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Multisensory Approaches to Human-Food Interaction

Edited by:

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Message from the Chairs

Welcome to the 2nd workshop on Multisensory Approaches to Human-Food Interaction (MHFI), Glasgow, Scotland, November 13th, 2017, held in conjunction with the 19th ACM International Conference on Multimodal Interaction (ICMI 2017). In this 2nd workshop on Multisensory Approaches to Human-Food Interaction, we called for investigations and applications of systems that create new, or enhance already existing, eating and drinking experiences ('hacking' food experiences) in the context of Human-Food Interaction.

After the 1st workshop on "Multi-sensorial Approaches to Human-food Interaction" last year in Tokyo, Japan, we decided to build on the success of this meeting by holding another in 2017. Here, we also called for works that were based on the principles that govern the systematic connections that exist between the senses. Moreover, we were also interested in sensing and actuation interfaces, new communication mediums, and persisting and retrieving technologies for human food interactions. Enhancing social interactions to augment the eating experience was another issue we wanted to see addressed in this workshop.

The final program included six position papers, one keynote talk, one industry talk, and three talks by the organizers. The program was made possible by our program committee, to which we would like to express our gratitude. Each position paper was evaluated by two reviewers.

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MHFI 2017 Chairs

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Contents

Are Food Cinemagraphs More Yummy Than Stills?

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ABSTRACT
Cinemagraphs are a new medium that is intermediate between photographs and videos: most of the frame is static, while some details are animated in a seamless loop. Given their vivid appearance we expected that food cinemagraphs evoke stronger affective and appetitive responses than their static counterparts (stills). In this study we measured the Liking (affective) and Wanting (appetitive) responses to both cinemagraphs and stills representing a wide range of different food products. Our results show that food cinemagraphs only slightly increase Wanting scores and do not affect Liking scores, compared to similar stills. Although we found no main effect of image dynamics on Liking, we did observe a significant effect for some individual food items. However, the effects of image dynamics on Liking and Wanting appeared to be product specific: for some products dynamic images were scored higher on Liking or Wanting, while static images were scored higher for other products. This suggests that image dynamics intensifies subjective Liking and Wanting judgements but does not alter their polarity. Further research is needed to resolve this issue.

CCS CONCEPTS
• **Human-centered computing → Empirical studies in visualization** • Information systems → Display advertising • Applied computing → Online shopping

KEYWORDS
Cinemagraphs; food; affect; appetite; liking; wanting

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1 INTRODUCTION
Viewing images of food triggers the desire for the real thing: just looking at pictures of food causes salivation [1] and an uptick in ghrelin, a hormone that causes hunger [2]. These effects increase when images represent food in a more vivid way. A new medium that is highly suited to produce vivid visualizations of food are cinemagraphs. Cinemagraphs are intermediate between photographs and videos: most of the frame is static, while some regions are animated in a seamless loop (for examples see www.cinemagraphs.com).

Because of their capability to provide vivid representations of food, in combination with the ease with which they now can be produced on smartphones, we expect that cinemagraphs will play an increasingly important role in the digital communication about food on social media. Also, we expect that they will increasingly be used to advertise food items on display boards in public spaces like bus shelters and stations, in supermarkets and in food courts and will appear in digital menus in restaurants [3].

Vividness [4] (also referred to as media richness [5]) refers to the sensory breadth (the number of sensory dimensions) and sensory depth (the information quality and resolution) of stimuli. Vivid stimuli allow observers to fill in more missing sensory information and thereby diminish the user perception of mediation. This enables users to activate a fuller, more concrete or vivid mental model regarding the actual product consumption experience, which in turn affects their product appraisal [6]. It has for instance been found that the vividness of in-shop advertisements positively affects purchase intention, product attitude and shopping enjoyment (for a review see [7]). Vivid (full color) images of pizza elicited higher levels of food craving, a stronger salivation response, and stronger eating intentions, than similar pallid (black and white) images [8].

Since food cinemagraphs appear to provide a 'deeper' or more vivid visual product representation than similar stills [9], we hypothesize that they evoke both (H1) higher liking responses and (H2) higher wanting responses compared to their static counterparts. In this study we therefore compared both affective responses (Liking - the positive hedonic evaluation) and conative responses (Wanting - the incentive salience or motivation to consume) responses to cinemagraphs of a wide range of different food products and their static counterparts.

The outline of this paper is as follows. First we describe the related work, followed by the experimental details, then we present the results of our experiments, and finally we discuss our present findings and draw some conclusions.

2 RELATED WORK

Previous studies suggest that their capability to draw attention and to create a vivid viewing experience makes cinemagraphs an interesting display medium for marketing. When showing electric appliances, cinemagraphs induce longer gazing times and stronger purchase intention compared to stills [10]. Cinemagraphs positively affect the perceived freshness, perceived taste, perceived value price, and intention to buy agricultural food products [9]. When displayed on screens of shopping malls, cinemagraphs result in increased purchase intention compared to stills [11]. When used to show food in e-magazines, cinemagraphs evoke more varied positive emotional responses compared to stills [12].

Previous studies using affective images and clips extracted from films and television programs, found that image motion mainly affected arousal [13]. Static frames extracted from dynamic videos also had an arousing effect (probably resulting from the fact that they contain cues that suggest frozen movement [14]), but the effect size was significantly smaller than for dynamic videos. Motion also appeared to slightly amplify valence ratings: compared to the static condition, positive scenes were liked more and negative scenes were liked less in the dynamic condition [13]. This effect was strongest for positive scenes, resulting in a small but overall increase in valence ratings for dynamic images. However, none of these studies investigated the effects of image dynamics on the affective appraisal of food. A recent study on augmented reality (AR) found that valence and arousal ratings for food stimuli presented in AR were similar to those for real food and higher than those for photographic stimuli [15].

Previous studies found that people's affective responses to food images are modulated by their global state of happiness [16] while their appetitive responses are affected by their BMI [17]). People with higher global happiness levels experience stronger positive emotional responses (feeling happy or glad) when looking at images of food (as if they were actually eating the food) than those with lower happiness levels [16]. However, global happiness does not affect the appetitive responses to food stimuli [16]. This implies that the level of subjective happiness affects Liking but not Wanting [18]. In addition, it has been found that BMI is positively related to desire to eat (Wanting) but not to appeal ratings (Liking: [17]). To control for these effects, we also measured the participants' global happiness levels and their BMI in the present study.

3 EXPERIMENT

3.1 Participants

Participants were 81 Dutch citizens (33 males and 48 females, mean age = 38 years, SD = 16 years, age range = 16-72 years) recruited by email among TNO employees, interns and their family and among students from the Utrecht University. The invitation excluded vegetarians (since the stimuli included non-vegetarian food items). Participants were asked not to start the experiment within two hours after consuming their last meal, and preferably at a time when they started to feel hungry again. The online experiment first presented an informed consent. By pressing a button labelled "*Continue*" the participants acknowledged that they had read and understood the informed consent and accepted the conditions. The experimental protocol was reviewed and approved by the TNO Ethics Committee and was in accordance with the Helsinki Declaration [19]. Participation was voluntary and did not involve any kind of compensation.

3.2 Stimuli

The stimuli used in this study were 24 cinemagraphs and 24 corresponding stills (single frames taken from the cinemagraphs), representing 24 different food and drink products. One cinemagraph (showing a Unox smoked sausage) was produced by Unilever (Unilever R&D Vlaardingen, The Netherlands). The remaining 23 food cinemagraphs were produced by Daria Khoroshavina (Moscow, Russia; see [20]) and obtained (with permission) from her website (kitchenghosts.carbonmade.com; see also www.behance.net/barelungs). The stimuli represented 19 different food items (chips with dripping ketchup, steaming corn on the cob, boiling crème brûlée, boiling noodle soup, Danish with dripping chocolate, melting ice cream cones, sizzling mushrooms, pancakes with dripping maple syrup, steaming seafood with vegetables, a sizzling pizza and a pizza being cut in slices, sizzling calamari, steaming shrimps, sizzling shrimps, a steaming sausage, a sorbet with cherries, a sorbet with coffee, steaming vegetables, sushi being sprinkled with sesame seeds) and five different drinks (beer, hot coffee, iced coffee, iced tea, prosecco).

The 48 stimuli were divided in two sets of 24 stimuli each. Each set contained 12 stills (the static condition) and 12 cinemagraphs (the dynamic condition). Stimuli represented as stills in one set were represented as cinemagraphs in the other set. Participants were randomly assigned to one of the two stimulus sets. Hence, each participant viewed all 24 food and drink items (12 in still and 12 in cinemagraph format), but participants assigned to different sets viewed complementary dynamic conditions. This was done to prevent a direct comparison of the static and dynamic versions of the same food or drink item (since people may be inclined to rate the second occurrence of a food item the same as the first occurrence to be consistent), while still enabling a global assessment of the effects of dynamics within participants.

We asked the participants to assess the images in the afternoon or evening, since several stimuli used in this study show food or drinks that are typically not consumed before noon. No time limit was imposed for the task.

3.3 Measures

3.3.1 Covariates: Demographics. Participants gave their age, gender, weight and height. Their BMI was calculated as weight (in kilograms) over height (in centimeters) squared. In addition, the participants reported the time that had elapsed since they had consumed their last meal.

Subjective happiness. Global (main) subjective happiness was measured using a Dutch version of the 4-item Subjective Happiness Scale (SHS) [21]. The SHS is easy to administer, has high internal consistency and an excellent reliability [21].

Hunger level. The participants' hunger level (degree of satiation) was measured through a single item ("How hungry are you right now?") that was rated on a labelled ("Not at all", "Neutral", "Very much") VAS (visual analogue) scale, providing a range of scores from 1–10.

3.3.2 Dependent Variables: Free association. For each stimulus the participants first reported their free associations in response to an open question ("Please enter what first comes to your mind when looking at this image?")

Affective response. The affective response was measured through two items ("This makes me happy", "This makes me glad") that were rated on labelled (Fully disagree, Disagree, Neutral, Agree, Fully agree) VAS scales, providing a range of scores from 1–5 (see [16]). A single composite affective (Liking) score was obtained by averaging the responses to the two individual items. These measures have previously been shown to reliably measure the affective response to food pictures [16].

Appetitive response. The appetitive response was measured through four items ("*I want this very much*", "*This looks delicious*", "*This gives me an appetite*", "*This makes my mouth water*"; see [16]) that were rated on labelled (*Fully disagree, Disagree, Neutral, Agree, Fully agree*) VAS scales, providing a range of scores from 1–5. A single composite appetitive (*Wanting*) score was obtained by averaging the responses to the four individual items. These measures have previously been shown to reliably measure the appetitive response to food pictures [16].

3.4 Procedure

Candidate participants were invited by email. After accepting their invitation, they received instructions and a link for the online questionnaire and were informed of their option to terminate the experiment at any time. The questionnaire started with the demographic questions, followed by the four SHS items and a question about their hunger level. Then the 24 stimuli were shown in random order. For each stimulus, participants responded to the two items measuring their affective response, to the four items measuring its perceived appetitiveness, and indicated how frequently they consumed the displayed product. All stimuli were presented on a black background. The response scales and questions were presented one at a time below each stimulus. Thus, each stimulus was continuously displayed while the participant responded to all questions.

3.5 Analysis

A two-way analysis of variance (ANOVA) was conducted to explore the impact of the between-subjects independent variable *image-dynamics* (dynamic, static) and *food item* (24) on the affective (Liking) and appetitive (Wanting) ratings. All statistical analyses were performed with IBM SPSS 24.0 for Windows (IBM, Armonk, New York, USA). For all analyses, a probability level of $p < .05$ was considered to be statistically significant.

