [14,21,22] provides a solution to this as well as opening up new opportunities to inform the design of taste-based interactions. In our study, we used *nūfood* (Figure 1), an innovative system using liquid

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3D food printing; developed and patented by Dovetailed Ltd. This study focused on the following research questions.

- What are the relationships between taste and emotions in real-life inspired scenarios?
- What is the feasibility of 3D printing food technologies for leveraging taste-emotion mappings in HCI?
- What scenarios are most relevant to HCI research for mediating novel user experience through 3D printed food?

RELATED WORK

To frame our research, we draw on previous work on how taste has been used to create user experiences in HCI, in particular, examples exploring taste and affect. We also reviewed relevant work from psychology on the mappings between taste and emotion.

Approaches to Taste and User Experience in HCI

HCI interest in food has grown steadily over the last two decades [1,16]. As the field has matured, critiques have called for novel applications, where enjoyment and sociality are afforded by the combination of the edible and digital [16,55]. There has been also a focus on platforms that encourage citizen science and sustainable lifestyles through making, eating, and speculating with food [24]. In the recent Future of Food and Computing manifesto [55], a call was made to sensitize people to the "*sensory, hedonic, and social functions of foods*" and the "*personal, social, and cultural experiences related to food*". Such work indicates a movement towards appreciating the nature of food experience within HCI. This poses the question of what is afforded when technology meets food. Prior work exploring the value of taste for user experience, mapped out the experiential qualities of sweet, sour, bitter, salty, and umami tastes, drawing attention to their temporal, affective and embodied characteristics [31]. It speculated on how such characteristics could support digital experiences, for example, connecting the lingering quality of a taste with events happening over time [31]. Additionally, interviews with non-HCI practitioners working with food revealed [13] the importance of time, and suggested new taste and emotion mappings (such as sourness with surprise). Despite initial work centered on affective experience through taste [9,13,31] there is a limited understanding of the mappings of tastes and emotions in applied contexts, particularly including those relevant to HCI community [30].

Affective Taste Interactions in HCI

Despite the growing body of work on affective technologies [8,18,33,37,41,46], to date, applications of taste-emotion mappings have been limited within HCI. Landmark examples come from gaming applications, in which taste supports an immersive experience in combination with other stimuli. LOLLio [26] is a game controller modelled on a lollipop which allows input via the mouth. The lollipop-controller delivers sour or sweet taste stimuli in response to events within gameplay, with the sour taste reinforcing negative events, and the sweet taste, positive ones. Using all 5 basic tastes: sweet, sour, bitter, salty, and umami, TasteBud [47] pumps liquid taste stimuli into a mouthpiece responding to outcomes in a game.

Aside from gaming, other uses of taste tend to be subtler and focus on food experience more generally. For example, Wei and colleagues [50] explored how technology could mediate affective experiences through a co-dining system allowing remote diners to share meals. It used transmission of tastes through 'food teleportation'. A simple 2D food printing process, allowing the modification of foodstuffs in one location by a remotely located dining partner. More explicit forms of 'messaging' through food include the *Food Messaging Service,* a system for food-based communication between colleagues [51]. Although not varying the taste (each message has the same taste and was printed in edible ink onto rice paper), the impact of a taste sensation combined with the wording of the message was noted by participants. As well as human to human communication, the idea of information exchange from computer to human through food and taste was also explored by *Edipulse* [21]. It used users' activity data to inform the design of 3D printed chocolate rewards after a workout session. The taste of the chocolate created user enjoyment as part of a "literal digestion" experience of the data. A common thread among these applications is the novel food production technologies they use to support expressive communication through food. Despite food being a key material in these experiences, most of these systems do not explicitly leverage different tastes and their intensity as a way to understand or express emotional experiences.

Taste-Emotion Mapping

A wealth of findings indicate that people associate sweet tastes to positive experiences [15,20,35,49,54] and bitter, sour, and salty tastes with negative ones [20,35,49,54]. The intensity of taste has been shown to modulate the affective response, with more intense tastes being related to more intense affective response [49,54]. These relationships or mappings have also been explored in scenarios where taste may influence moral judgements [11], or moral provocations [12]; where metaphor may mediate the experience [17] and where emotional states themselves impact taste perception [29]. Such findings indicate the connection between taste and emotion as bidirectional, with taste stimuli influencing affective experience and emotional stimuli impacting on taste perception. Embodiment has been cited as a mediator in connecting taste and emotional experience [12]. If mappings are shown to be useful in the design of affective interactions, the bodily aspect of experience provides an additional layer and an enticing direction for exploration. The extent to which taste-emotion mappings identified in lab-based experiments, also hold true in real world contexts has been previously questioned [9]. A challenge of moving from lab to real-world setting, is the creation of specially designed taste-only stimuli (known as tastants) as part of robust tools for interaction. To address this challenge an exploration of the optimum method for delivery of taste

