Temporal, Affective, and Embodied Characteristics of Taste Experiences: A Framework for Design

Marianna Obrist[1,2], Rob Comber[1], Sriram Subramanian[3], Betina Piqueras-Fiszman[4], Carlos Velasco[4], Charles Spence[4]

m.obrist@sussex.ac.uk | rob.comber@ncl.ac.uk | sriram@cs.bris.ac.uk | betina.piqueras-fiszman@psy.ox.ac.uk | carlos.velasco@psy.ox.ac.uk | charles.spence@psy.ox.ac.uk

[1]Culture Lab, School of Computing Science
Newcastle University, UK

[2]School of Engineering and Informatics
University of Sussex, UK

[3]Deptartment of Computer Science,
University of Bristol, UK

[4]Department of Experimental Psychology,
University of Oxford, UK

ABSTRACT

We present rich descriptions of taste experience through an analysis of the diachronic and synchronic experiences of each of the five basic taste qualities: sweet, sour, salt, bitter, and umami. Our findings, based on a combination of user experience evaluation techniques highlight three main themes: temporality, affective reactions, and embodiment. We present the taste characteristics as a framework for design and discuss each taste in order to elucidate the design qualities of individual taste experiences. These findings add a semantic understanding of taste experiences, their temporality enhanced through descriptions of the affective reactions and embodiment that the five basic tastes elicit. These findings are discussed on the basis of established psychological and behavioral phenomena, highlighting the potential for taste-enhanced design.

Author Keywords

Taste; user experience; taste experiences; sensory research; explicitation interview technique; sensual evaluation tool.

ACM Classification Keywords

H.5.2 Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Experts in taste perception agree on at least five basic tastes [40]. Beyond this, however, we lack insights into the rich experience of these tastes. This lack of experiential understanding extends beyond HCI, as sensory researchers have also acknowledged that: *What is not well researched is the link between the food that goes into our mouth and what we think of it* [12]. There is a growing interest in taste within the HCI community [e.g., 16,17,18,22,27,28], particularly relating to technical challenges in designing for taste stimulation and one-off designs to enhance user experiences through the manipulation of taste.

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There is a need for a more systematic study of people's taste experiences and their specific characteristics in order to make a fuller use of this sense in future taste-enhanced technologies. This paper stands as a first step in addressing this need. Drawing on neuroscience and sensory research in combination with user experience evaluation techniques, we investigated how all five basic tastes are experienced at a given time (synchronic) and how they evolve over time (diachronic). We used pure tastants (i.e., that have no smell or visual qualities) with an explicitation interview technique [41] designed to encourage the participants to verbalize their experiences. Additionally, we used physical objects from the Sensual Evaluation Instrument [13] to elicit affective responses, and create a flexible, non-verbal channel of communication between the user and designers.

This paper makes a number of contributions: First, we provide a rich description of subjective taste experiences along both the diachronic and synchronic characteristics of the five basic tastes. Second, these taste characteristics establish a framework for taste experiences and elucidate the potential design qualities of individual tastes. We demonstrate how each quality can be described along three main themes: *temporality, affective reactions,* and *embodiment*. Third, our findings extend human-computer interaction research on taste through a user experience perspective. Overall, our findings provide interaction designers and user experience researchers with a richer understanding of taste experiences and their specific power to influence human behavior and decision-making. The framework presented here enables the HCI community to think and talk about taste in the design of interactive systems in a fine-grained manner.

RELATED WORK

This section provides an overview of the human sense of taste and its relevance for HCI based on ongoing research.

The sense of taste

Sensory researchers and neuroscientists agree on five basic tastes (sweet, sour, salty, bitter and umami), and a 'gustotopic map' linking these classes of receptors with particular brain areas is currently being developed [40]. However, despite breakthroughs in understanding the sense

of taste, scientists have still not approached the phenomenology of taste nor developed a semantic understanding of how taste is experienced [30]. Although a wide body of sensory research has studied the temporal evolution of taste perception using labeled intensity scales [e.g., 1,8] and more specific time-intensity sensory evaluation scales [26], insights are limited to the quantification of temporal responses to perceived taste intensities. Such scale-based evaluations leave us uninformed as to the subjective qualities that lie behind the ratings of the perceived taste experience over time.

Recently, neuroscientists have studied taste-specific temporal profiles by comparing sensory evaluation scales with functional MRI (fMRI) data [19]. Their results suggested that salty tastes change more rapidly than sweet tastes in the cerebral cortex, and confirm the same patterns that have been observed using time–intensity sensory evaluation [19]. While such results are intriguing, they cannot explain the differences in experienced tastes. To account for subjective differences, the 'taster status' measure has been introduced [2,6]. By means of such tests, it is possible to identify participants' subjective sensitivity to bitter tastes and to distinguish between supertasters (25% of population), medium tasters (50%), and non-tasters (25%) [3]. Taster status has been considered to partially explain why some consumers like certain foods more than others and how they describe the way they experience them.

Food-interaction design

The last few years have seen increasing interest in designing human-food interaction in HCI [e.g., 4,9,11,33]. Such research looks to position human-food interaction within the wider spectrum of social, environmental, and physiological influences on our food practices. In this area, there is a growing realization of the potential for new technologies to support pleasurable experiences around food [20,35], and the potential for designers to draw on the extensive research on multisensory experiences (i.e., auditory, tactile, visual, olfactory, and gustatory). Despite this increased interest in food experience, we know little about the richness of people's taste experiences. The majority of the studies on food experience combine taste with other modalities, where taste is but one component [e.g., 18,27,28].