4 RESULTS

Most participants had a normal or healthy weight (mean BMI= 23.8, SD=4.6). In addition, participants were typically very happy (mean SHS score = 5.6 on a scale from 1 to 7, SD=1.1). The SHS had a good internal consistency with a Cronbach alpha coefficient of .86. The Liking and Wanting constructs also had a good internal consistency over all 24 stimuli, with Cronbach alpha coefficients ranging between .86–.96 for Liking and between .91–.98 for Wanting. On a scale from 1-10 the mean hunger level was 5.62 (SD = 1.94). Thus, the participants were moderately hungry, but not satiated nor extremely hungry. There was no significant correlation between the covariates BMI, Happiness, or Hunger Level and the dependent variables Liking and Wanting. Hence, these covariates were not included in the further analysis.

A two-way analysis of variance (ANOVA) showed a significant main effect of *image dynamics* on the Liking and Wanting ratings for the 24 different products used in this study ($F_{1,68}$=4.66, p=.03), while there was no significant difference between both groups of participants ($F_{1,68}$ = .58, p = .45). Further analysis showed that Wanting was scored significantly higher ($F_{1,68}$=5.48, p=.02, power = .36, d= .27) for dynamic images (M=3.34, SD=.54) than for static images (M=3.19, SD=.59), while there was again no significant difference between both groups of participants ($F_{1,68}$=.06, p=.50). However, the effect size was rather small, while image dynamics had no significant main effect on Liking. Thus, the present results only weakly confirm our second hypotheses (H2) that dynamic images evoke stronger appetitive (wanting) responses than comparable stills. The data do not support our first hypothesis (H1) that dynamic images evoke stronger affective (liking) responses than their static counterparts.

A further explorative analysis showed that the effects of image dynamics on Liking and Wanting were product specific. Although image dynamics had no significant main effect on Liking, image dynamics significantly enhanced Liking for iced coffee ($F_{1,68}$= 4.60, p= .04, power = .53, d= .51), sizzling pizza ($F_{1,68}$= 6.05, p= .02, power = .70, d= .62) and waffles ($F_{1,68}$= 4.25, p= .02, power = .64, d= .58), while it significantly reduced Liking for pancakes ($F_{1,68}$= 5.21, p= .03, power = .81, d= .69). Also, while image dynamics enhanced Wanting for waffles ($F_{1,68}$= 5.25, p= .03, power = .69, d= .57), it reduced Wanting for pancakes ($F_{1,69}$= 8.69, p< .01, power = .82, d= .73).

5 DISCUSSION

In spite of their vivid appearance we found that food cinemagraphs in general only slightly increase appetitive (Wanting) responses, while they do not evoke stronger affective (Liking) responses, compared to similar stills. Thus, our present results only partly confirm our initial hypotheses (only H2 is weakly supported). Although there was no main effect of image dynamics on Liking, we did observe a significant effect for some individual food items. However, the effects of image dynamics on Liking and Wanting appeared to be product specific: for some products the dynamic images were scored higher on Liking or Wanting, while the static images were scored higher for other products. This suggests that image dynamics intensifies Liking and Wanting responses but does not alter their polarity.

5.1 Limitations and Future Work

Repeated exposure to images of food is known to decrease peoples' appetite [22]. In this experiment the participants subsequently rated 24 images on 6 items each. As a result their appetite may have decreased over the course of the experiment, which may have affected their judgements. In a future experiment we plan to present less images per participant and ask fewer questions per image.

Some of the stimuli included other items besides the product of interest, which may have influenced the observer ratings. In a future experiment we plan to use stimuli that only show the product of interest.

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Development of a Mobile Multi-device Nutrition Logger

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ABSTRACT

In this paper we present a mobile system for nutrition logging which integrates multiple devices and modalities to facilitate food and drink tracking. The user is free to decide in each situation to use the most appropriate device combination out of a smartphone, smartwatch and smartscale. We describe the design and implementation of our system which is based on a requirements analysis. Finally, first results of a preliminary in-situ study with the prototype are reported giving first hints about the benefits and challenges of this multi-device approach in daily life scenarios.

CCS CONCEPTS

• **Human-centered computing → Mobile devices**; **User interface programming**;

KEYWORDS

Nutrition Logging, Food Journal, Multi-Device, Smartwatch

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1 INTRODUCTION

In general nutrition is a complex topic where different types of questions occur that can often only be answered by logging the intake of foodstuff. This can be especially helpful for people suffering from diseases like diabetes, overweight and food allergies, but also for others that wish to detect nutrient deficiencies or a too high calorie intake prematurely.

Nevertheless, recording the exact type and amount of each food and drink is a time-consuming task and often makes people to stop it soon as they find the effort being too high [7]. In this paper we will present a multi-device system consisting of a smartphone, a smartwatch and a smartscale. We will show how to leverage the situation-specific capabilities of the individual devices in order to reduce the overall effort involved in the nutrition logging process.

The smartphone provides the most flexible user input possibilities and already significantly reduces the effort in comparison to traditional pen and paper methods [15]. A smartwatch can supplement a smartphone since it is always in reach and can be used in a less conspicuous manner. However, due to the small screen size, it is limited in its input capabilities. A smartwatch is in particular useful in situations when a user is in a hurry and when repeating foodstuff has to be logged that can directly be selected from favorites or recently used entries. An entry with missing data like the amount is better than no record at all since the user still can edit and complete the entry with the smartphone afterwards. Already incomplete entries can provide medical relevant information about the time and frequency of nutrition intake [15].

Usually it is necessary to input the amount of food and drink intake. Estimating it can be a hard task. We therefore include a Bluetooth scale prototype (smartscale) in the system. The scale is designed to be easy to use by transmitting the current weight to the smartphone and the smartwatch without requiring to pair them. The user can leave the scale switched on for several weeks without charging. Furthermore, we tried to make the scale compact so that it is possible to place it wherever the user prefers to use it. Like with the smartwatch the usage of this device is optional.

While the usage of multiple devices appears to be a promising option for food tracking, the design of multi-device user interfaces that enable smooth transitions from one device to the other is a non-trivial task. To our knowledge this paper contains the first multi-device application combining smartwatch and scale with a smartphone. In literature covering multi-device interaction Dong et al. [8] identified two dimensions of inter-device usability. Users should be able to transfer knowledge obtained from the usage of a previous device to the next one (*knowledge continuity*) and they should be able to continue a task started on one device on another one (*task continuity*). Both types of continuity may be supported by a consistent user interface design to enable the user to easily switch from one device to the other. Another aspect to consider in the design of multi-device user interfaces is the timing of the tasks to be carried out by the user. Sørensen et al. [21] distinguish between the simultaneous and sequential execution of tasks distributed over multiple devices. In the case of food logging, a user may place an item on a smartscale while adding information on the type of food via his or her smartphone (*simultaneous use*). Furthermore, the user may want to use the smartphone to complement information on food consumption recorded with the smartwatch while being on route before (*sequential usage*). In both cases, automatically recorded or manually input information on the foodstuff has to be synchronized across devices.

With our prototype we want to find answers to the questions:

- Do people make use of multiple devices and if so, how are they used?
- On which factors does the device usage depend?
- When are users doing the nutrition logging?

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In the next section, we will discuss related work on recognition techniques and user interfaces to support (semi-)automated nutrition logging. After that, we will identify requirements for a multi-device nutrition logging system. We then describe how the requirements have been met by the design and implementation of a system integrating a smartphone, a smartwatch and a smartscale. To evaluate our multi-device approach to food logging, we conducted preliminary in-situ studies whose results will be discussed and can be used for further in-depth studies and extensions.

2 RELATED WORK

2.1 Logging of Nutrition Intake

The simplest form of nutrition logging is the usage of pen and paper which requires the biggest recording effort, however. Especially the estimation of the amount of foodstuff is a big problem. For food there are several manual portion size estimation aids (PSEA) that enable a higher accuracy than photos, but they can still introduce high inaccuracies depending on the individual [21].

For an automatic detection of the nutrition intake cycle, several processes can be recognized. Augmented cutlery, such as a fork [13] or an augmented drink vessel [4], can be used as sensors. Pressure changes that occur during the manipulation of plates or vessels on a table can be detected using a pressure sensitive table cloth [25]. To recognize arm movement leading a piece of food or a drink to the mouth, accelerometers have been used [1] which can be included in a smartwatch [24]. Chewing can be sensed by detecting the vibrations using audio [2]. Microphones of a regular headset [11] or smartwatch [14] are applicable, too.

Automatic methods that are able to detect the intake of food and / or drink mostly can't be used to detect the type and / or amount of the foodstuff. For example with audio data it is possible to discern food according to its consistency [23] so that for instance soft or crispy food can be distinguished. Nevertheless, with audio data, it is not possible to detect whether a person ate fatty potato chips or fat reduced ones (with the same consistency). Most precise methods are the ones that can directly weigh the foodstuff like a modified vessel for a drink. Relatively good precision can also be achieved by camera-based volume estimations [12] in case the food type has also been detected correctly.

Our current prototype supported by a smartscale is work in progress and currently serves as a basis for further automation of the nutrition logging process. Nevertheless, currently the limitations identified above indicate that manual or partly automated systems for nutrition intake logging are still required if a higher accuracy and precision for food recordings is important. It might even be beneficial to involve the user in the manual completion of the tracked data to make him or her aware of possible misbehavior [6, 15].

2.2 Smartphone and Smartwatch Apps

Mobile devices offer various methods to simplify the logging process and are nearly always at reach. The preference of a smartphone app over a website or paper diary has been the result of a study conducted by Carter et al. [5] where just users of the smartphone app still recorded their daily nutrition intake after six months. To get an impression of features offered by popular smartphone apps, we refer to a survey of nutrient-related mobile apps by Franco et al. [10] and an overview of related health apps by Murnane et al. [20].

An app that tries to simplify nutrition intake logging by using a multi-modal approach including image recognition, but also text input as a fallback is presented by Lim et al. [17]. Their study participants were trying the automatic detection occasionally, but in the end they preferred manual input as it was more reliable although taking photos was more convenient. This observation indicates that as long as automatic systems don't work nearly as precisely as manual logging they have to be designed in a way that manual input for correction or entry is possible.

Since smartwatches are still not widely used, just few apps and relatively few related work can be found dealing with the task of nutrition logging. Arsand et al. [3] presented a smartphone and smartwatch app (for Pebble) for diabetes patients that act as a diary. The apps are optimized for this target group, but it was found that the smartwatch simplified the entering process which should also be the case for nutrition logging.

Lutze et al. [18] presented a special smartwatch app for elderly people that serves to prevent dehydration and to provide support in emergency situations. In their case the smartwatch was mainly used standalone, providing sensor data, giving reminders to drink and allowing the user to answer simple questions in case an emergency situation was assumed by the system before help is being called. Also in their work it becomes apparent that the smartwatch offers the advantage of allowing fast input since it is in easy reach whenever there is a need to interact with it.

According to the related work the usage of a smartphone is beneficial as they are widely spread and nearly always at reach. Smartwatches show additional advantages for example in situations where fast input is necessary as it is possible to directly interact with them as they are in direct reach.

2.3 Smartscale

In the following we define a smartscale as a scale that can directly communicate with a smartphone or smartwatch to enable easy weight transmission.

SITU[1] is a commercial smartscale intended to be used with an iOS exclusive app that can estimate the calories and nutrients by the weight of food after inputting its type. Our most recent scale prototype is more compact than the SITU scale and doesn't require to be paired with a smartphone. We also wanted to investigate the usage in combination with a smartphone and smartwatch without any restrictions by proprietary software.