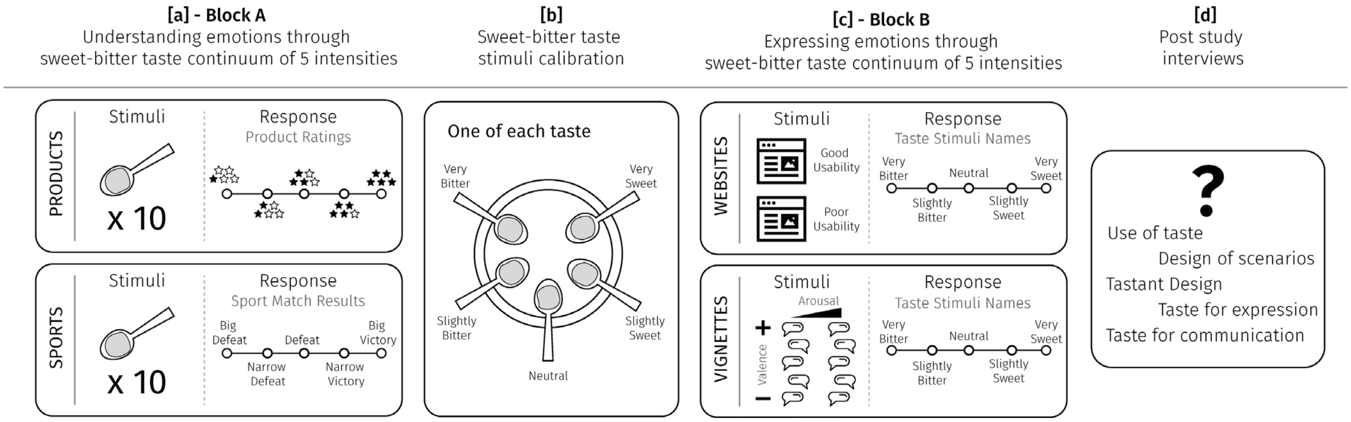


Figure 2. The study design showing block A scenarios, taste stimuli calibration, block B scenarios and interviews

stimuli is needed which would allow the identification of mappings by users, while controlling for other confounding variables such as smell and visual appearance. For terminological clarity, in this paper, we use *flavor* for the complex multisensory experience combing taste, smell, touch and temperature; *taste* as a single sensory experience on the tongue of sweet, sour, bitter, salty, and umami; *tastants* as stimuli designed to control for the non-taste parts of flavor experience, so that the differences in the experience of taste can be used to create specific modes of experience. To note, 3D printed tastants are tastants made via 3D liquid food printing.

METHOD

Our exploratory study followed a methodology similar to the one employed by Wilson and colleagues in their exploration of novel thermal interfaces, also in a range of real-life inspired scenarios [53]. After careful consideration, we created our own 4 real-life inspired scenarios through which we aimed to explore the understanding and expression of emotion in connection with the taste experience of 3D printed food.

Experimental Procedure

This section offers an overview of the entire study, before outlining more details in the subsequent subsections. The four experimental scenarios in the study were split into two blocks, A and B (Figure 2). Block A (Figure 2a) consisted of the "product ratings" and "sports match results" scenarios, whilst block B (Figure 2c) consisted of the "experiential vignettes" and "website usability" scenarios. These scenarios were carefully selected to explore the *understanding of emotions through sweet-bitter taste continuum of 5 intensities* (block A), and the *expression of emotional response through sweet-bitter taste continuum of 5 intensities* (block B). In addition, two scenarios capture digitally mediated experiences, i.e., "product ratings" and "website usability", while the other two capture nondigital (or analogue) experiences, i.e., "sports match results" and "experiential vignettes". Each scenario included ten stimuli with the exception of "website usability" which only has two stimuli. This was designed differently as the task of booking a trip on the website takes longer than listening to a vignette, or tasting a stimulus of 3D printed food, making it impractical to include 10 websites.

Block A scenarios were undertaken first and involved the consumption of 3D printed tastants (Figure 2a). Participants responded to each given tastant, by matching it to the outcome of that scenario, reflecting their understanding of the tastes as emotional information. As they made each decision, participants thought aloud, and answered several questions at the end of both scenarios to reflect on the difficulty of articulating the mappings, their confidence in the mappings, general reflections on scenarios and which tastes they would use to represent scenarios. Participants were introduced to the entire range of tastants only after the completion of block A scenarios as part of the *sweet-bitter taste stimuli calibration* (Figure 2b). For this, they consumed each of the tastants so that they could understand the association of each tastant with its unique taste label. The calibration was performed after, rather than before block A, to avoid biasing responses that the awareness of the full range of available tastes could have led to.

For block B scenarios, the calibration served the role of making the full range of 5 intensity levels alongside the sweet-bitter continuum available to participants, so that they could use all those levels to express the emotions elicited in block B. Here they were introduced one by one to emotion elicitation stimuli to which they responded by selecting a taste label from the provided range, that they considered most appropriate (Figure 2c). Similar to block A, tasks in block B also involved think aloud and involved follow-up questions. Within each block and within each scenario the order of stimuli was randomized to limit the order effects. In addition, to limit contamination between taste stimuli, participants rinsed their mouths with water before each taste stimuli. The study concluded with a final interview (Figure 2d).