For instance, Schifferstein et al. [31] elicited emotional experiences across the different stages of food product usage, from choosing a product in the supermarket through to cooking and eating [31]. Taste experience is interwoven with vision, touch, and olfaction, which, in combination create multisensory food experiences. Desmet and Schifferstein [5] also explored the emotions elicited through eating and tasting food. They describe variables related to food-evoked emotions, such as sensory features, product type, food-related activities, context, and the agent (who consumes, prepares, or produces). Due to the wide range of influencing variables, it is not clear how well these findings translate beyond the specific context of their studies.

Taste-enhanced technology

Technological advances in creating taste stimulations [27,28] and one-off applications exploiting taste in games [16] and other scenarios [18,22] demonstrate a growing interest in the use of taste in interactive applications. For instance, Ranasinghe et al. [27,28] developed a tongue interface that creates taste through the combination of electrical and thermal stimulation. They use electrical pulses applied to the tongue. Verbal descriptors provided by participants were, for instance, a 'refreshing taste' or 'minty taste' in relation to the change in temperature. The authors call for future work to understand the particularities of such taste (flavor) experiences. They focused on the introduction of taste in digital communication to enhance long-distance family relations and create remote co-presence and co-living experiences (e.g., remote dining) [28].

Murer et al. [16] designed a gustatory game device, LOLLio, which consists of an interactive lollipop that serves as a haptic input device that dynamically changes its taste between sweet and sour. Remote triggering of taste while motion sensing with accelerometers allows LOLLio to be used as an input modality. The authors identify various ways in which taste could be used in an interaction, such as to provide reward or punishment or else to provide hidden information through taste stimuli. LOLLio was evaluated in a game context with children [17]. Sweetness was constantly used in the game session and sour stimuli were used in combination with game mechanics to provide 'negative reinforcement'. Their findings suggest an enhanced playing experience through taste stimulation motivating further explorations of such taste-enhanced interaction experiences.

STUDY METHOD AND PROCEDURE

Sensory research provides important information regarding the objective measures of taste perception, temporality, and subjective sensitivity levels. Yet, an understanding of the subjective understanding of taste experiences is missing. This study explores the diachronic and synchronic structure (explained below) of each of the five basic tastes.

Methodology

For our study, we combine two verbal and non-verbal user experience and elicitation methods, the explicitation interview technique (verbal method) and the 'Sensual Evaluation Instrument' (non-verbal method).

The *explicitation interview technique* [41] is used to elicit verbalizations of subjective experiences. This technique helps to explore the unfolding of an experience over time, the 'diachronic' dimension, and examines the specific facets of the experience at a particular moment, the 'synchronic' structure (see also [24,39]). The value of this interview technique lies in helping participants to express their experiences at a specific moment. Participants are encouraged to talk about the experiential (cognitive, perceptive, sensory, and affective) aspects of the moment without building on rational comments and explanations [24]. Questions related to the diachronic structure help to

understand how the description of an experience unfolds over time (e.g. "What happened after you opened the door?" and "What did you perceive next?"). With respect to the synchronic structure of an experience, the participant is questioned about a particular moment (e.g. "At the moment when you pushed the handle down, how did it feel?" or "What else came in your mind?"). In comparison to open questioning approaches, this technique is non-inducive but directive [24] in the sense that it keeps the participant talking about the experience without inducing any content; it focuses on the structure of the experience, and directive, as it keeps the participant focused on the singular experience being explored. Although it is typically used retrospectively to support the reconstruction of an experience, it has also been used in-situ (e.g., [15,23]).

The *Sensual Evaluation Instrument (SEI)* is a non-verbal tool that can be used to elicit users' affective reactions [13]. SEI is composed of sculpted objects that can be held in the hand, used by a person to indicate how they are feeling as they interact with a system. The SEI includes eight objects with different shapes, which represent various levels of arousal and valence (positive and negative). Isbister et al. [13] describe SEI objects as evoking and expressing a range of emotions; they do not claim a direct mapping between the objects and the mentioned emotions, but emphasize the benefit of the objects for stimulating expressiveness. The value of the SEI is to elicit real-time, affective responses, and to create a flexible, non-verbal channel of communication between user and designers. The latter defines a key advantage compared to other methods that are often limited to verbalizations or visualizations that lack physicality.

Taste stimuli

The stimuli used for each taste are specified in Table 1. Each stimulus was prepared as an odorless and colorless water solution using a stock solution as specified in ISO 3972. We prepared the solutions according to the specifications detailed by Hoehl et al. [10] and used deionized water for the tastants. These compounds standardised stimulus features and controlled for sensory differences, such as texture, vision, etc. All of the solutions were prepared the day before each study day. The participants received 20 ml of each stimulus in a disposable 40 ml cup. A Latin square design was used to avoid order bias [42].

Taste	Stimuli used	Solution (g/L)
Sweet	Sucrose	24.00 mg
Sour	Citric acid	1.20 mg
Salty	Sodium chloride	4.00 mg
Bitter	Caffeine	0.54 mg
Umami	Monosodium glutamate	2.00 mg

Table 1. Stimuli used for the five main tastes, including the stock solution (indicating the threshold specified in ISO 3972).