Recently methods show how specific smartphones can be used directly as a scale to weigh smaller objects that are being placed on their screen by exploiting pressure sensitive touch features [2]. Although this would have been an interesting option, currently this feature is very device-specific, it is not as precise as a scale, it can just be used with small foodstuff / vessels that fit on the screen and the maximum weight is quite limited. This is why we chose to focus on smartscales. Smartscales are already used to weigh food and drink and usually provide a good precision especially compared

[1] http://situscale.com/ (accessed: July 27 2017)
[2] http://money.cnn.com/2015/09/03/technology/force-touch-weigh-objects-huawei/ (accessed: July 27 2017)

to automatic detection methods or often also estimations by users. For a nutrition logging system they offer a helpful addition and simplify the entry of the amount of foodstuff.

Lessel et al. [16] used a smartscale as a drink sensor for an app providing gamifications to motivate users to drink more. Soubam et al. [22] presented a system that incorporates a smartwatch to detect drinking activity and a smartscale to measure the fluid amount. The prototypes bear some similarities to ours since there are not many design options when a load cell is being used as sensor. The prototype by Lessel et al. has a top plate that is surrounded by a rim of the case which prevents directly positioning larger plates on the scale. Additionally, it is necessary to press a button located on the scale to send the weight to the smartphone app and may get hidden by a plate. The smartscale by Soubam et al. partly lacks a surrounding case and it is unclear whether the battery or a charger is integrated.

The main difference of our prototype is the communication method between the smartphone and smartscale by using BLE advertisement packets which makes pairing unnecessary and allows sharing one scale with multiple users. By using this transmission method and techniques to reduce power consumption, the battery of our prototype usually lasts for three weeks.

3 REQUIREMENTS

In this section we will present the most important requirements we gathered for our nutrition logging system from the following sources: related work, popular Android apps (PA) and semi-structured interviews (I). We followed these requirements during the development of our prototype, and we will also discuss to what extent they were met later on. Several requirements were derived from the work by Cordeiro et al. [7], which points out many problems that may occur during food journaling. They gathered a variety of issues by compiling the results of a survey of 141 current and lapsed food journaling persons and additionally collecting posts from the community forums of three mobile food journals. Furthermore, we considered the overviews of nutrient-related mobile apps by Franco et al. [10] and health apps by Murnane et al. [20].

3.1 Popular Apps

We selected four apps by their popularity and feature set from the Android app store to find further requirements: "MyFitnessPal" (1.469.230 ratings), "S Health" (233.598 ratings), "FatSecret" (171.922 ratings) and "Lifesum" (70.224 ratings). Since most of the apps don't just focus on an efficient way to record nutrition intake, but also on statistics, other health related information and tracking of activities, we mainly tested the recording of foodstuff entries. At this time we couldn't find a popular app that includes a smartwatch allowing the input of foodstuff entries, S-Health on the Gear S2 allows for fluid (in counted glasses and cups) only. Each of the apps was used by us for one day to log our nutrition intake. The feature set was examined in detail, containing bar code reading for adding new foodstuff, adjoining topics such as activity recognition and details on healthy nutrition (recommended amount of vitamins). Gamification and visualization approaches were collected, but just considered for future extensions of the prototype.

3.2 Semi-Structured Interviews

Finally, we conducted semi-structured interviews with 24 (13 females, 11 males) persons in the age between 16 and 55 (avg. 26.2). Most of them were students of a school or university. All of them were familiar with using a smartphone. The interviews contained about 25 questions concerning demographic data, smartphone usage, experience with health apps, willingness to use smartwatches, privacy concerns, knowledge on tools for nutrition tracking, their motivation to do nutrition logging and preferred schedule for logging. Some questions were reused for the evaluation of the prototype.

3.3 Reducing the Effort of Nutrition Logging

The reduction of the overall nutrition logging effort is the main goal of our system. Several requirements have been identified to guide our design towards this target.

- The recording process should be as easy as possible since high logging effort is a "major barrier" [7].
- The system should help determine the amount of a portion since this is usually a hard task [7].
- The system should include a food / drink database to simplify text input (PA).
- User defined foodstuff favorites should be integrated (PA).
- The user should be able to choose from a list of recent foodstuff entries (PA).
- In less public situations, speech recognition could be used as an alternative input method (I).

3.4 Privacy, Flexibility of Use and Others

Additionally, following requirements were found that concern the privacy, flexibility of use, reminders and possibility to reflect.

- Adding entries into the system should be possible in an inconspicuous way as some persons don't want to log foodstuff in front of friends or colleagues [7].
- The system should allow the addition of own notes (I).
- The user should be able to edit entries (I).
- People should get reminders since they tend to forget to journal as it has been reported by Kim et al. [15].
- Reflection about intaken foodstuff should be possible [7].

3.5 Multi-Device Interaction

Our approach is based on the assumption that the effort required to track food intake may be reduced by leveraging the capabilities of multiple devices. The following requirements have to be met in order to ensure a high amount of inter-device usability:

- In order to enable the user to easily switch from one device to the other, a high amount of GUI consistency has to be maintained across all devices while following standards of the individual platforms [8].
- Data synchronization has to be supported across all devices to enable the synergistic use of multiple devices [21].

The functionality of the system should be split across the different devices to be able to take advantage of their specific strengths [8]. In our case, the smartphone is the main device that includes all features. Due to its small display the smartwatch just shares functionality of the smartphone that is important in situations where fast or more private logging is wished. The smartscale can just weigh objects and allows a more comfortable and precise input of the amount of foodstuff while using the smartphone or smartwatch interface.

3.6 Smartscale Prototype

The prototype is part of the solution to the requirement to support the recording of the amount of a portion in an easy manner. We decided to include a scale into our nutrition logging system as it is able to measure the weight of food and drink with high precision and its general functionality is already known to users. Even though our prototype is not limited to fluid intake, some requirements identified by Lessel et al. [16] are applicable in our case as well:

- The scale should be easily transportable.
- The stability of the prototype should be high enough to be able to measure foodstuff including a containment.
- Weighing should have a reasonably high precision.
- The prototype should have a relatively low price.

Some additional requirements are not met by the prototype developed by Lessel et al., but are relevant for us:

- It should have very low battery consumption.
- The user should not be bothered with Bluetooth pairing.
- It should be possible to place plates on the scale.

4 DESIGN OF THE SMARTSCALE

4.1 Development Process

To measure the weight of objects, there are two commonly used sensor types: resistive pressure sensors and load cells. Our first prototype used resistive pressure sensors. This type of sensor is not only more expensive than a load cell, but also suffers from noise and sensor value drift over time. To filter these disturbances out of the signal to obtain a sufficiently precise weight is not a trivial task.

Our second and third prototype are based on load cells that are commonly used in kitchen scales. Quite recently, many tutorials and necessary libraries - especially for Arduinos - can be found on the Internet. Two similar prototypes - also based on load cells - have been developed by Lessel et al. [16] and Soubam et al. [22].

Since the scale should be able to communicate with a smartphone energy efficiently, Bluetooth LE is currently the best choice. The requirement for the scale was that the user is able to interact with it just by placing an object on it - usually no further interaction with the scale should be required. Furthermore, no pairing with a smartphone should be necessary. This is why we decided that the scale should use Bluetooth advertisement packets that are broadcasted every two seconds. Bluetooth advertisement packets are also used by Apple's iBeacon or Google's Eddystone protocol. For our prototype, we use custom packets since we send the currently measured weight as payload. Nevertheless, the scale still can be used as a beacon and an app can detect whether the user is near the scale by considering the RSSI value. The broadcasts additionally allow for sharing a scale with multiple persons.

For the second prototype, we modified a low-cost kitchen scale by removing all electronic components except of the load cell and by building an Arduino Mini Pro, a HX711 analog-digital converter (ADC) and a nRF24L01+ RF module (capable to send Bluetooth compatible packets) into the case. The HX711 ADC was connected to the built-in 5 kg load cell. Finally, we created a third prototype which is more mobile than the modified kitchen scale since it is smaller (10.0 x 10.0 x 3.2 cm compared to 16.2 x 12.7 x 3.3 cm) and integrates a rechargeable 18650 lithium battery with protection circuit and a capacity of 3.4 Ah. It can be charged with an integrated charger (TP4056) via USB (with adapter cable). The LEDs of the charger indicating the state can be seen from the side. These components are basically the same as used in the work by Lessel et al. [16] and Soubam et al. [22]. We didn't use a case printed by a 3D printer since those are often less stable which has been a problem reported by Lessel and colleagues. For our latest prototype, we use Nordic's NRF51822 Bluetooth 4.0 SoC. This SoC saves space since there is no need to use a microcontroller with an additional Bluetooth module making it more energy efficient. The biggest drawback of the NRF51822 is that there is usually no direct or just limited Arduino support. This is why we first had to port the HX711 library code for this controller to be able to use it directly with Nordic's SDK.

Unlike Soubam et al. we didn't include an accelerometer or gyroscope in our prototypes since we assume that users usually know that a scale should be placed on a stable and even base. Nevertheless, it could be used to detect whether the scale is being transported to save energy. The overall price of our prototypes is about 30 Euro (prototype 2 without battery) / 40 Euro (prototype 3) which is comparable to the one by Lessel et al. (ca. 26 Euro [16]) and the one by Soubam et al. (ca. 22 Euro [22]) since some components are different. The battery lifetime of the prototypes can just roughly be compared since they use different components, but also transmission and power saving strategies. The prototype by Lessel et al. runs for about 31 hours [16], the one by Soubam et al. for around 8 hours [22], but up to 20 hours with different settings. Our prototypes usually run for about 3 weeks permanently, but there is still room for improvement by adjusting software and hardware.

4.2 Usage of the Scale

The scale can be used to weigh the portion of food, but also the volume of many fluids as they mostly contain water which has a density of 1.000 kg/m^3. Usually vessels are used to place foodstuff on the scale. Thus, we need to subtract the weight of the vessel to get the amount of the portion. In combination with our app the user can choose out of the most convenient sequence in each situation. The user can decide whether to first weigh the empty and then the full vessel or the other way round. It is also possible to save the weight of empty vessels so that it can directly be selected in the app. Another option we provide is to save a portion of food or drink amount including the type as favorite if the portions are usually about the same. Of course this depends on the type of foodstuff. Although this method is less accurate, this feature helps to reduce the necessity to use the scale every time.

5 IMPLEMENTATION

5.1 Overview

For the integrated prototype, we used the two Bluetooth scale prototypes, a smartphone (Huawei Nexus 6P) with Android 7.1 and a round smartwatch with "chin" (Motorola Moto 360 gen 1) running Android Wear 1.5. In Figure 1, all devices used for the high fidelity prototype including the two Bluetooth scales are shown. The communication between the devices is visible in Figure 2.

Figure 1: Devices used for the high fidelity system prototype

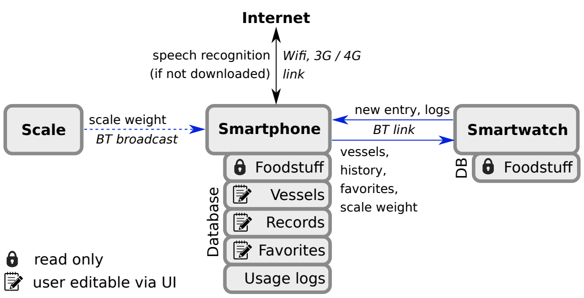

Figure 2: Communication between the devices

Due to their size, smartphones have a much higher battery capacity than smartwatches (for our devices: 3.450 mAh vs. 320 mAh). Thus, battery consuming tasks like wireless communication should be offloaded to the smartphone. For this reason the connection to the Internet via Wifi is established by the smartphone and it is also listening for the Bluetooth advertisement packets of the scale. Internet is currently just required for Android's speech recognition if the language has not been downloaded. The method for Android's offline speech recognition achieves a word error rate of 13.5 % [19].