Design of Scenarios

This section offers a brief overview of the process of selecting scenarios, while each scenario is later described alongside the findings to support increased readability by presenting the hypotheses and results side by side. The four

Figure 3. The set-up for block A scenarios

selected scenarios were chosen from a list of 8 generated scenarios, to ensure a balance between scenarios relating to digital, and physical experiences, as well as for exploring both the expression, and comprehension of emotions. The intention was to create scenarios suited to the nature of taste (sweet and bitter) as suggested by the literature [15,20,35,49,54]. In other words, scenarios had the possibility to elicit emotions with negative, neutral and positive valence that could correspond to expected mappings for the tastes.

Taste Stimuli Design

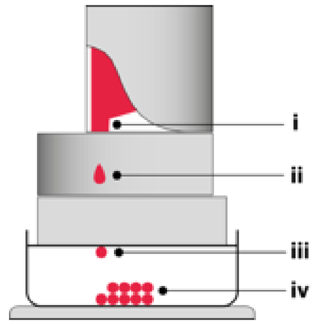
The selected taste stimuli consisted of: "very bitter", "slightly bitter", "neutral", "slightly sweet" and "very sweet" laying along the bitter-sweet continuum, exploring thus the tastes most commonly associated with emotional valence (sweet with positive emotions, bitter with negative emotions), as well as emotional arousal (high and low taste intensity with high and low emotional intensity) [4,20]. This scale was initially derived from Bredie and colleagues' study on affective response to taste stimulus [4], who used 'high', 'med' and 'low' concentrations of the 5 basic tastes. In our study, the intention was to have perceivable differences between each taste stimuli. Therefore, we used the low and high conditions from Bredie et al. [4] to create our 5-point scale. Due to the printing method we doubled concentrations from Bredie study in the liquid to be printed (Table 1), resulting in the same concentration of tastant as Bredie et al. in the printed stimulus.

Pilot study of taste stimuli

To evaluate users' ability to discriminate between our taste samples and whether the printed bitter-sweet tastes were associated with the emotional responses shown in prior work [20,35,49,54] we ran a small pilot study. For this, we recruited 5 participants (4 Female, 1 Male, mean age 28.7 SD=4.0) to try our taste samples and asked them to identify each taste given in randomized order. These participants did not take part in the main study that followed. Participants took a sip of water between each taste to clean the palate. Pilot study findings show that all 5 participants could correctly identify the very sweet taste, and that 4/5 identified the very bitter taste in a free selection. Mean confidence (scored 1-5 with 5 most confident) in these responses was 3.68 (SD=.1.25). There was a positive correlation ($r_s(23) = 0.74$, $p<0.01$) between the stimuli given and the reported

Stimuli	Additive	Concentration
Very Bitter	Caffeine	1g/L
Slightly Bitter	Caffeine	0.25g/L
Neutral	--	--
Slightly Sweet	Sucrose	12g/L
Very Sweet	Sucrose	48g/L

Table 1. Concentrations of tastants in the 5 stimuli used



i - 'ink' tank containing flavor,

ii – droplet deposited

iii- droplet forms a sphere as it meets the bath

iv- droplets falls in the bath and bonds together to form the shape

Figure 4 Diagram of the printing process

taste on a bitter-sweet scale, mean confidence in these scale ratings was 3.8 (SD=1.0). Such consistent ratings suggest confidence that our choice for each taste sample was appropriate both in terms of the two basic tastes and the chosen intensities.

Experimental Apparatus

All scenarios involved entering answers on a laptop provided during the study. Participants sat at a table with the laptop in front and the plate of tastes for that scenario to the side of the laptop. A glass of water was provided for each participant (Figure 3) and topped up as necessary through-out the study. For both the pilot and the main study, the taste samples were 3D printed as small 10ml cubes and presented on identical white plastic teaspoons arranged in their randomized order on identical white china plates (Figure 3) with new plates being used for each presentation of taste samples in block A scenarios, and during the calibration session.

3D Printed Tastant Preparation – nūfood Printer

As food experience is multisensory [44], a challenge in preparing taste samples is controlling for the impact of other variables such as color, smell, temperature and texture. The *nūfood* printer [56] is a novel additive manufacturing technology which allows for such control. The prototype used in our study is an in-house technology to be launched by Dovetailed Ltd. as a commercial product. The printer works by dropping one liquid (the 'ink') into another (the 'bath') where a chemical reaction occurs forming a droplet with a gel-like surface (Figure 4). As further droplets are printed, adjacent droplets join together forming a 3D structure. Once the printing is finished, the completed form is removed from the bath and is ready to eat. In contrast to other food printers, *nūfood* is liquid based and better supports taste stimuli designed with consistent qualities whilst varying the taste - such stimuli are known as tastants. The food produced for this study had consistent shape and mass and was colorless and odorless. Due to the current speed of printing and the need for repeated stimuli to be prepared, all printing was done prior to the study session with the prepared samples kept refrigerated until needed for the study appointment.