Participants

The study was conducted with 20 participants (nine female) aged between 21-38 years (M=29.4, SD=5). Participants were recruited based on the following criteria: not having any food allergies, being non-smokers, not being pregnant, and not having any sensory dysfunction (e.g., dysguesia, a taste disorder), by self-report. The participants were recruited through the staff list within the lead university. 16 participants were native English speakers, and the remaining four were fluent in English. All participants gave informed consent prior to the study.

Study set up and procedure

The participants were instructed and reminded 2 days prior to the study not to eat spicy food 24 hours before the study and not to drink or eat 1 hour before attending the study. The study had 2 parts (see Figure 1): In the first part, we applied the explicitation interview technique for all five tastes; in the second part we introduced the SEI objects to enhance the verbalizations for each taste.

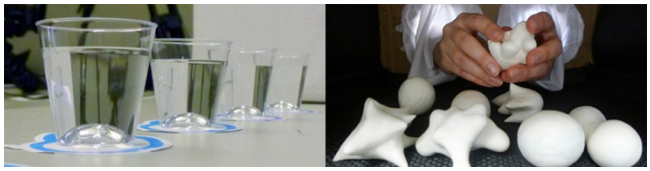

Figure 1. Study set up: *Left* shows the five taste stimuli (40ml cups with odorless and colorless water solutions for each stimulus). *Right* shows the SEI objects placed inside a box.

In the first part, participants were given 5 minutes per stimulus. They could take as many sips as they wanted of the stimulus and were prompted with specific questions about their taste experience (e.g., Could you describe what you perceive? How does it feel in your mouth?). The aim was to receive insights regarding the diachronic and synchronic structure of the taste experience. We used this technique in-situ in order to account for the rapidly decaying sensory memory trace related to the human sense of taste [21]. Before continuing with the next stimulus, the participants were asked to have a sip of the deionized water in order to cleanse their mouth. The same procedure was repeated for all stimuli.

In the second part of the study, the participants were instructed to match each taste experience to one or more of the eight shapes inside the box. The participants could only feel, and not see, the objects, to exclude any visual influences and to focus on the mapping between 'taste and shape' via the sense of touch. The participants were instructed to select one or more or none of the shapes (they could also reuse shapes for different tastes). Before going through each taste stimulus again, the participants were given the chance to put their hands into the box and familiarize themselves with the 8 shapes.

Next they were asked to take a sip of water and start with the first taste stimulus. They were asked to express the thoughts they had in mind and to describe their choices or lack thereof (if none of the shapes was selected). Finally, the participants were asked to rate the pleasantness/ unpleasantness of the shapes on a four-point Likert scale from 'very pleasant' to 'very unpleasant'. They were also asked about their personal favorites amongst the 5 taste

stimuli and their personal food preferences to support the interpretation of the data.

In a final step, we tested the participants for their taster status, which classified participants into supertaster, normal tasters, and non-tasters. Overall, the study lasted one hour and was audio/video recorded with the consent of the participants. No incentives were paid to the participants.

Data analysis

All 20 tasting sessions were transcribed and a qualitative analysis based on the transcripts was conducted. Two researchers independently performed an open thematic coding based on 5 cases (25%). The resulting themes were discussed and an initial coding scheme was established. Two more cases (10%) were coded independently leading to a final coding scheme consisting of three main themes (described in the next section), which were then applied to the remaining 13 cases by both researchers. We also performed a qualitative analysis of the mapping between the SEI objects (see Figure 4) and the taste experiences, captured through the transcripts and the visual material from the recorded hand movements in the second part of the study. Based on participants' ratings of the shapes (their physical pleasantness/unpleasantness) we could confirm previous ratings of Isbister et al. [13] – the more spiky shapes were rated as 'unpleasant to slightly unpleasant' (shapes 8,7,2), the more rounded shapes were rated 'very pleasant to pleasant' (shapes 3,4,5,6), and only one shape was perceived as 'neutral' (shape 1). Finally, the supertaster test provided us with insights on the different taste sensibility of participants and ensures a good distribution of taster statuses in our study. Overall, we identified 5 non-tasters, 11 normal taster (4 tending towards the upper edge of bitterness sensitivity), and 4 supertasters. These results are consistent with the known distribution amongst the general population [3].

STUDY FINDINGS

The description of taste experiences is based on both parts of the study. We describe the characteristics of taste experiences across all five tastes along three identified themes: *(1) temporality*, *(2) affective reactions*, and *(3) embodiment* (see overview in the supplementary material). We also discuss the particularities of each individual taste in order to elucidate the potential design qualities of single tastes. Each identified theme is represented in a pictorial visualization of its key characteristics based on the identified patterns across participants' verbalizations.