To enable continuous interaction between the devices, data synchronization is essential and one of the requirements identified above. The synchronization between the smartscale, smartphone and smartwatch is done by using Bluetooth (BT). The favorites, history (at most 10 entries) and vessel lists are sent to the smartwatch after an update request from the smartwatch has been received. Weight values from the scale received by the smartphone are directly sent to the smartwatch. New entries created by the smartwatch, but also usage logs are transmitted to the smartphone where they are getting stored.

Following the requirements listed above, the smartphone and watch have a local foodstuff database used to simplify the selection of the food and drink type. The database has been populated with German foodstuff names that were gathered from websites on the Internet as there is no free national database. The smartwatch database is reduced to more essential entries (from around 30.000 to about 7.000 entries) since it is quite difficult to search for specific ones on a smartwatch without any text input and speech recognition not always being an option. All data that has to be stored is added to an additional database on the smartphone. All vessels, foodstuff entries (including pictures), favorites and app usage logs are stored here. The table with vessels is populated on first start up with entries which can directly be used, but also edited by the user later on. Also, new vessels can be added.

5.2 User Interface

In Figure 3 the most relevant screens related to the recording process of the smartphone and smartwatch app are shown. We will focus in the following on food, but for drinks the process is similar.

The task on both devices can start directly from the main screens of the specific device. This means on the smartphone the home screen where a widget has been placed on the watch, a custom watch face is used which is visible in Figure 1. On both devices, the user can select whether to record food, drink or output the currently measured weight from the scale. Our smartphone prototype additionally allows for viewing and editing already recorded entries by touching a specific entry in the history (see Figure 3). It also enables the supplementation of incomplete entries from the smartwatch later on which are highlighted in orange. In general just type and weight are mandatory to be entered by the user.

On both platforms the user can use the left or right swipe gesture to switch between the tabs. On the smartphone we also provide buttons. Aborting the task is possible by using the Android back button or by pressing "cancel". Due to the lack of space these buttons are not included on the smartwatch GUI. Still, the hardware button of the watch can be pressed and the user can also use the swipe right gesture until the watch face is visible again.

After entering the food record mode, a screen is shown where the user can select items from user-defined favorites or a history of the last 10 different food entries (screen *Record 1*). This also applies for the smartwatch although favorites are marked with a star and recently used entries (history) with a clock icon. Since there is few space on the smartwatch display, the food entry mode is indicated by the background image. An entry can be selected by touching it. This automatically sets the food type, amount and vessel type / weight. On both devices the last screen *Record 4* / *Record 5* will be shown after the selection of the favorite / history entry.

If the user decides not to use a preset, he or she can proceed to "Record 2" where the type of food is selected. On the smartphone this is possible by using text input with auto completion (a list with possibly matching entries is shown) and speech recognition using the Google API. Also, a photo of the food can be made by the user or an existing one can be selected from the internal storage. The smartwatch is quite limited in its input capabilities. The entries can just be shown in a list. To make it easier to find a specific entry, presumably rarely used entries were removed from the smartwatch's foodstuff database. The first letter of an entry can be set with an additional list on the left so that the user doesn't have to scroll through the whole list. If the user can't find a specific entry or is in a hurry "later on smartphone" can be chosen and is preset. On the smartphone, the user can edit the type later on, which is possible in a more comfortable way. After that, the user can proceed to *Record 3* where the amount can be entered.

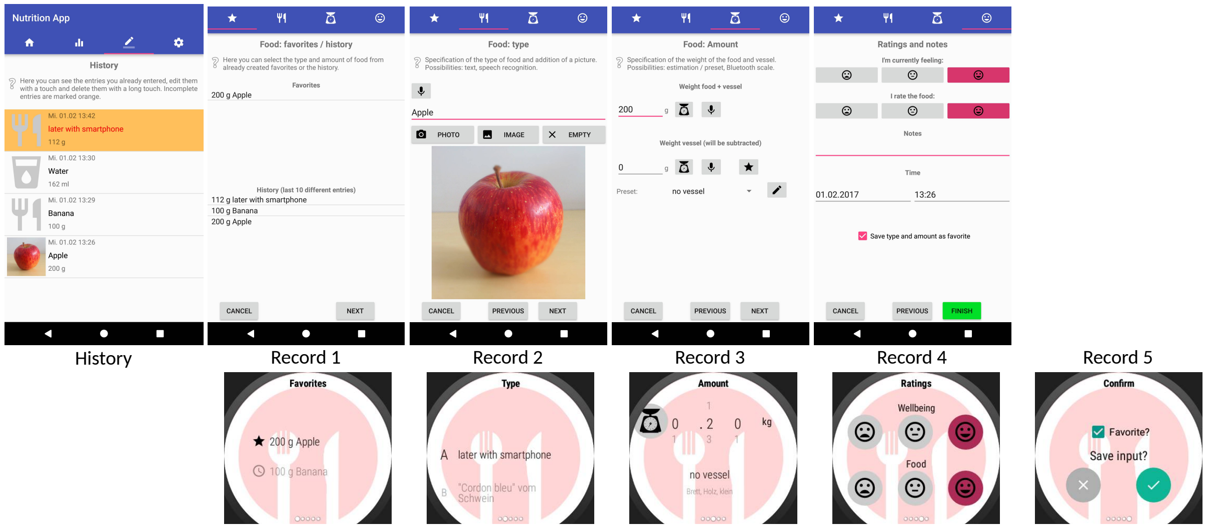

Figure 3: Selected screens of smartphone (top) and smartwatch (bottom)

On both devices the weight of the food including the vessel can be set. The weight can optionally be received from the smartscale. In this case, the user just has to place the food on the scale and press the according button on the smartphone / watch. On the smartphone speech recognition and the on-screen keyboard can additionally be used. The value on the smartwatch can be changed by scrolling through three lists with single digits. The weight of the vessel being subtracted from the total weight can be selected by using a preset list including user defined entries. On the smartphone additionally the weight of the vessel can directly be specified by text input, speech recognition or by using the scale with an empty vessel. The user can additionally directly create a new vessel entry using the current vessel weight (button with "star" icon). A vessel editor is available. On the smartwatch just the selection of an already existing vessel using the list is possible. If the user wants to estimate the weight of the food excluding the vessel or no vessel is used (e.g. a fruit) the default preset can be left unchanged.

On the next screen the overall well-being and the food itself can be rated by the user using a three point scale with smileys. Additionally, on the smartphone custom notes can be entered and the time / date can be changed, which can be useful if the recording is done later on. On the smartwatch just the current system time is used to speed up the process. On the smartwatch the check box allowing to save the entry as favorite is displaced to the confirmation screen (*Record 5)* to prevent the necessity to scroll vertically.

After pressing the buttons "Finish" or the button with a check symbol the process is finished and the entry is getting stored. If there are missing required fields (type and amount) on the smartphone or the vessel weight is higher than the sum of foodstuff and vessel weight an according information is shown with a message.

6 EVALUATION

6.1 Setup of the Preliminary In-Situ Study

To evaluate the high fidelity prototype, we gave the prototype for one day to persons that were interested in logging their nutrition intake. We selected people that were already using an Android smartphone with Android 6 or higher since this usually means that they are already familiar in using Android and also the device is recent enough. Several new problems can occur if different devices are used, but it was important that the test persons can use their own devices since it would introduce a different user experience and usage behavior if they had needed to carry an additional smartphone around with them.

We first informed the participants about the procedure and what data would be recorded for the study. Then we presented the prototype. All devices and functions were explained to them. After that we paired the smartwatch with the participant's smartphone. Hereafter the apps for the smartphone and smartwatch were installed. The custom widget and watch face were setup after that. Finally, a short test of the prototype together with the participant was conducted to make the user familiar with the functionality of the prototype. For all participants the smartwatch was a new device which they didn't wear and use before.

The test persons were asked to use the system with their smartphone, the smartwatch and the smartscale for a day to register their food and drink. They could decide on their own where and how to use devices of the prototype. After this day the database with logs and the recorded foodstuff entries were offloaded from the participants' smartphones while they were present.

Additionally, the persons were questioned in a semi-structured interview, containing questions that were included during the gathering of requirements (see section 3). The interviews took about 15 minutes per person and covered 25 questions concerning demographic data, smartphone use, experience with health apps, willingness to use smartwatches, privacy concerns, knowledge on tools for nutrition tracking, motivation, preferred schedule for logging.

6.2 Semi-Structured Interviews

In total, we tested the prototype with five participants (females: 1, males: 4) in the age between 24 and 31 (avg. 26.2). Most of them were students or working at the university. At first, we obtained demographic data from them as well as information on wearable device usage and nutrition logging.

One of the participants (P5) already logged her fluid intake with a smartphone app ("Plant Nanny") to drink more. All participants rarely used to take pictures of their food, for example, to show them to friends or family members or when they found them exceptionally "aesthetic". Just one person (P1) found that he was able to estimate quite accurately the amount of food and drink. The others thought that they were able to estimate food intake only roughly or food and drink equally inaccurately.

After the general part of the interview, participants were invited to give comments on the nutrition logger and the integrated devices.

Concerning weight estimation, the scale was considered as "an absolute must" to record the amount of food with a sufficient degree of accuracy. P2 thought "the scale was brilliant" since it greatly simplified the weight input. He was also surprised how badly he estimated the weight of food. For example, he did not expect an orange (235 g) to weigh more than a sandwich he had made (135 g).

The participants shared the same opinion regarding the usage of smarwatch, smartscale and speech recognition, when it came to upholding privacy.

P5 was concerned about using the scale in public: "It is also strange to weigh in public. If I go to Mc Donald's I wouldn't unpack my scale to place my burger on it." The smartwatch was also appreciated by users who did not want to reveal to others that they had to log their nutrition. P3 said: "It could be embarrassing if other people find out that you have to track your nutrition." The speech recognition feature for text input was especially appreciated by P2 for usage at home, but he wouldn't use it, for example, at work: "At work, when I'm standing near a colleague, I would feel awkward." The speech recognizer worked correctly for the words he inputted to log nutrition. Other participants also thought that the speech recognition could provide a useful addition in private situations. Nevertheless, most of them used it only rarely during the tests.

The context also influenced the preference for one or the other device: P4 said that the smartwatch could be useful when being in a hurry: "If there is no time to input data in detail, entries can be completed later on with the smartphone." Only P1 found the scale little useful since he was mostly on route during the time he tested the prototype. The other participants employed the smartscale at home. They could also imagine using it at work, but not on the go.

Viewed from the point of usability, the multi device setup showed advantages. Participants thought that the smartwatch (in combination with the scale) was in particular useful when repeated food items had to be recorded since in this case the favorites / history could be used. Furthermore, they found the smartwatch convenient in situations where hands were busy or when the smartphone was out of reach. While users relied on the smartwatch when repeated entries had to be made, they preferred the smartphone for inputting new food categories or for providing more details on data that was previously recorded with the smartphone. Overall, the users found the smartphone useful since it included all the necessary functions for food logging.

The participants did not report any problems when having to switch from one device to the other. P2 said that he had noticed that the GUI of the smartwatch had a similar structure as the GUI of the smartphone and that the mapping of GUI elements was clear to him.