Participants

We recruited 16 participants via social media and mailing lists associated with Dovetailed Ltd. Each took part in a session lasting between 45 minutes to 1 hour and were rewarded £5. We recruited healthy participants with no food allergies or sensitivities, between 18 and 65 years old, with the upper age limit to avoid the impact of aging upon taste [52]. Only non-smoking participants were recruited; we defined non-smokers according to [6]. Our sample was gender-balanced (9 Female, 7 Male), as research suggests no influence of gender on taste-emotion mappings [35]. Half of participants (8) hold postgraduate qualifications, 7 bachelor's degrees, and 1 high school educated. The mean age was 36.88 (SD=10.68). With respect to ethnicity, 11 participants were White-British, 4 White-European and 1 Mixed Background.

FINDINGS

We now describe the design and hypothesis of each scenario, followed by the quantitative data analysis – descriptive and inferential statistics – for hypotheses testing, and an overall qualitative analysis of the study interviews.

Understanding Emotions (block A) - Product Ratings

This scenario aimed to see how participants understood customer ratings through taste. They were given 10 samples (2 x 5 different tastes) and asked to select a matching star rating on a 5-point Likert scale. They were told a 5-star rating was "a very good product" and a 1-star rating was "a very poor product". The star rating of the product was chosen to align with affective response; positive affect with a high product rating and negative affect with a low product rating.

Hypothesis H1 - Sweet tastes map to positive ratings, bitter tastes to negative ones. The intensity of the taste relates to the level of the rating (very bitter would be rated lower than slightly bitter).

Understanding Emotions (block A) - Sports Match Results

This scenario required participants to use provided taste samples to select the appropriate outcomes of a sports match matching that respective taste. Again, 10 samples were given (2 x 5 tastes); for each, participants chose whether they felt it represented a "big defeat", "narrow defeat", "draw", "narrow victory" or "big victory". They sampled each taste and made their selection of the most appropriate match result for that taste. Following Noel and Dando [29] we used results of sports matches to explore affective experience; positive affect aligned with victory and negative affect aligned with defeat.

Hypothesis H2 – Sweet tastes map to victory and bitter tastes map to defeat. The intensity of the taste maps to the level of outcomes of the sports match (e.g. more bitter = bigger defeat).

	1 star	2 star	3 Star	4 Star	5 star	Totals
Very Bitter	17	8	4	3	0	32
Slightly Bitter	16	7	8	0	1	32
Neutral	11	7	12	1	1	32
Slightly Sweet	4	13	7	8	0	32
Very Sweet	3	4	2	13	10	32
Totals	51	39	33	25	12	160

Table 2. Frequency counts for each taste sample to each product rating in product rating scenario. Shading shows most common (red) to least common (white).

	Big Defeat	Narrow Defeat	Draw	Narrow Victory	Big Victory	Totals
Very Bitter	13	6	7	6	0	32
Slightly Bitter	5	7	12	7	1	32
Neutral	3	8	17	4	0	32
Slightly Sweet	2	5	8	12	5	32
Very Sweet	5	2	1	10	14	32
Totals	28	28	45	39	20	160

Table 3. Frequency counts for each taste sample to each sports match result in sports match scenario. Shading shows most common (red) to least common (white).

Quantitative Findings

For block A scenarios we present the frequency counts (Table 2 and 3) and then test H1 and H2 with Spearman's correlation and Friedman tests (as our ordinal data was not randomly distributed). Table 2 shows that participants' agreement on the relationship between taste and product rating, and that this agreement was the strongest for "very bitter" and "slightly bitter" mapped to "1 star", and "2 star" rating, respectively. Table 3 reflects a similar agreement on the relationship between tastes and sports match results, but in this scenario, the agreement is the strongest for "neutral taste" and "draw". Both Table 2 and 3 show that on the first diagonal, the weakest agreements occur at intermediary points: "slightly bitter" and "slightly sweet", suggesting that greater differentiation in taste needed to identify these points. To further explore the relationship between tastes and the rating/results stimuli, we ran correlation tests, with findings showing significant correlations between tastes and product ratings ($r_s(23) = 0.50$, $p<0.01$), and tastes and sports match results ($r_s(23) = 0.43$, $p<0.01$). This is an important outcome indicating that the sweeter the taste, the more positive the experience, and the more bitter the taste, the more negative experience, in both of these two real-life inspired scenarios. This confirms H1 and H2 with respect to the mapping of positive experiences (as positive product ratings or wins for one's team) to sweet tastes, and of negative experiences (negative product ratings or defeats for one's team) to bitter tastes.