Temporality

While taste experiences have expected elements of changing intensity (e.g., strong taste, weak taste), the tastes were also perceived as being mobile (e.g., moving within the mouth, moving intensities), and occasionally exerted a physical presence (e.g., building up, eroding, lingering). These temporal characteristics are intertwined in the unfolding of the experiences from its initial stimulation (diachronic structure) and set the stage for the different taste journeys (synchronic structure). Below, we describe the different time-intensity profiles of taste experiences. Taste intensities are generally experienced as being dynamic and participants' verbalizations offer a lexicon of growth and decline. The diachronic nature of taste experience is also revealed in the immediacy or longevity of dynamic intensities. For instance, all participants agree on the immediacy of the sour taste. Such immediacy is expounded in similes such as 'a firework in the mouth', 'a punch', and 'a flash that hits you'. Yet, despite the immediacy of this experience, it is short-lasting and decays rapidly. *"When you drink it, you get that bit of a rush. Yes, it's basically gone now* [P15, sour]. In contrast, other tastes were described as slowly building up or maintaining consistent intensities (e.g., high for umami, and low for salty). Such intensities could be seen to be 'lingering', rather than 'explosive', as one participant described it: *"You've got this "Whoa" sensation, feels quite strong to start with. Then it has gone super quick"* [P19, sour].

While the dynamics of intensity imply variation (intensity increasing and decreasing), the vocabulary of movement animates these changes. Describing the bitter taste, one participant stated: "*I guess it's not sticky like the first one [umami]. It's a bit lively... I feel like it's moving around"* [P15, bitter]. While certain movements can be attributed to mouth-feel (e.g., moving left to right across the tongue), others were externalized (e.g., *"I feel it almost into my sinuses and into the rest of my face"* [P14, bitter]). These expressions were not confined to the temporal characteristics of taste experiences, but already shed light on the bodily reactions that can be elicited by tastes. Movement was also invoked to describe stasis (e.g., 'stays') and repetitive movement (e.g., 'waves'). *"So it is kind of strong and it also stays. It doesn't have a peak; it doesn't go up and down; it just stays"* [P2, umami]. Other tastes fluctuate rapidly: *"Yes, ups and downs, but quite quick. They're quite sudden crests and falls…"* [P3, sour].

Participants often appealed to similes of physicality in order to explain their taste experiences (e.g., 'round', 'soft', 'heavy'). Such physical experiences are tied to a synchronic perception of taste. In contrast, the diachronic physicality of taste experiences is given in the implied and experienced characteristics of taste as a residual presence (e.g., 'lingering', 'stays there'): *"It just stays in your mouth, so it kind of keeps developing"* [P10, umami] or *"it just leaves its mark in your mouth and doesn't go"* [P7, umami]. Such experiences are, much like the increasing intensities, those that 'build up', or 'get a bit stronger". Such presence is understood to 'erode'. Moreover, the implied residual physicality is associated with experiences of absence. When tasting sourness, many participants described the immediate, almost physically imposing intensity followed by a marked absence. This absence is seen to draw the taster back into the taste, leaving them wanting more: "*it creates an expectation of sweet flavour, like if you were biting into a slice of orange or something. ... It's gone now and actually I'd quite happily have another sip, to be honest*" [P18, sour]. This residual physicality can also be

Figure 2. Temporal characteristics of taste experiences showing the intensity (thickness of the lines), the movement (frequency of the lines) and the residual physicality (length).

Figure 3. Affective characteristics of taste experiences (green = pleasant, red = unpleasant, orange = neutral, white = absence of taste). Umami shows two experiences: pleasant and unpleasant.

seen to afford agency to taste experiences, where tastes 'grab you', and 'hit you in the face'. As such, taste experiences can become reified in exerting influence over the taster. This can be achieved in the residual physicality or in absence, for instance, where the marked absence in sourness is seen as *"a forward feeling… It has the feeling of tartness, your mouth moves forwards"* [P14, sour]. Sweetness in contrast is associated with the feeling of filling the mouth, and when the taste is gone it leaves one with a kind of stickiness on the teeth.

Figure 2 shows a pictorial representation of the different types of temporality identified based on the above descriptions across all five tastes. The intensity is represented through the thickness of the lines in the bars, while movement is captured through the frequency of the lines. Finally, residual physicality as temporal characteristic is shown through the length of the whole bar. Overall, sour is the taste delivering the highest intensity, followed by umami and bitter. Umami presents a high intensity, and is also characterized by lingering without losing much of its intensity. Such an extensive residual presence can also be seen for bitter, however with a lower intensity. Sweet and salty are also of low intensity and can be characterized by particular movements. While sweet starts slowly, builds up and then dies out, salty does not peak at all and is constant in its perception and moderate in unfolding over time. Sour, by contrast, is short-lived with a rapid end. Specific to sour is the sharp beginning followed by the absence of a taste and the return of it through a forward pulling feeling, which disappears quickly.

Affective reactions

Affective reactions refer to both the sense of pleasure or displeasure gained from the taste experience, but also feelings most often regarding familiarity, such as comfort, or, by contrast, unfamiliarity, such as surprise and suspicion. These affective characteristics, to be captured as pleasant-unpleasant and familiar-unfamiliar, operate not only as a static attitudinal response to taste experiences (synchronic structure), but also as evolving characteristics of the taste experience (diachronic structure).