According to our logs P1 didn't use the scale with the smartwatch. P2 and P4 employed the scale with the smartwatch and smartphone several times. P3 mentioned that he wanted to make use of the scale in combination with the smartwatch, but at first didn't notice that there was a button to get the values of the scale on the smartwatch. The other participants didn't mention such a problem.

Reminders for nutrition intake logging were requested by P1 and P5. P5 would appreciate if the system reminded her to drink regularly every two / three hours. The other participants didn't mention any problems remembering to log food or drink intake, but rather were concerned that frequent reminders might be disturbing. They mentioned that they would just appreciate reminders on working days (P2) or if they were context-sensitive (P3).

The multi-device nutrition logger helped people reflect on food intake. P2 who was reporting issues with kidney stones said that rating the foodstuff made him "think about whether it tasted good or not". He also enjoyed taking photos of foodstuff and looking at them later. P2 also expressed strong interest in using the nutrition logger on a long-term basis since he felt the system helped him ensure that he intakes a sufficient amount of fluid.

7 SUGGESTED EXTENSIONS

One problem the participants identified was the organization of the large number of foodstuff database entries. As a consequence, the selection of foodstuff was very time-consuming and hardly possible on the smartwatch. P5 mentioned that the foodstuff database was partly inconsistent and confusing since, for example, some entries included a brand name that did not always appear at the beginning. She also mentioned that the auto-completion showed many other foodstuff entries even if she just wanted to insert chocolate as the word is included in several other food entries. In line with her comments, P2 suggested organizing the many entries in a better manner. P1 and P4 asked for a possibility to add a meal including multiple ingredients so that the input could be additionally simplified.

Natural language interaction had been requested by P1 as he mentioned that he would like to tell the ingredients of a meal directly to the system while cooking it and having busy hands. This feature does not seem to be included in commercial apps [10] and would be an interesting addition that would have to be researched independently and is also very situation-specific.

8 DISCUSSION

Our study showed that the participants can imagine using multiple devices for nutrition tracking and have no problem switching between smartphone and smartwatch. Smartwatches would be accepted as additional device in everyday situations, while the smartscale usage would be mostly limited to private situations e.g. at home. Speech recognition faces the same issue in raising awareness and would be rather used in private spaces.

Non the less smartscales are attested to convey potential to enhance the accuracy of nutrition logging as people can hardly estimate weights without training or the usage of tools like portion size estimation aids. The smartwatch on the other hand raises less attention to the act of logging and therefore would encourage the logging in public.

On the topic of reminders for nutrition intake, we think they might also be given in combination with reminders to log nutrition data. Furthermore, we believe that the custom watch face served as a kind of ambient reminder and had a similar function as the stickers used by Kim et al. [15] even though the participants were not aware of it. The interviews indicate, that photos were especially taken of self-made well-prepared dishes. As own cooking is harder to track than ready-to-use food with according labels and takes place mostly at home, a smartscale seems a to be a natural fit here.

9 CONCLUSION

In this paper we presented a nutrition logging system that leverages the specific capabilities of multiple devices and modalities for recording nutrition. Our system combines a smartphone, a smartwatch and a smartscale and offers touch- and speech-based input in addition to tangible input by placing objects on the smartscale. This way, our nutrition logging system offers greater flexibility to users than currently available smartscale systems that typically rely on a smartphone only as an additional interaction device. A preliminary in-situ study revealed that users indeed made use of all three devices and exploited the advantages of all of them in a situation-specific manner.

As future work, longer in-situ studies should be conducted so that more situations can occur to enable us to test the usability of specific components of the system in more detail by study participants. There are still several possibilities that could improve the presented system. It is also possible to add a context-aware intelligent reminder which could be implemented using the mobileSSI framework [9] with different modalities. Like Franco et al. [10] already mentioned natural speech processing (NLP) and image recognition could also be a useful addition. A study comparing the different input modalities like it has been done with picture and text input by Lim et al. [17] could also give further insights.

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Let's Drink This Song Together: Interactive Taste-Sound Systems

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ABSTRACT

We present three digital systems: the Augmented Glass, the Bone-Conduction Hookah, and the sound installation T2M, designed for displaying sound and taste stimuli, with applications in research on crossmodal taste-sound interactions, multisensory experiences and performances, entertainment and health.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI) → Interaction devices → Sound-based input / output**

KEYWORDS

Crossmodal; music; taste; technology; multisensory; gastronomy.

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1 INTRODUCTION

A number of recent studies have analyzed the influence of music and sound on food or drink evaluation ([1], [2]). Crossmodal taste-sound congruence has been shown to have a perceptual impact on taste intensity and other qualities such as bitterness or sweetness ([3], [4]). As multisensorial integration is more likely to occur in conditions of spatial and temporal proximity between the stimuli in different modalities ([5], [6]), and music and taste are time-varying in nature, it seems interesting to develop technologies that favor these situations of synchronization and co-location, while allowing to keep track of multisensory interactive effects along time [7]. Some existing virtual reality technologies go in this direction, such as the straw-like interface of [8] or the Mouth Jockey [9].

The devices we present in Sections 2.1 and 2.2 (the Augmented Glass and the Bone-Conduction Hookah) are designed to deliver sound and/or subsonic vibrations exactly while the user is eating or drinking. The Hookah, moreover, locates vibrations on the lips, tongue and teeth, near where taste sensations appear subjectively to come (perhaps, vibration slightly modifies taste localization, see [10]).

Among several possible mechanisms underlying taste-sound correspondences, a relevant one is semantic matching [11]. This consists in the tendency to associate taste and sound stimuli that are described by the same or similar verbal labels (such as the word "sweet" used metaphorically to refer to the expressive character of a melody). Inspired by this fact, the multimedia system T2M seeks to exploit free verbal associations arising from taste experiences, using music-language semantic mappings to generate a sonic atmosphere for a food or drink tasting (see Section 2.3).

Along with the description of our digital systems, we describe in Section 2 a pilot study on the influence of music on the taste of coffee using a simple version of the Hookah; also, we mention possible uses of our systems for promoting healthy drinking or eating, and present some feedback from the users.

Some new technologies for human-food interaction change our food experiences by enhancing, or exploiting in some way, crossmodal taste-sound correspondences [7,12]. Other applications of these technologies are connected to art, in the context of multisensory performances and installations involving food [13], [14]. In a similar vein, the devices and the multimedia system T2M presented here are mainly meant to be employed in experimental dining or degustations. We will briefly describe two of our projects in this field, the performance Beyond Intimacy and the installation Let´s Drink This Song Together.

2 THREE SYSTEMS FOR SOUND-TASTE INTERACTION

2.1: Augmented Glass

This device consists in a wine glass with sensors that are able to detect two main gestures of the user: when the cup is taken by the hand and when the liquid contacts the mouth while drinking. The sensing is performed through electrodes attached to the surface of the cup, next to the edge, and connected to capacitive sensors. These sensors generate an electric field and work by detecting other present fields interacting with it, for example that generated by the body. We extend the detection area to reach the hand holding the cup, using a special non-toxic metallic paint that is employed routinely in glassware. To avoid wiring, the sensor data are sent wirelessly to a computer. In this way the intervention of the object is minimal and its use is similar to that of a normal glass. When the hand and cup are both detected, a sound or vibration is activated (Fig. 1).

Figure 1: Augmented glass.

We implemented a pilot exploration of the Augmented Glass by making it activate motors and transducers placed in an upright piano (a video can be seen at https://www.youtube.com/watch?v=HWEBJT2vxCI), and asking users to drink red and white wine with different sounds (low and high pitched). From this initial experience we collected some opinions of the users, who in all cases enjoyed the interaction with the glasses: "this sound makes the wine feel like a Rutini [an expensive Argentine red wine], with strong body and expanding taste", "the low pitched sounds seem to give weight to the wine", "the pizzicatos [probably referring to the motors bouncing over the strings] bring forward sour fruit notes". Also high pitched sounds were judged to be more congruent to white wine, and low pitched sounds to red wine.

The initial motivation for designing the glass was a recent study [15] on the effect of music on wine taste, that employed time-based methodologies such as time-intensity curves and temporal dominance of sensations. Participants had to evaluate wine in short periods of time (30-45 sec.) while listening to soundtracks of classical and contemporary music. Significant effects of events such as climaxes and relaxations in the music on taste qualities were observed, so that the musical form organized, to some extent, the evolution of the taste curves. An illustrative video can be seen at https://www.youtube.com/watch?v=DIxBXXKZEFY.

The Augmented Glass could be useful, for this kind of studies, in achieving more precise synchronization between the music and the act of drinking, allowing to differentiate automatically the different stages of tasting and aftertaste, either by instructing participants to remove the glass from the lips each time they swallow, or detecting the swallowing by accelerometers placed on the neck. Other stimuli may be synchronized as well with each sip, such as lights, videos or smells.

Applications to healthy drinking behavior are also easy to implement: we imagine varying the music emotion or pleasantness with the number of sips, or giving an alert sound or vibration when some limit on this number has been exceeded.

2.2: Bone-conduction Hookah

This contraption, whose basic mechanism is similar to the straw-like user interface (SUI) [7] , is meant to deliver vibrations on the lips, tongue and teeth while drinking or eating, and also transmit sound by teeth-bone conduction.

The Bone Conduction (BC) device in which the Hookah is based has three parts: a sound player, an amplifier and an actuator. The sound player can be a computer, a portable music player or a smartphone. We use a mono audio channel, and connect the device, via the mini plug output, to a class D amplifier giving a signal of 15 watts. This signal feeds the actuator, a continuous current motor attached to a straw, fork, spoon, etc.

2.2.1: Pilot study: coffee and sound . We are currently using the BC system in a study exploring the incidence of sound perceived through teeth conduction on coffee taste perception (see Fig. 3). We use two soundtracks previously found to be congruent with sweetness [16] and creaminess [17].

Participants taste five small cups of instantaneous coffee (without knowing it is the same coffee each time) in the following conditions: 1) perceiving the creamy soundtrack through the BC; 2) perceiving the sweet soundtrack through the BC; 3) listening to the creamy soundtrack with headphones; 4) listening to the sweet soundtrack with headphones; 5) in silence. They have to rate each time the creaminess, sweetness, bitterness and pleasantness of the coffee in 7-point scales, with ‘1’ being ‘not at all’, ‘4’ ‘neutral’ and ‘7’ ‘very much’. So far, 15 participants (6 females), aged from 21 to 37 years have completed the experiment. Analysis of results using RM-ANOVA, with conditions as factor, shows no statistically significant differences between the conditions. However, in all cases and for all dimensions substantial individual differences between the maximum and minimum value attributed to a given dimension was observed between the different conditions. For instance, for creaminess rating, the mean of these differences across participants is 3.33 (about half of the available punctuation range), with standard deviation 1.44. This is also confirmed by the reactions of the participants: ‘lots of change in sweetness and creaminess’, ‘arpeggiated sounds enhance the creaminess’, ‘I am sure that it is the same coffee but I perceive it differently each time’. So, although there is no reliable crossmodal effect in this pilot study, at the subjective level there is an impact of the sound on the taste, which we think is a relevant observation for aesthetic purposes. Since participants reported no differences between BC and headphones in the sound source localization or quality, we will add subsonic vibrations to the sound transmitted by BC in future experiments to look at their crossmodal and emotional effects on taste perception.

Also for this system, applications to healthy eating or drinking as mentioned in Section 2.1 could be easily implemented. The device could be employed for amusement, matching funny sounds to food and drink, or adapted to a toothbrush for fostering dental hygiene of children.