Friedman Tests with *post hoc* Bonferroni adjusted pairwise comparisons were run on the tastes matched with each response for both the product rating and sports match result scenarios. These indicate that 1-star ($\chi^2(4) = 22.90$, $p<0.05$)

was best represented by very bitter, 4-star ($\chi^2(4) = 17.11$, $p<0.05$) by very or slightly sweet, and 5-star ($\chi^2(4) = 23.20$, $p<0.05$) by very sweet. For the sports match scenario "big victory" ($\chi^2(4) = 27.70$, $p<0.05$) was best represented by very sweet, "draw" ($\chi^2(4) = 22.35$, $p<0.05$) by neutral tastes, and "big defeat" ($\chi^2(4) = 16.76$, $p<0.05$) by very bitter. These findings indicate that mappings are more consistent at the end points, partially supporting H1 and H2 with respect to the relationship between taste and emotional valence, but less so the relationship between taste intensity and emotional intensity (or arousal). The latter would require consistent mapping across the all five levels of responses, but we found mappings mostly at the end rather than at the middle points of the response scales. "2 star", "narrow victory" and "narrow defeat" in particular were not mapped reliably to middle intensity tastes ("slightly sweet", "slightly bitter").

Expressing Emotions (block B) - Experience Vignettes

The vignette task asked participants to respond to 10 vignettes taken from the Affective Norms for English Text library [2]. Each vignette was read to each participant, who then selected a taste label, i.e., "very bitter", "slightly bitter", "neutral", "slightly sweet" and "very sweet", to best express the emotional experience triggered by the vignette. We chose vignettes to cover a range of emotional valence and arousal. Scenarios in block B did not involve the consumption of any taste samples.

Hypothesis (H3) The more positive valence vignettes map to sweeter tastes, and more negative valence vignettes map to more bitter tastes. The intensity of the taste will map the emotional intensity (arousal) triggered by the vignette.

Expressing Emotions (block B) - Website Usability

The final scenario involved the direct experience of using a website. Participants were asked to use two travel websites to book a flight and accommodation for Rome. The websites were selected as landmark illustrations of 'good' and 'bad' usability, according to a recent comparison of travel booking websites [42]. The websites chosen were Skyscanner [57] (best performer in the report) and Co-operative Travel [58] (worst performer). The websites were accessed through a chrome browser on a MacBook Pro laptop. After completing the booking, participants selected one of the five taste labels, i.e., "very bitter", "slightly bitter", "neutral", "slightly sweet" and "very sweet", which best expressed their experience of using the site. Participants also assessed both websites' usability in terms of effectiveness, efficiency and satisfaction on a 5-point Likert scale [59]. We computed usability scores as the average of participant's effectiveness, efficiency and satisfaction ratings for the two sites and ran paired t-tests. Findings indicate that Co-op website had a significantly lower usability score (M=5.56, SD=1.82) compared to Skyscanner website (M=9.13, SD=3.65) ($t(15) = 3.23$, $p<0.05$). This confirms that participants' perception of websites' usability is as predicted.

Hypothesis (H4) more positive experience of using the website (evaluated by a higher usability score) maps to more intense sweet taste, and inversely, a more negative experience maps to more intense bitter taste.

	Very Bitter	Slightly Bitter	Neutral	Slightly Sweet	Very Sweet	Totals
Strongly Negative	18	10	1	1	2	32
Negative	15	7	4	3	3	32
Neutral	4	10	10	7	1	32
Positive	2	4	5	15	6	32
Strongly Positive	1	2	2	9	18	32
Totals	40	33	22	35	30	

Table 4 Frequency counts for each taste sample to vignettes grouped by valence in experience vignette scenario. Shading shows most common (red) to least common (white).

	UX Score	Very Bitter	Slightly Bitter	Neutral	Slightly Sweet	Very Sweet
Co-op	M=5.56, s.d. 1.82	7	6	2	0	1
Skyscanner	M=9.13, s.d. 3.65	1	4	3	4	4
	Totals	8	10	5	4	5

Table 5. Frequency counts for each taste sample to websites in website usability scenario. Shading shows most common (red) to least common (white).

Quantitative Findings

For block B scenarios the frequency counts are presented in Table 4 and 5, and we ran Spearman correlation and Friedman tests to test H3 and H4. In order to test H3, we grouped the vignettes into 5 classes according to the rating of emotional valence defined for each in the ANET database. Thus, we had 2 vignettes in each of the 5 levels: "strongly negative", "negative", "neutral", "positive" and "strongly positive" (Table 4). Table 4 shows participants' agreement on the mapping between tastes and the emotional responses elicited by the vignettes, with the most frequent matches occurring at the extremes. Thus, strongly positive emotional responses were most often associated with very sweet taste, and strongly negative emotional responses were most often associated with very bitter taste. Similar to findings on block A, the agreement at intermediary points was lower: "negative" and "neutral" emotional response received the least number of matches with "slightly bitter", and "neutral" tastes on the first diagonal. Table 5 reflects a similar agreement on the relationship between tastes and website usability results, but in this scenario, the agreement is the strongest for "very bitter" and "slightly bitter" taste (over 80% of participants) and Co-op travel website's poor usability. Interestingly, the mapping of tastes to the Skyscanner website's strong usability has been less consistent, with the highest frequency of counts (4) mapping its usability equally to "very sweet", "sweet", and surprisingly, also to "slightly bitter" tastes. Indeed, only 50% of participants associated Skyscanner website's usability with "very sweet" or "sweet" tastes.