When sampling the taste stimuli many participants related their own uncertainty (e.g., I don't know what to expect). After one sample, this uncertainty is replaced for familiar tastes. For unfamiliar tastes, particularly bitter and umami, the sense of unease pervades and persists. Thus familiarity produces responses at singular points (e.g., I am/am not familiar with this), while also producing responses across time (e.g., I know/do not know what to expect). A recurring phrase throughout the taste study was "*I know what it is, but I don't*". While we can at times attribute this to the nature of the stimuli as water solutions (i.e., those not regularly experienced by participants), the sentiment expressed also refers to the lived and felt experiences of the tastes. That is, while participants on the one hand had the taste 'on the tip of their tongue', those tastes also brought to mind a variety of known experiences, or, in the absence of known experiences, feelings of uncertainty or unease. Such feelings must presumably be associated with evolutionary causes (considering many bitter foods are poisonous) or in form of personal memories (e.g., salt, salty water, and the seaside) and cross-modal experiences (e.g., with color, or sounds). *"If I drink or eat something that leaves that kind of trace, I always imagine a colour. Glowing…. It's weird. I have no idea what this is, but there's a bitterness that stays"* [P2, bitter]. Participants identified as supertasters expressed their affective reaction more clearly: *"Definitely bitterness... I don't like it"* [P8, bitter], or *"It's immediately bitter…. It's like swallowing medicine"* [P18, bitter].

There were few predictable or consistent affective reactions among participants, and those experienced as pleasurable by some, were experienced as disgusting or unsettling by others. The affective response of participants could often be tied to the participant's familiarity with the taste. This was particularly noticeable with umami. Participants who were familiar with this taste indicated familiarity with savory Asian cuisine, and could therefore interpret the perceived taste and experienced it as pleasant. Those who did not eat Asian cuisine were less familiar with the taste, particularly in this intensity, and described unease and uncertainty when tasting it. Such responses also evolved over time, notably with sweet and sour tastes. While, as mentioned, sour produced an immediately unpleasant experience, followed by a refreshingly pleasant experience (e.g., *"yes it probably gets more pleasant as the intensity of the taste dissipates"* [P17, sour]), the taste of sweet was often initially pleasant, followed by a distinct unpleasantness. This unpleasantness could be so strongly felt as to produce nausea for some participants (e.g., *"although it's dying off over time. It's quite sickly actually"* [P20, sweet]). Such experiences were tied to the physicality of the taste residing in the mouth, and were perceived in two extremes for umami, influenced through the participants' familiarity/unfamiliarity with this taste. Participants familiar with this taste perceived the mouth filling and lingering experiences as comforting (satisfaction after a full meal), while other participants who were unfamiliar with it perceived it as disgusting, obtrusive, and annoying referring to the fact that the taste takes over control, without the chance to get rid of it quickly.

As with temporality, we created a representation of the different types affective reactions on the five tastes (see Figure 3). The pleasant-unpleasant characteristics of the taste experience are represented through the 'green' and 'red' colors and in cases of a neutral experience colored as 'orange', and finally 'white' in case of absence of the taste. The familiar-unfamiliar characteristics only find an explicit representation for the umami. The familiarity of the taste lead to its pleasant perception (upper bar for umami), while unfamiliarity with the taste was expressed through unpleasantness (lower bar for umami). Overall, some tastes are characterized by the change from unpleasant to pleasant (sour) or the other way around from pleasant to unpleasant (sweet), while the bitter taste was clearly unpleasant and salty was described as neutral. For umami, we identified two separate experiences (participants either love or hate it) grounded in the familiarity and unfamiliarity of the taste.

Embodiment

Although we would expect food experiences to involve embodied, textural, responses (such as 'crunchy', 'slimy'), here each taste stimuli is experienced in the same form (i.e., as a colorless and odorless solution), and yet produce varied embodied responses. Embodiment in relation to the described diachronic and synchronic taste experiences refers to the mouth-feel of tastes (how something is felt in your mouth). Some participants additionally describe whole body reactions (reactions described beyond the mouth) and others refer to imagined and disembodied responses (resulting from the taste stimulation and its associations).

Mouth-feel, referring to the experienced chemical and physical sensations in the mouth, is frequently used to describe different characteristics of foods, including coffee, wine, and textured foods. Such descriptions are offered by our participants for qualities of texture and viscosity. "*It's just like a softness, but I guess a little bit more viscosity even though I'm quite sure it doesn't have any viscosity. It's just sort of the feeling of viscosity, the sweetness and this cloud is just a bit more mouth feel*" [P14, sweet]. The mouth-feel also relates to a sense of movement, where tastes evolve in space. Most often these are lateral movements within the mouth, or commonly tastes are felt to move backwards. Such experiences can be a feature of the physical movement of the taste stimuli during the swallow reflex and also associated with the location of taste receptors on the tongue. However, in other cases, taste experiences defied the location of taste receptors and tastes could be experienced on the teeth, gums, and lips. One participant goes as far as to describe the absence of mouth-feel: "*I don't know really. It leaves this numbness in my mouth like the lemon, but without the initial burst"* [P9, sour]. In addition to the sensations described in mouth, some participants described bodily reactions that were opposed to the mouth-feel or isolated taste experiences. *"I think the first part of it, the sour part, is a bit of a shock to the system. I don't think you're expecting it to be like that"* [P16, sour]. Another participant said "*I kind of see it from the moment it enters my mouth and goes down all the way to my stomach. It's like I can see where it's going"* [P2, bitter]. In this sense, participants described tastes as producing expansive responses, including pleasure, nausea, and, others including reactions associated with allergy such as increased body heat (e.g., *"If you eat it, it's like your body – the heat just changes"* [P2, umami]). Feelings of pleasure were often described as filling, particularly filling the face or the whole body. A participant describes it as such: *"I feel that my whole face feels pleased with it"* [P14, umami]. Such feelings were not always positive and for some participants, overwhelming feelings of nausea accompanied tastes of salt, umami, and sweet. Nausea could also be experienced in undulating taste experiences – those taste which were experienced as prone to fluctuations in intensity, almost mimicking travel or sea sickness.