2.3: T2M

T2M is a generative text-based music system for interactive performances. T2M takes words from tweets produced by the audience or Twitter™ trending topics and composes music using Freesound™ sound-files (labeled with those words) as raw material. A demo using trending topics including the word “food” may be seen at https://www.youtube.com/watch?v=cRTWl5u-m8c

T2M explores the intra-sonic and extra-sonic semantics of sounds that are given by the tags of audio files in the Freesound database, with the purpose of generating soundscapes from textual input.

The motivation for this installation was research on music-taste crossmodal correspondences ([18]), which studied musical representations of the extra-musical semantic domain of taste words. Previous systems mapping text to music are for example [19] and [20]. Semantics of music in connection with language is a vast topic, see for instance [21]. Language is considered an important factor in crossmodal associations [22].

The base implementation for this installation (https://github.com/smrg-lm/ttm) is made with SuperCollider [23] as an external library (quark in SC jargon). It consist in a set of classes that organizes information retrieval, both from Freesound (http://www.freesound.org) and Twitter (https://twitter.com) using external command-line utilities on Linux, processing and storage of that information, sequencing, sound synthesis and visual feedback of original messages and retrieved sounds.

An autonomous T2M execution loop is schematically as follows: tweets query, text parsing and storage, sound query based on selected words, sound-files pull and storage, sound processing and reproduction and visual presentation of information.

Freesound querying and sound-file download depends on the Freesound.sc quark (https://github.com/g-roma/Freesound.sc) which is a higher level interface to communicate with the Freesound API from within sclang (SC programming language). Twitter CLI program (https://github.com/sferik/t) is used for querying tweets using Twitter’s API. A basic text parsing consisting in noun and verb selections is performed by a command-line utility provided by Apertium (http://wiki.apertium.org/wiki/Main_Page). See the flowchart in Fig. 2.

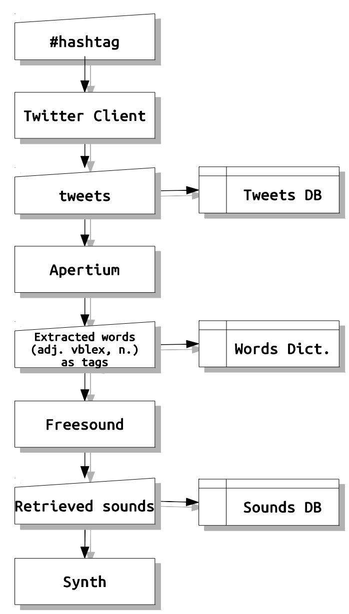

Figure 2: Flowchart of T2M.

We have presented T2M at the Museum of Contemporary Art in Mar del Plata, Argentina. Four specially designed food perfumes were successively spread in the auditorium, and the audience was required to tweet any associations or memories evoked by the aromas. The tweets were displayed on a screen while T2M generated a sonic atmosphere.

We envisage several aspects of the use of T2M in a gastronomic context. By asking people to exteriorize, via Twitter, free verbal associations produced by tasting a dish or a drink, we may encourage focusing attention on the sensorial evaluation of food. Moreover, by extracting terms related specifically to taste and flavor from the tweets, we can transform the musical flow in order to have music congruent (or contrasting) with the perceived taste, potentially modulating it ([3], [4]). This could be done for each guest, using individual loudspeakers. Another possibility is analyzing the affective content of the tweets using sentiment analysis and, by automatic evaluation of music emotion in the Freesound sound files, producing music sensitive to the emotional states of the diners. Again, using individual loudspeakers would permit to distinguish between different emotions expressed in the room, localizing the music near each commensal in a spatialized polyphony. Of course, some ordering of the sound events in time would be needed to avoid sonic chaos.

Figure 3: Pilot study with the bone conduction device.

4 FUTURE PERFORMANCES

We plan to use the Augmented Glasses for a multisensory performance (Beyond Intimacy). Our general concept will be exteriorizing the intimate sense of taste that inhabits the personal sphere of the inner body cavities, to generate a shared enveloping atmosphere of sound, dance, and smell. Beyond Intimacy will proceed in layers, beginning with the audience (limited to few people each time) drinking in silence, then activating piano sounds and smells, and finishing with live dance performance in the created multisensory landscape.

The Hookah design aims at a shared, convivial multisensory experience in an installation (Let´s Drink This Song Together). We decided to work based on a known object, the hookah, and transplant its shape and modality of use to our crossmodal object. This reference gives us two advantages; one is to implant a new functionality in a format that gives an orientation on its usage, the other is the possibility of transforming a subjective experience in a shared and relational one (Fig. 4)

Figure 4: Sketch of the Bone Conduction Hookah.

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Assessing the Impact of Music on Basic Taste Perception using Time Intensity Analysis

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ABSTRACT

Several recent studies have examined the impact of music on the evaluation of food and drink, but none have relied on time-based methods. Since music and food/drink are both time-varying in nature, it would seem only appropriate to take temporality into account when studying the impact of music on the eating/drinking experience. A common method of time-based sensory evaluation of food products is time-intensity (TI), where a specific sensory attribute is measured over time. In the present investigation, we used TI analysis to measure temporal changes in sweetness and sourness evaluations of an off-dry white wine when the music stimulus changed from a soundtrack commonly associated with sweetness to one associated with sourness instead, and vice versa. The results revealed that a change of soundtrack results in a change in taste intensity (for both sweetness and sourness) in the same direction as the change in the soundtrack. More specifically, a switch from the sweet to the sour soundtrack enhanced the intensity of sourness, whereas a switch from sour to sweet soundtrack enhanced the perceived intensity of sweetness. Potential implications for the mechanisms underlying the auditory modification of taste and opportunities for future studies are discussed.

CCS CONCEPTS

• **Applied Computing → Psychology**

KEYWORDS

Multisensory taste/flavor perception; attention; sound; drink; crossmodal correspondences

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1 INTRODUCTION

Attention is intrinsic to how we perceive sensory inputs ([1]), and is considered by some psychologists and neuroscientists to be closely linked with consciousness ([2][3] though see [4] for an argument against conflating the two). We are often bombarded with vast amounts of sensory information, and attention helps prioritize our limited neural resources towards more relevant information for further processing and storage ([5]). Notably, attention plays a crucial role in determining what we perceive in food and drink. In his review, Stevenson ([6]) illustrates the role of attention in flavour perception, where the unitary experience of flavour is attributed to attentional capture by somatosensation over olfaction. Moreover, attended flavour elements become relatively more salient than less attended elements ([7][8]).

The question addressed here concerns the role of attention on the way sound-flavour correspondences may influence the tasting experience. In the present study, a time-based sensory evaluation method was used in order to examine whether different auditory stimuli can modify the perceived intensity of a particular taste. Crossmodal correspondences between pitch and spatial location modulate attentional orienting ([9]), so it is conceivable that auditory stimuli (specifically taste-congruent soundtracks) may be able to shift our attention towards specific tastes/flavours as well. Moreover, since music and food/drink are both time-varying in nature, it seems only appropriate to take temporality into account when studying the impact of music on the eating/drinking experience.

Several recent studies have examined the impact of music on the evaluation of food/drink, but none have relied on time-based methods. Time intensity (TI) is a well-established method for the time-based sensory evaluation of food products which works by measuring the sensory perception of a specific attribute's intensity over a certain time period; by so doing, the methodology enables the monitoring of temporal changes during product evaluation ([10]). It is has been used on a large variety of food products such as ice cream ([11]), beer ([12]), and wine ([13] [14]), to name but a few. In the present study, TI is used to assess whether changes in intensity can be observed in a specific taste component in a wine if the auditory stimulus changes. If crossmodally congruent soundtracks work by shifting people's attentional focus, then we should be able to see changes in taste intensity (as shown by [7] as the soundtracks change during the tasting procedure. The experiment focused on two distinct basic tastes – sweet and sour – since they would be easy for participants to attend to. Accordingly, we selected as experimental stimuli those soundtracks that have been shown previously to correspond to sweet/sour tastes, as well as a wine with both pronounced sweet and sour tastes.

2 METHOD

2.1 Participants

A total of 21 participants (11 women, 10 men) aged 21-69 years (M=37.6, SD=12.8) took part in the study. The participants were recruited at the Universidad de Tres de Febrero in Buenos Aires, Argentina. All of the participants gave their informed consent to take part in the study. None of the participants reported a cold nor any other known impairment of their sense of smell, taste, or hearing at the time of the study. The study was approved by the Central University Research Ethics Committee of Oxford University (MSD-IDREC-C1-2014-205).

2.2 Auditory Stimuli

The study involved soundtracks designed to match with sweet and sour tastes. The sweet soundtrack came from Wang et al.'s ([15]) study, comparing and ranking 24 different soundtracks that had previously been designed to be associated with taste attributes (comparison based on ratings made on basic tastes scales). For this study, we chose the soundtrack that was most commonly matched with sweetness. The soundtrack (chosen by 89 out of 100 participants), was developed by Jialing Deng and Harlin Sun as a soundtrack for Synaesthetic Appetiser, part of Deng's Masters of Arts Thesis project (June, 2015). People associate the soundtrack, Superscriptio, by Brian Ferneyhough with the taste of sourness ([16]). Two concatenated soundtracks were then created based on these sweet and sour soundtracks. One was a sour-sweet soundtrack consisting of 15 seconds of 'sour' music followed immediately by 15 seconds of 'sweet' music. The other was a sweet-sour soundtrack produced in the reverse order.

2.3 Wine

The study involved an off-dry wine produced in Argentina from Chenin Blanc grapes – Santa Julia Chenin Dulce Natural 2015. This wine has low alcohol (7.5%), crisp acidity, and a medium level of residual sugar (73.3 g/l). It has aromas of white peach, apricot, and citrus, and citrus flavours with a good balance between acidity and sweetness.

2.4 Design and Procedure

Each participant was seated in front of a computer screen with headphones and a cup of water to cleanse their palates. The experiment was programmed using the Sensomaker tool for the sensorial characterisation of food products ([17]). On each trial, the participants were given a 15 mL sample of wine by the experimenter and told to focus on either the sweetness or sourness of the wine. They were instructed to start the trial as soon as they put the wine in their mouth, and to hold it there for the 30-second duration of the trial. During the trial, they were asked to continuously move the cursor along a horizontal 11-point intensity scale scale to rate the sensation of sweetness or sourness as it evolved in their mouth, until the end of the trial. The experimenter started the music at the same time as the participant clicked on the start button.

There were a total of four trials, two trials where the participants had to rate sweetness intensity (once listening to sour-sweet soundtrack, once listening to sweet-sour soundtrack), and two trials where the participants had to rate sour intensity (once while listening to the sour-sweet soundtrack, and once while listening to the sweet-sour soundtrack). The order of the trials was randomised using a Williams Design Latin Square. The experiment lasted for around 10 minutes and the participants were debriefed afterwards.

3 RESULTS AND DISCUSSION

TI graphs and parameters of I_{max} (maximum intensity), TI_{90} (time when intensity is at 90% of I_{max} at increasing part of curve), TD_{90} (time when intensity is at 90% of I_{max} at decreasing part of curve), and the areas under the curve (AUCs) were produced by the Sensomaker software (see Figure 1 for an illustration). An I_{30-15} measure, which is the difference in participants' intensity ratings at 15 and 30 seconds, was calculated to take into account participants' taste ratings with changes in the soundtrack (namely at the beginning and end of the second part of the two-part soundtracks). Repeated-measures multivariate analyses of variance (RM-MANOVA) with within-participant factors of soundtrack type (sour-sweet, sweet-sour) and taste rating (sour, sweet) were conducted on the time intensity graph parameters.