To further explore the relationship of the elicited emotional responses via vignettes we also ran correlation tests. Findings show a significant positive correlation between taste and valence of the emotional experience elicited by vignettes ($r_s(23) = 0.61$, $p<0.01$), supporting H3, but no significant correlation between arousal and taste. These findings suggest the increased importance of valence in the relationship between tastes and emotions. The outcomes of "website usability" scenario also show a significant positive correlation ($r_s(8) = 0.62$ $p<0.01$) between the usability scores and tastes, supporting our hypothesis that sweet tastes are associated with positive usability experiences. and bitter tastes to negative ones (H4). Friedman Tests with *post hoc* Bonferroni adjusted pairwise comparisons were run on the number of tastes assigned to each vignette. These findings indicate that: "very bitter" ($\chi^2(4) = 9.30$, $p<0.05$) was best represented by strongly negative or negative vignettes, "slightly sweet" ($\chi^2(4) = 16.32$, $p< 0.05$) positive vignettes, and "very sweet" ($\chi^2(4) = 26.22$, $p<0.05$) strongly positive vignettes. These findings also suggest that mappings are more consistent at the end points as in block A. This partially supports H3 regarding the relationship between taste and emotional valence, but less so the relationship between taste intensity and emotional intensity, due to the absence of significant difference in the mappings of bitter and neutral.

In order to test H4, we conducted Friedman tests for this scenario but did not find significant differences between the tastes selected for each website. Due to the small sample size for this scenario (only two stimuli given compared to 10 in others) we are unable to draw robust conclusions. Together with the correlation results, study findings partially support hypothesis H4 that poor usability is more often associated with bitter taste. They also only partially confirmed the mapping between strong usability and sweet taste. Indeed, findings indicate a less clear picture, as strong usability has been most often associated not with one but three tastes: "very sweet", "sweet", and "slightly bitter". This suggests that taste has potential to communicate both high and negative emotional responses, albeit it more consistently communicates emotional responses of intense positive valence.

QUALITATIVE ANALYSIS

We now report on the thematic analysis [3] of our interviews and the key findings regarding participants' perception of tastes, perceived difficulty of each scenario, and the specific tastes, flavors, or foods that each scenario suggested to them. All responses during exposure and after each scenario were audio recorded and fully transcribed. The lead author conducted an initial deductive coding from the collected material. Themes were identified and iteratively refined through discussions between the 1st and 2nd author.

The taste stimuli were commonly described as 'watery' (n=37) or 'fruity' (n=18), or in terms of texture (n=14) reflecting the material qualities of the 3D printed food. This makes sense since the 3D printed stimuli consisted of liquid-filled gel balls, giving the appearance of fruit and the sensation of liquid when bitten into. Participants also reported how their taste experience was highly embodied, focusing on the mouth (n=9) : "*[it] does fill your mouth"* [P13]; *it's not like too much in your mouth. It's quite a pleasant flavor when it is first on your tongue*" [P8]. These findings suggest that taste-based interfaces have the potential to further advance the growing HCI interest in embodiment. Through the think-aloud process during the scenarios, participant's made comparisons from sample to sample based on taste (n=15) *"it has definitely got a sweetness to it which I prefer to the others'* [P9], arousal (n=13) *"maybe not as much as the one before because on the first taste it was stronger"* [P8] and valence (n=9), *"it wasn't as unpleasant as* [previous] *ones"* [P4].

In the post-study interview, we also invited participants to rate each scenario for difficulty. The scenario perceived as the easiest was the website scenario (n=9), and the one perceived as the most difficult was product ratings (n=7). P3 described the difficulty of the product scenario arising "*because I was reviewing an undescribed product*". This imagined product review contrasted to the direct experience of using the booking websites where "*the functionality didn't seem to work, so because it was quite frustrating, it instantly became very bitter*" [P3]. The sports and vignettes scenario were rated as easy by 7, and 8 participants respectively. When asked to propose their own tastes, flavors, or foods to understand or communicate the experiences involved in each scenario, we observed a theme of favorite and least favorite foods being suggested to map to the either end of the scale. Example foods being "*hot, buttery toast*" [favorite food suggested for a 5-star product rating, P16] or "*carrots because I hate carrots*" [least favorite for a big defeat, P10]. In addition, participants identified foods relevant for that specific scenario, or what we called *context-related flavors:* "*I am always relating post game beers [to] watching football*" [sports match results, P11]. Interestingly, "sweet" and "bitter" (both n=5) remained popular choices for the sports match scenario but not for the product scenario. P8 acknowledged the role that taste metaphor plays in such choices by referring to the common metaphor of "*sweet taste of victory*" as highly appropriate for the sports match scenario. Findings also indicate that flavors tended to trigger remembering of specific past experiences: "*wallpaper paste […] when I was a kid I remember tasting it when my parents were papering the wall*" [P7]. This kind of artificial, wet-like taste resembles qualities of the 3D printed food. What is interesting here is the ability to connect the taste sample (very bitter in the case of P7) to a childhood memory. This is an important outcome suggesting that unlike taste which maps mostly to emotional valence (but not arousal), flavor may better map to specific episodic memories [25,39].