Participants also described disembodied reactions, which refer to something experienced that lingers between the mouth and the body. Rather than experiencing direct bodily reactions, participants describe an imagined reaction. *"It's like it's there but it's not there"* [P2, salty]. Disembodied reactions could also be seen in expected or caricatured responses, such as the imagined 'pucker face' of the sour taste. Although few participants actually exhibit such a reaction, it is an ingrained image of biting into a lemon. "*It feels a little bit, not uncomfortable, but it feels like it makes you kind of screw you face up a bit"* [P11, sour].

Shapes assigned to the overall taste experiences

The usage of the SEI objects (see Figure 4) as a physical engagement with shapes enriched the description of the taste experiences. The shapes particularly contributed descriptors related to the combined temporal, affective, and embodied experiences of each individual taste. Below, we summarize the key characteristics and the mapping of the eight objects for each taste across all participants.

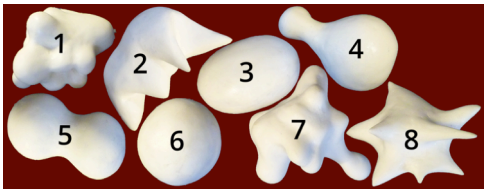

Figure 4. SEI – Sensual Evaluation Instrument consisting of 8 objects with different shapes by Isbister et al. [13].

The *sweet taste*, generally experienced as 'smooth' and 'rounded', was most reflected in shapes that present elements of change such as "phases" (shapes 4 and 5) or have protruding elements (like 7 and 1, or even the half-spiky shape 2). While typically a pleasant taste, there is a dynamic modulation of intensity and pleasure in the shapes. The *sour taste* produces a 'sharp' response and for many is best characterized by shapes such as 8 or 2. There are, however, also elements of temporality, a shifting/phasing associated with shape 4, starting with the big part as an explosion and then rapidly decaying. The *salty taste* has a broad aspect (mapped towards 3 and 6) and a finer

granulated and dynamic experience expressed through the shape 1. Similar to sweetness and sourness there is a repeating wave assigned to this taste experience, verbalized around shapes 4 and 5 though this time associated with an unpleasant feeling/sickliness as aftertaste. More than other tastes, salty was associated with a subtlety of the temporal characteristics, an experience of something moving, not doing much, but still being there. This made participants want a shape that they could manipulate (*"These* [objects] *are kind of too permanent; you're not able to manipulate them"* [P6]) or something more neutral, such as a flat shape, or a shape, which can be changed. Despite the fact that the *bitter taste* was experienced as unpleasant, the mapping to the shapes created two distinct experiences. For some participants, bitter is a spiky but lingering experience associated with a dull unpleasantness (1, 2, and 7 shapes selected). For others it is a rounded and smooth taste (these participants chose shapes 5 and 6), associating it with medicine (form of pills), which dissolves in the mouth, and you cannot get rid of it. Similarly to bitter, the mapping for *umami* resulted in two distinct experiences. If umami was experienced as unpleasant, participants tended to describe the taste as disgusting and chose the shape 8 or 2. In those cases where umami was perceived as pleasant, participants described it as a more rounded taste with depth and chose combinations of the rounded shapes (such as 3 and 1 shape were used most, and combined with either the 5, 4, or/and 7 shape). This mapping confirms the descriptions of umami as a full, mouth-filling experience with lots of things to it.

Overall, sweet and sour seem to be the two tastes where participants show high agreement with respect to mapping the shapes to taste experiences. Bitter and umami seem to share some associations and create two different mappings between shapes and taste experiences, while salty shows a tendency towards smooth and round shapes, but with the lack of the ability to change and manipulate the shapes.

Combined representation of the taste experiences

Figure 5 shows the final pictorial representation of all three characteristics combined for each of the five tastes. The length of the forms represents the temporal aspects, while the width captures the mouth-feel. Whole body and imagined embodiment could not be captured as such, but are described in detail above. The expression 'lingering' was used particularly for sweet, bitter, and umami. When used for sweet and umami 'lingering' is experienced in combination with a 'mouth filling' element (it is filling the whole mouth), while for bitter there is no filling experience but it is described as a thin (straight through your mouth to the back) experience, next to being unpleasant. In the bitter case, 'lingering' thus refers to the residual physicality of this taste (in the back of your mouth). Sour has an initial unpleasant taste, dies down quickly, but comes back after a short absence and leaves one with the feeling of wanting more. Salty at last is similar to bitter, however with a shorter life and perceived as less unpleasant. Salty is perceived as a neutral taste with little consequence.

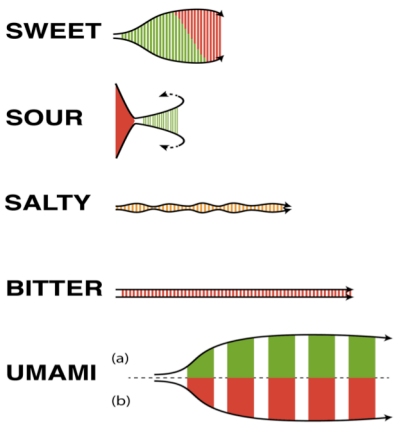

Figure 5. All taste characteristics combined: the temporality shown through its length; affective reactions through the color (green pleasant, red unpleasant, orange neutral experience); and the embodiment through its form (mouth feeling).