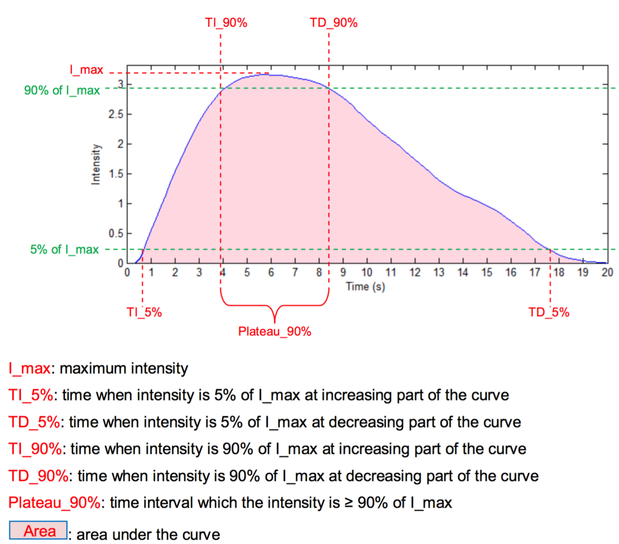

Fig. 1. Time-intensity curve parameters used in the present study. Reproduced from SensoMaker user guide ([18]).

Figure 2 shows the average TI graphs for each of the 4 conditions. The 15-second point is demarcated on the graphs, showing when the soundtracks changed from sour to sweet (see Figures 2A and B) or from sweet to sour (see Figures 2C and D). Visually inspecting the graphs, there is a notable difference in the slope of the average TI curve in the 15-30 second region between 2A and C), where 2A is positive and 2C is negative (in other words, sweetness rating during the sweet section of the soundtrack increased, but decreased during the sour section). A similar difference can be seen between panels 2B and D.

Average values of I_{max}, TI_{90}, TD_{90}, and AUC in the four experimental conditions are shown in Table 1. An RM-MANOVA revealed a significant interaction between soundtrack type and taste rating, $F(4,16)=5.32$, $p=.006$, Wilk's Lambda=0.43. Further univariate ANOVAs revealed that the significant interaction applied to the TI_{90} ($F(1,19)=9.66$, $p=.006$, $\eta^2=0.34$) and TD_{90} ($F(1,19)=13.00$, $p=.002$, $\eta^2=0.41$) ratings. Post hoc pairwise comparison tests with Bonferroni corrections revealed that, for the sweet-sour soundtrack, TI_{90} occurred before the 15 second mark for sweet intensity evaluation but after the 15 second mark for the sour intensity evaluation ($TI_{90\_sweet}=12.56$ s, $TI_{90\_sour}=17.60$ s, $p=.035$). Similarly, TD_{90} occurred significantly earlier for the sweet intensity evaluation than for the evaluation of sour intensity ($TD_{90\_sweet}=23.88$ s, $TD_{90\_sour}=28.05$ s, $p=.023$). In other words, when participants listened to the sweet-sour soundtrack, the period of 90% taste intensity registered occurred significantly earlier in time for sweetness evaluation than for sourness evaluation. A similar, but non-significant, trend was also observed during the sour-sweet soundtrack, where the period of 90% sour taste intensity occurred earlier than the period of 90% sweet intensity ($TI_{90\_sweet}=16.22$, $TI_{90\_sour}=13.91$, $p=.19$; $TD_{90\_sweet}=27.26$, $TD_{90,sour}=23.66$, $p=.051$).

There were no significant main effects of soundtrack ($F(4,16)<1$, n.s.) or taste rating ($F(4,16)<1$, n.s.).

For a more precise look at how changes in the soundtrack might have influenced participants' taste ratings, the differences in participants' intensity ratings between 15 and 30 seconds ($_{I30\text{-}15}$) were measured (see Figure 3). When the participants were asked to rate the sweetness of the drink, $I_{30\text{-}15}$ was negative for the sweet-sour soundtrack but positive for the sour-sweet soundtrack. In other words, sweetness decreased when the soundtrack went from sweet to sour, but increased when it went from sour to sweet. The exact opposite pattern was observed for the sour ratings, where $I_{30\text{-}15}$ was positive for the sweet-sour soundtrack but negative for the sour-sweet soundtrack. This provides evidence that a changing soundtrack can modify people's taste ratings over time, even when the beverage itself does not change.

A RM-ANOVA analysis of $I_{30\text{-}15}$ revealed a significant interaction effect between soundtrack and taste rating ($F(1,19)=17.96$, $p<.0005$, $\eta^2=0.49$). Post hoc tests with Bonferroni corrections revealed that for sweet ratings, $I_{30\text{-}15}$ is lower during the sweet-sour soundtrack as compared to the sour-sweet soundtrack ($p=.044$). On the other hand, for sour ratings, $I_{30\text{-}15}$ is higher during the sweet-sour soundtrack as compared to the sour-sweet soundtrack ($p=.022$). There were no significant main effects of soundtrack ($F(1,19)<1$, n.s.) nor taste rating ($F(1,19)<1$, n.s.).

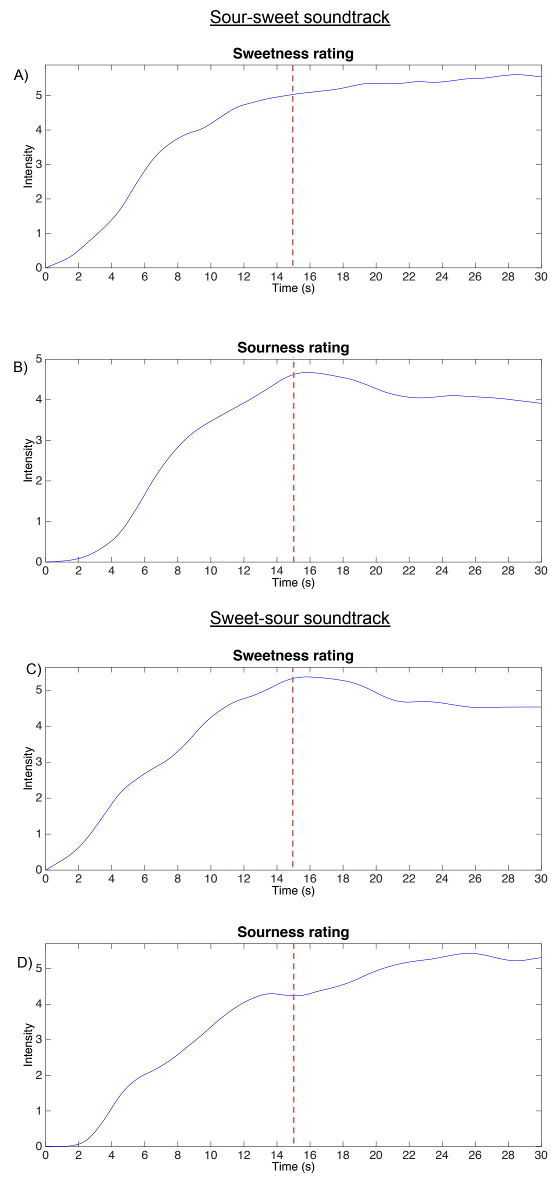

Fig. 2. Mean values of time intensity (TI) values for each of the four soundtrack-rating conditions: A) sour-sweet soundtrack, sweetness rating; B) sour-sweet soundtrack, sourness rating; C) sweet-sour soundtrack, sweetness rating; D) sweet-sour soundtrack, sourness rating. The dotted line is shown at the 15-second mark, where the soundtrack changed from either sweet-to-sour or sour-to-sweet.

Table 1. Time-intensity graph parameters from the present study, grouped by soundtrack condition and the taste that the participant had been asked to focus on during the trials. Standard errors of the means shown in parentheses.

Soundtrack	Taste rating	I_{max}	AUC	TI_{90}	TD_{90}
Sweet-sour	Sweet	5.91 (0.46)	117.75 (11.81)	12.56 (1.47)	23.88 (1.29)
Sweet-sour	Sour	5.32 (0.50)	110.14 (12.63)	17.60 (1.77)	28.05 (0.87)
Sour-sweet	Sweet	6.31 (0.47)	125.44 (13.66)	16.22 (1.89)	27.26 (1.16)
Sour-sweet	Sour	5.32 (0.50)	97.29 (10.10)	13.91 (1.61)	23.66 (1.53)

The results of the present study demonstrate that, as predicted, a change of soundtrack results in a change in taste intensity. Furthermore, the change in taste intensity is in the same direction as the soundtrack in question – a switch from sour to sweet soundtrack enhanced sweetness intensity, whereas the switch from the sweet to sour soundtrack enhanced sour intensity. These results are especially striking considering that participants evaluated the same mouthful of wine at different points in time, with the knowledge that the wine itself cannot have changed (see [19], for a demonstration of the unity assumption as it applies to tasting).

Figure 2 shows an inflection point at around 15 seconds (especially evident in panels 2B and C). Since 15 seconds is the point at which the soundtrack changed from sweet to sour, or from sour to sweet, this supports the anecdotal report (see [20]) that changes in auditory stimuli can influence taste evaluation quickly. For instance, Crawshaw ([21]) noted that "the gustatory and olfactory changes [in the wine] perceptually appear to occur immediately, coinciding with changes in mode, tempo, and more generally, the style/genre [of the music]" (reviewed in [22]). Moreover, this could be interpreted as a counterexample to the theory that music might operate by changing the taster's emotional state, since it would take several seconds (eight, according to [23]) for the emotional impact of music to build-up (see [22], for a more in-depth discussion of this issue). Of course, we cannot rule out the possibility of demand effects, where the participants simply changed their intensity evaluations according to the music (because they considered the music more sweet or sour than the previous one), without any changes in their perception of the wine itself. It would be interesting to conduct a fMRI experiment to assess whether changes in music results in a change in activity in the primary taste cortex ([24]), or simply in areas associated with the evaluation of experienced pleasantness ([25]).

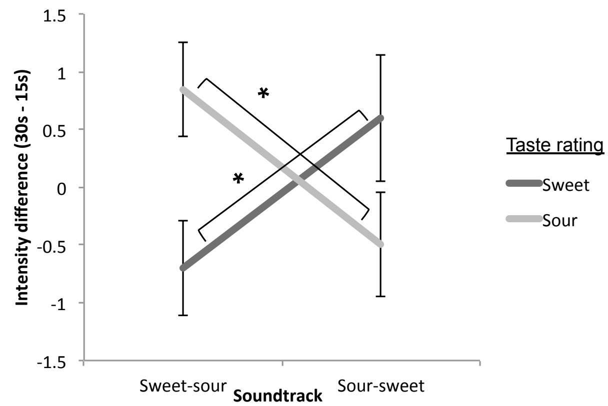

Fig. 3. Mean values of time intensity (TI) differences between participants' ratings at 30 seconds and at 15 seconds. For the sweet-sour soundtrack, 15 seconds denotes the switch from the sweet to the sour soundtrack. The same holds, reversed, for the sour-sweet soundtrack. Error bars denote the standard error of the means. Asterisks ('*'), indicate statistical significance at $p<.05$.