DISCUSSION

We now discuss our findings and their novelty by reflecting on our research questions. With respect to the first research question on the relationships between taste and emotions in real-life inspired scenarios, findings indicate taste-emotion mappings as hypothesized in each of the four scenarios we presented. Study outcomes confirm that "sweet" tastes are understood by users as a "positive product rating", "one's team winning a sports match", and conversely, "bitter" tastes were understood as a "negative product rating" and "defeat of one's team". In addition, participants were also able to use tastes to express their own emotional experiences in the vignettes and travel websites scenarios. Thus, "sweet" tastes were used to express positive emotions elicited by the vignettes and positive experiences of engaging with a website with strong usability.

Our findings make two contributions to the state-of-the-art. First, we provided evidence that the taste-emotional valence mapping (sweet-positive, bitter-negative) extends beyond lab-based studies [15,20,35,49,54] into real-life inspired scenarios, although such extension has been previously questioned [9]. This also applies to the less explored mapping of taste to emotional arousal (intense taste-intense emotions) [49,54]. In particular, our findings indicate that the latter mapping is more challenging in real-life inspired scenarios and that while the highest arousal emotions are consistently mapped to the strongest tastes, intermediate levels of arousal in emotional responses are not. In addition, when both emotional valence and arousal are considered, tastes can be used to communicate both high arousal and negative valence emotional responses. These findings suggest interesting potential for HCI research, where the exploration of taste as resource for design has focused mostly on taste types [26,47,50,51] and less on taste intensity, nor on the relation between taste type and intensity with user experience [13,31]. Future work should further explore the relationship between taste intensity and user experience, possibly by leveraging flavor experience and other multisensory stimuli [34].

We now look at the second research question on the feasibility of 3D printing food technologies for exploring the taste-emotion mappings in HCI. Our exploration with taste was enabled by the novel 3D food printing technology. This allowed us to keep constant non-taste aspects of food experience (e.g., texture, color or smell), which in turn, enabled a more controlled exploration of taste. Previous work on 3D food printing technology suggested that its acceptance will be driven by its experiential rather than gastronomic value [14]. We argue that using such technology to support affective interactive experiences offers such an opportunity. The *nūfood* printer used in this study has two tanks allowing the varied tastes to be delivered on demand. In this way it offers an advantage over the single-tank extrusion printers used in *EdiPulse* [22] and co-dining experiences [50]. In particular, our findings suggest that 3D liquid food printing is a suitable technique for stimulating taste sensation in HCI contexts. As explored in the study, the printer is able to produce taste output, but it is also capable of producing more complex flavor experiences. This is an important functionality to be leveraged in future work.

Indeed, participants suggested the value of flavors which could be more personal and scenario-specific, as alternatives to the limited range of sweet and bitter tastes used in the study. Also for future consideration is the combination of taste-stimuli with other multisensory aspects of experience, including color and shape [43] manipulated through 3D food printing technologies. Findings provided evidence for the embodied quality of user experience mediated by 3D printed tastants. Such outcomes extend the current HCI approach to embodiment which emphasizes the human body, emotions, and the challenge of mind-body dualism [31]. The key new insight in this direction is the value of mouth as a novel space for bodily interactions. Our findings highlighted movement within the mouth as well as ideas of filling and coating as qualities of bodily experience. For designers interested in taste-based interfaces, the mouth should not be seen simply as part of the body, but as a gateway, unique as a space for entry into the body, extending the traditional approach to the body as a resource for design [27]. Compared to haptic experiences *on* the body, taste experiences are taking place *within* the body. This internal-ness is unique to the way we experience food, and opens up a space for more intimate interactions, more related to our physical selves.

With respect to the third research question on the relevant HCI scenarios for taste-based interactions, we now reflect on our four scenarios: "product ratings", "sports match results", "experiential vignettes", and "website usability". Their choice was grounded in their connection to tastes, and ability to capture both analogue- and digital-related contexts. Regarding the potential for different scenarios of use, validation of each hypothesis indicates that taste-emotion mappings are likely to work well across a range of scenarios where there is a clear emotional aspect to the information being communicated. However, our qualitative findings indicate that although all scenarios allowed the exploration of taste-emotion mappings, they differed in participants' perception of their difficulty level.

At a closer look, this suggests the importance of user's direct engagement in the experience outlined by the scenario. For instance, the "website usability" scenario allowed for the highest level of engagement as participants actually performed the booking tasks themselves. Thus, their ratings were grounded in their personal, almost visceral experience, given the high negative arousal experienced with the poor usability website. In contrast, the "product ratings" scenario facilitated the least engagement, as participants neither chose the product themselves, nor had had prior experience with the rated products. This made it challenging to deliver a rating, as this was not grounded on any personal experience. The "sports match results" and "experiential vignettes" scenarios can be placed somewhere in between, as although they did no enable direct experiences, they provided common contexts or *cultural scenarios* [36] that people could easily connect to and imagine the associated emotional experience. Some participants could even remember sport matches they attended, and hence could bring a valuable experiential quality to their rating. Hence on the continuum of engagement, our scenarios varied from involving direct experience (i.e., "website usability"), remembered or easily imagined (i.e., "sports match results" and "experiential vignettes") to difficult to imagine (i.e., "product ratings"). The best scenarios for taste-based interfaces are those engendering directly mediated emotional experiences that leverage cultural scenarios that people can easily make sense of. One way to strengthen these scenarios is by leveraging taste metaphors. For instance, in the "sports match" scenario the taste-based metaphors of winning and losing were easily drawn upon by participants.