DISCUSSION AND FUTURE RESEARCH

While sensory researchers and neuroscientists study the perception of taste and its temporality, their focus is on quantifying the intensity and perceived changes of intensity via a wide range of evaluation scales [26] or, in some recent attempts, by means of time-intensity profiles of fMRI data [19]. Our findings add a semantic level of understanding underlying the taste experiences, their temporality enhanced through descriptions of the affective reactions and embodiment that the five basic tastes provoke. This understanding may be useful when designing for taste experiences as it provides designers and developers a vocabulary to talk about taste and the design potentials related to the different characteristics. First, we discuss the particularities of each taste quality, and then discuss them with respect to established psychological and behavioral phenomenon highlighting their design potential for HCI.

How is taste experienced?

Here we discuss the specific experiences each of the five basic taste qualities create and can inspire design in HCI.

Sweet: Pleasant but with a bittersweet ending

The sweet taste was consistently described as pleasant, which turned into something unpleasant. Participants struggled between the instinctive taste likeability and the learned taste values and rules (sweet is bad for the teeth), which can be seen in light of learned associations, discussed by Schifferstein and Hekkert [32] with respect to taste experiences of products. Of particular interest with respect to our findings on crossmodal interactions for sweet stimulations are the embodied reactions (e.g., "*It's just sort of the feeling of viscosity, the sweetness and this cloud is just a bit more mouth feel*" [P14]). Such reactions can be explained through learned associations with sweetened food and beverages. It is a combination of learned as well as innate, genetic, and cognitive factors [32]. Sweet sensations can be used to stimulate and enhance positive experiences, however, on a limited timescale, as the sweetness is quickly disappearing leaving one unsatisfied. It's a pleasant taste but one that is tinged with a bittersweet ending.

Sour: Unpleasant at first, but with the need for more

In contrast to the sweet taste, the sour taste is described as short-lived and it often comes as a surprise due to its explosive and punchy character. This taste overwhelms one with its rapid appearance and quick decay. It leaves one with the feeling that there is something missing. Based on childhood memories, such as for instance of sweet-sour drops, participants were expecting sweetness, but were left disappointed, leaving them with the feeling of wanting more. This phenomena was also observed in the evaluation of a gustatory gaming interface with children, where sour was used for negative reinforcement linked to the game dynamics [17]. Children intentionally failed in the game in order to get another sour stimulation.

Salty: Not doing much

The salty taste experience was not linked to an extreme reaction unlike sour, bitter, and umami. This taste is often described as 'bland', 'discrete', and 'just being there and not doing much'. It is minutely moving around, giving the feeling of cleansing the mouth, but not being mouth filling as sweet or umami, and certainty not as unpleasant as bitter, however lingering almost as long as the bitter taste. The modesty of saltiness in contrast to all of the other tastes opens up some interesting questions when looking at the neuroscience findings. Nakamura's [19] findings based on time-intensity fMRI profiles suggest that salty tastes change more rapidly than do sweet tastes. This is not quite consistent with how our participants described their experiences and needs further studies.

Bitter: Unpleasant, not to be experienced again

The perceived intensity of the bitter taste was not the same for everyone, as confirmed by the supertaster test. While supertasters felt the experience with more immediacy, others had to allow the taste to travel to the back of their mouth to recognize it. After this initial difference, the bitter experience becomes consistent with respect to its 'lingering' features, of 'staying' either on the tongue or at the back of the mouth. Bitter was also described as 'thin'. The character of bitter was further revealed through learned associations referring to 'biting into a flower', or 'medicine', things you had to take as a child, but after which you would rather avoid this experience of bitterness. Bitterness can indicate the presence of toxins [32] and is found in evolutionary development of humans (e.g., feeling of suspicion regarding bitter food as poisonous) [7]. It may be useful for design to make people avoid certain behaviors.

Umami: Like/dislike, but still confusing as a taste

The familiar-unfamiliar characteristics of umami caused much confusion in our study and participants could not rely on their intuition. While the 'like' or 'dislike' of the taste was decided instantly, the unpicking of the still 'confusing' elements of the umami taste was more challenging. Different word pairs depending on the like/dislike of the taste were expressed: 'pleasant–unpleasant', 'comforting–uncomforting', and 'liking–disgusting'. We could also see participants using additional bodily descriptors, in particular when describing umami as a pleasing experience ('face feels pleased' or 'body heat changes'). In cases of dislike, the focus of attention in the verbalizations was the lingering characteristic of the taste founded in the inability to get rid of it. In these cases, the residual physicality can be seen to afford agency. The taste experience becomes reified in the influence it exerts over the taster. Depending on personal familiarity/unfamiliarity (which may be defined by cultural factors) and personal preferences, this taste experience is quite interesting for design. Umami grabs one's attention and initiates a conscious process of reflection. While judgment on the taste is defined quickly, the reflective thinking brings to the fore the richness and variety of the taste. Even when perceived as unpleasant, the richness is recognized, and linked to the motivation to remove the taste from the mouth.

How can we design with taste experiences?