Design Implications

We now offer three design implications for novel taste-based interfaces drawing on the identified mappings, the design of flavor-based interfaces, and the use of taste for evaluating user experience.

Novel Taste-based Interfaces with 3D Printed Food

Findings indicate that 3D printed food with "sweet" and "bitter" tastes map to, or connect best with, the emotional valence of the associated experiences. We used different levels of intensity of "sweet" and "bitter" tastes to support both the understanding and expression of emotional experiences with different levels of intensity in four scenarios. Our findings open up new opportunities for taste-based interaction design. One could imagine what we would call *emotastes*: droplets of sweet or bitter taste 3D printed in real time to augment mediated communication. This could support remote connectedness, adding a layer of embodied affective response to the expression of emotions between two people, extending thus previous explorations with visual, thermal, and haptic information [23].

Findings also suggest the importance of choosing application scenarios which can benefit most from taste-based interactions. We have seen how those leveraging taste-related metaphors and the personalization of tastes, possibly through 3D printed foods or flavors, are better positioned to reflect intuitive and easy to understand mappings between tastes and emotions. Such scenarios could offer the best starting points in the exploration of taste based interfaces in HCI. For instance we can think of scenarios where taste-based interfaces can be used to support reminiscing of "bittersweet memories", a metaphor capturing ambivalent feelings of happiness and sadness.

Designing Novel Flavor-based Interfaces

Findings also indicate that flavors best map or connect with specific, personal, emotional narratives. This suggests the value of augmenting 3D printed tastants such as the ones used in our study, with smell, texture or temperature qualities to support a more embodied experience of food and its flavor. Flavors will not be as universally perceived as tastes but do offer opportunities for strong personal narratives to be built that better position the user in relation to the interaction scenario. In turn, this could allow for stronger recall of personal past experiences. One can think of new flavor-based interfaces that can reconstrue and deliver droplets of flavor to support reminiscing in old age [38,40] or for sufferers of dementia, or connect with aspects of identity curation and expression, particularly amongst migrant communities.

Novel Taste-based Methods for Evaluating User Experience

Findings indicate that 3D printed tastants worked best in the "website usability" scenario as tools for expressing the user experience prompted by the website's usability, such as frustration with poor usability. This is a significant finding given the limited HCI tools for measuring user experience. We argue that through its powerful emotional and temporal qualities, taste offers an exciting avenue for accessing user experience in less verbal and more embodied ways. HCI work exploring such nonverbal means to assess user experience has been limited. A notable exception is the *sensual evaluation instrument* [19] that leverages affective dimensions through sculptural shapes. We argue that taste provides a similar embodied experience, whilst adding an additional layer of meaning making through reliable emotion mappings. For instance, we can think of using tastes during website evaluation which may allow real-time experience capture, as tastes are adjusted and printed on-demand until the best taste expressing one's emotions is found. We can imagine user experiences leveraging metaphors such as "sour note", "bitter end" for expressing negative experiences, or "sugar" and "honey" for positive ones. This is consistent with neuroscience findings indicating that both taste sensation and taste-related words used in sentences activate emotional processing areas of the brain [7].

Limitations

This exploratory study focused on real-life inspired scenarios but was nonetheless abstract from participants' real world usage. Future work should build on our insights to further understand how the scenarios presented fit within people's everyday, lived experience with technology. The cultural bias amongst participants leaves open the question of generalizability. Whilst differences in taste-shape mapping have been shown cross-culturally [5,48], further research has found the mapping of sweet and bitter tastes to positive and negative valence emotions to be consistent across both Eastern and Western cultures [20,54]. An additional limitation of taste exposure is the decay in pleasantness for repeated exposure to the same stimuli [45], so scenarios with repeated, similar stimuli exposure should be mindful of this. However the temporal dimension of food experience [10] could indeed be an opportunity for designining with delay, and repeated exposure to create narrative flows.

CONCLUSION

This paper explored the potential of 3D food printing technologies in an experimental study investigating the relationship between taste and emotional experience. Findings indicate that the taste-emotional valence mapping (sweet taste-positive emotion, bitter taste-negative emotion) extends beyond lab studies into real-life inspired scenarios, and that the taste-emotional arousal mapping in real-life inspired scenarios holds true for highest arousal emotions (intense taste-intense emotions). Our findings led to three design implications for novel taste-based interfaces drawing on the identified mappings, the design flavor-based interfaces, and the use of taste for evaluating user experience.

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