Taste experiences can be discussed with respect to their relevance for design, building on existing psychological and behavioral phenomenon: rational and intuitive thinking, anchoring effects, and behavior change. The dual process theory [14,37], for instance, accounts for two styles of processing: the intuition based System 1 with associative reasoning that is fast and automatic with strong emotional bonds, and reasoning based on System 2 which is slower and more volatile, being influenced by conscious judgments and attitudes. Based on our findings, we can see that sweet is intuitively perceived as pleasant, and bitter as unpleasant, while sour, salty, and umami cause a reflective process, confused, for instance, by the surprise appearance and rapid disappearance of the sour taste. Our findings also give insights into how to time the presentation of the taste qualities so that the user can transition from System 1 thinking to System 2 thinking. Figures 2, 3, and 5 can be used to create the appropriate transitions and time them. For example, the rapidity of the sour taste experience does not leave enough time for System 1 to engage with it and triggers System 2 to reflect on what just happened. Such reactions when carefully timed can prime users to be more reason based in their thinking during a productivity task (e.g., to awaken someone who may be stuck in a loop). Moreover, an appropriately presented taste can create a synchronic experience that can lead to stronger cognitive ease (to make intuitive decisions) or reduce the cognitive ease to encourage rational thinking. For example, a pleasant taste can be used to provide achievements across the workflow, however with the slight hint that there are still more tasks to do before you are finished (e.g., the slight unpleasant aftertaste of sweetness). Below, we outline potential design directions for using taste experiences in work-related activities and for personal behavior management. Doing so, we draw on the potential of different taste qualities and their power to stimulate intuitive and rational thinking described above.

Managing anchoring effects through taste

A common aspect of everyday activity is interruption. We are often interrupted by emails, telephone calls, or other unanticipated events. These interruptions can either be short

(e.g., a quick glance at an email pop-up) or slightly longer requiring us to change our activity (e.g., a line-manager walking into your office to ask for something). All these activities have anchoring effects. In other words, the initial activity affects our judgments and decision making in the latter activities. It has also been shown that users often find it hard to avoid these biases in their judgments [38].

Our study of taste experiences suggests that taste interfaces can be carefully designed to manage interruptions in such a way that anchoring effects can be either minimized or maintained. For example, we know that the salty taste has a long temporal component with a feeling of "not doing much but being there". This taste could be very useful in those situations where the interruption is small and the user is expected to return to the initial activity soon. As an example, when the user notices a pop-up in the bottom left corner of their desktop (for email or other social media interruptions) a small salty taste in their mouth which starts just before the user switches their activity can be useful. This will prolong their initial experience and remind them of the initial activity when still checking the social media page. This could enable smoother transitions back to the initial activity. Alternatively, however, if the interruption is a longer activity then it is useful for the user to drop any priming effect that might transfer to the new activity. In this case, a sour taste in the mouth would leave the user a quick sharp taste engaging their rational System 2 but rapidly decaying helping the user return to a more neutral state by the time they switch to the new activity. Such management of anchoring effects is not only useful for productivity activities but also in other activities, such as gaming. For example, LOLLio – the taste-based game device described above [16], currently uses sweet and sour for positive and negative stimulation during the game play. We suggest that such a game could be improved based on our framework by providing fine-grained insights regarding the specific characteristics of taste experiences, which can be integrated into the game play. When a person moves between related levels of a game a continuing taste like bitter or salty is useful. Whereas when a user is moving to distinct levels or is performing a side challenge an explosive taste like sour, sweet, or umami might be useful. The choice of specific tastes in each category can be tuned by the designer to create different affective reactions and a sense of agency.

Priming positive behavior through taste

Taste and taste preferences play an important role in our food choices [24] and food plays a significant role in our health and wellbeing. The stimulation and manipulation of taste experiences therefore offers potential to improve a variety of food behaviors. Using taste stimulation technology to alter the taste of unpleasant but healthy food is one obvious route. Expanding the design space for healthy taste technology, our framework suggests alternative routes. Taste experiences might be heightened through appeal to related experiences and sensations. Morphing physical objects, such as recently suggested shape-changing devices [29], might also be used to replicate the embodied expansiveness of the umami taste to stimulate an increased taste experience for patients receiving chemotherapy who may suffer from hypogeusia, a decrease in taste sensitivity. Taste stimulation might also facilitate sustainable food practices, for instance, linking food waste to taste experiences. Taste stimuli might thus supplement other post-actional cues in the effective disturbance of food waste habits and promote critical reflection. When disposing over-ripe bananas, a user might get a sour stimulation for the waste of food but the immediate reward for waste separation. Taste stimulation might also reflect various characteristics of food waste, such as its lengthy impact on environmental sustainability through the bitter taste. In this way, the framework for design points to the potential for taste experiences to be incorporated into timely and rewarding persuasive messages for positive food behaviour.

CONCLUSIONS

In this paper we presented the results of a user study exploring the experiential characteristics for each of the five basic taste qualities. Our analysis of participants' verbalizations, collected by means of verbal and non-verbal methods, resulted in three key themes. We provide rich descriptions on the temporality, affective reactions, and embodiment of taste experiences. We discuss these themes for each individual taste elucidating the design potentials with respect to the specific structure and qualities of sweet, sour, salty, bitter, and umami tastes. Our findings help to establish a framework for the design of taste experiences in HCI, enhancing existing technology driven research around taste, and food interaction design research. Although we do not provide guidance for the design of a specific interactive system in this paper, we are convinced that our framework provides a starting point for designers and developers to think about design/development potentials for taste in HCI.

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