4 CONCLUSIONS

The results of the present study represent one of the first attempts to use time-based methodologies to investigate the influence of auditory stimuli on the tasting experience. The successful deployment of TI here opens many future avenues of research, with a focus on the temporal aspects of the music listening experience as well as the tasting experience. As discussed by Spence and Wang ([26]), most off-the-shelf music has not been ideal for research purposes since stylistic changes often occur and, unless one is careful, there is a real danger in a piece of music corresponding to different tastes/flavours at different points in time. Learning more about the temporal characteristics of such "sonic seasoning" effects could free researchers from such constraints, as well as enable experience designers to create more fluid and sophisticated experiences which take advantage of the evolving nature of both the listening and the eating/drinking experience.

ACKNOWLEDGMENTS

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An Exploration of Taste-Emotion Mappings from the Perspective of Food Design Practitioners

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ABSTRACT

This paper explores taste-emotion mappings and how they may inform the design of user experience in HCI. We report interviews with 7 food industry professionals and discuss the findings against laboratory-based psychology studies. While the sweet-positive affect and bitter-negative affect mappings were confirmed, those for sour, salty and umami tastes were challenged. Our outcomes highlight a more nuanced understanding of taste-emotion mappings, the influence of taste intensity and the importance of narrative and temporality when designing taste experience in naturalistic settings.

CCS CONCEPTS

Human-centered computing → Human computer interaction (HCI) → Interaction paradigms

KEYWORDS

3D Printed Food, Taste, Emotion, Affective Computing

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1 INTRODUCTION

Food is an interesting design material which has received increasing HCI interest. Whilst a few prior studies have started exploring interactive systems around food, there has been little work on food as an interactive medium. With the rise of technologies such as 3D food printers there is now a real possibility of developing 'edible interfaces' [36], challenging designers to understand how food can be leveraged to create novel and meaningful user experiences. A promising possibility for edible interfaces arises from the connection of taste and emotion. In lab-based studies there is a weight of evidence showing mappings between basic tastes and specific affective responses [3,14,23,28,39]. We know little, however, of how such mappings apply to food experience in everyday, ecologically valid contexts.

In this paper, we report on interviews with 7 experts in food design to explore their understanding of how tastes facilitate various affective responses, and of specific foodstuff illustrating such mappings. For this, we are drawing from previous work on the psychology of taste and emotions, as well as theories of embodiment, and focused on the following research questions:

- Is sweet taste predominantly mapped to positive emotions as suggested by psychology of taste?
- Are sour, bitter and salty tastes predominantly mapped to negative emotions?
- How does the intensity of the taste link to emotional responses?

2 BACKGROUND RESEARCH

Much previous work on tastes and emotions has shown their relationship, both in terms of mappings of emotional responses to tastes [3,23,28,39] and as tastes' influence on the perception of affective stimuli [8,25]. Most of these existing studies rely on pure tastants (that only trigger taste receptors) as their stimulus, and occur in controlled, laboratory environments. Thus, their findings tend to lack the ecologically validity required to support their use in an applied field such as HCI.

Sweet taste has been shown to map predominantly to positive emotions [23,35,37,39] and influence mood and moral decision making through enhancing positive, and limiting negative responses to affective stimulus [8,11]. Negative affective response has been linked to bitter [12,14,17,28,35], sour [28,37,39] and salty tastes [23,28,35,37,39]. Disgust specifically has been mapped to bitter [3,8,38], sour and salty tastes [3,26]. Bitter taste specifically has been used to explore the influence of embodied cognition [6,8].

Among the few studies conducted under ecologically valid conditions is Noel and Dando's [20] exploration of the relationships between taste and emotion following hockey matches. At a series of matches supporters to tried one sweet and one sour ice-cream. Findings show that sweetness was

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promoted in positive situations (after a win) and depressed in negative ones (following a loss), whilst the reverse was true for sourness. The study design used controlled samples of real food, rather than tastants. Hinting at the way an edible interface could function, and highlighting the value of taste-emotion mapping for designing experiences in-the-wild [27]. A limitation of this study is that the taste was delivered as an addition to the experience of the match instead of exploring how taste can be embedded in the total experience.

Within HCI, studies exploring taste as a design variable have started to emerge. Obrist et al. [22] used a human-centered approach to assess the qualities of basic tastes. They conducted interviews using the Sensory Evaluation Instrument [13] and the Explication Interview Technique [15] to investigate the affective, temporal and embodied characteristics of taste experiences.

Embodiment has also been explored in HCI, particularly in affective mappings for multimodal interfaces. Antle et al. used experts [1] and users [2] to derive mappings for bodily movements. Within studies on taste, Eskine et al. [8] and Chen and Chang [6] both explore how embodiment shapes the mapping between bitter tastes and disgust.

The correlation between emotion and taste has also been associated with both action and personality by Meier et al. [18]. They found that preference for sweet foods could be used as a predictor of prosocial personalities, intentions and actions.

The potential for taste to influence mood and intention suggests it could form a powerful tool for affective, interpersonal communication. In particular, the influence of embodiment on the interaction between food and affective response suggests a novel direction for tangible interfaces through which physical, bodily experience on the one hand, and affective, cognitive experience on the other hand can be simultaneously stimulated. This study aims to lay the foundations for the application of taste and emotion in the development of affective, edible interfaces.

3 METHOD

To understand how taste-emotion mappings are perceived, created and used in an applied context, we conducted semi-structured interviews lasting between 30 and 45 minutes with food industry professionals. The interviews focused on experts' emotions; both discrete [7] and continuous ones [29]. The study consisted of three parts. First, we asked participants to place a typical food experience of each of the five basic tastes, i.e. sweet, sour, salt, bitter and umami, onto Russell's circumplex map [29]. Second, we asked them to describe emotions they associated with each of the basic tastes. Third, we asked for tastes or flavors they associated with Ekman's discrete emotions [7]. As we wished to explore how tastes' intensity influenced the mappings we did not suggest any levels, allowing participants to define themselves how different intensity levels influenced their affective responses.

Interviews took place in person or via the phone and were recorded and fully transcribed. The data analysis involved a hybrid approach where existing concepts were used for the deductive coding while new concepts grounded on the empirical data, contributed to inductive coding [10]. The deductive coding included the mapping of sweet to positive valence, and bitterness, saltiness and sourness to negative valence [3,26,28]. The resulting coding list was iteratively refined in the light of the interview data, as new codes emerged under the themes of intensity of taste, the typical foodstuffs triggering taste, typical flavors stimulating multiple tastes, the influence of narrative on taste and its embodied response. The coding was conducted by the primary author and iterated through weekly discussion over several months between authors until stability was achieved.

3.1 Participants

We recruited 7 food industry professionals with knowledge of how tastes can be used to create experiences (3 female, 4 male) aged between 29 and 38 (M=32.9, SD = 2.7). The convenience sample consists of chefs (n=4) and food designers (n=3). Participants were recruited all work within the UK.

4 FINDINGS

We now report the findings of our mapping exercises starting with the circumplex model followed by the identified taste-emotion mappings.

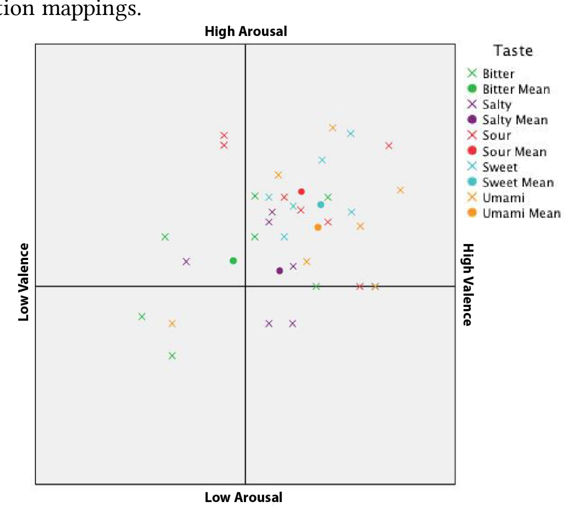

Figure 1 : Circumplex Mapping of Tastes on Emotional Arousal and Valence

Figure 1 shows each participant's mapping of tastes on the circumplex model. A few trends are emerging from these findings. First, most tastes appear in the high arousal-high valence top right quadrant. The highest emotional arousal is triggered by sour taste, whilst the highest valence by sweet and umami tastes. Salty and bitter are both perceived as lower arousal, with bitter being the only taste with an average negative valence.

4.1 Tastes with Positive Affective Response

The association between the sweet taste and positive affective response was highlighted by our participants, often with the additional association of *comfort* (n=6). Intriguingly, for happiness, a combination of sweet, umami and salty tastes was mentioned. These tastes were described as *'like mother's milk kind of thing. You know it is an innately pleasurable trio'* [P5]. This suggests how taste can still play an important role in affective response even at the level of a complex, compound experience. Another important finding is the mapping of umami to *happiness* (n=3) and positive affective response. This contrasts with less conclusive prior findings on the mapping between umami and discrete emotions [14,37,39].

4.2 Narrative and Memory

This section outlines the value of narrative and episodic memories in food experience. Where reported, the positive affect of both bitter and sour tastes was linked to narratives reflecting childhood memories. Enjoyment of bitter tastes is known to be a learnt response [4] and our findings confirm this process of acquiring a taste for bitterness: *'there is a sort of desire to attain that level of maturity with bitterness'* [P1].

Sour sweet treats were a common example of a food stuff in which the sour taste was enjoyed. Often this response was linked to early childhood memories: *'it reminds me of sour sweeties like really sour stuff, reminds me of childhood'* [P5]. For bitter and sour, respondents often pointed to prototypical food stuffs, such as sour sweets or coffee, that were enjoyed.

Sourness was most strongly related to surprise (n=7) and excitement (n=3), which supports the circumplex map findings in which sour had the highest mean arousal. One interviewee described sourness as *'adventure [...] a sort of bravery, I think that is the emotional bravery and a desire to enjoy something that actually is quite difficult to enjoy'* [P1]. With both bitter and sour tastes, ideas of transgression, bravery and maturity also emerge.

4.3 Tastes with Negative Affective Response

Bitterness was also mapped to anger, fear and disgust, confirming previous lab-based findings [6,9,12]. Fear however was interpreted in a more physical manner: *'I feel caffeine just bunches up your energy really tightly and uses it all up at once and leaves you completely useless afterwards'* [P6]. Sour provided little evidence of negative affect, although interviewees reported *'some sort of displeasure [which makes it] exciting'* [P5].

4.4 Salty Taste

A surprising finding was that salty taste was mapped to neither positive nor negative affective response. In the circumplex model, we can see that salty taste is associated with both a lower arousal and valence than other tastes. Our interviewees reported this as *'some kind of contemplation'* [P3], *'idling'* [P4] and *'mellow'* [P2].

4.5 Non-Taste Food Characteristics

No taste mappings were reported by several participants for both anger and sadness. For anger; chili, overcooked and burnt foodstuffs were proposed. Anger-inducing foods were often defined by their textures, being *'quite sharp and if you try to eat [them, they] will scratch your gums up a bit'* [P6]. The same participant also described the temporal aspect of 'anger' foods as *'quite hard to escape from [as they have] rolling, ongoing consequences and need time to calm down, which seems perfect for [anger].'* Sadness was described through a lack of food, or bland and thin foods; not a taste mapping but highlighting how the absence of a taste could be manipulated in experience design.

4.6 Taste Intensity

Herbert et al. [12] argued that the intensity of taste is positively correlated to emotional response. Our findings suggest a more nuanced understanding, such as an inverse U curve, where emotional response is positive for most levels of intensity but becomes negative for the lowest intensity (i.e. bland foodstuff) and the highest. For example, too much sweetness was described as negative, *'there is definitely an upper limit to what you can consume because it will very quickly start to make you sick, so it is sort both an attractive thing but also something that you're aware can turn on you a bit'* [P6]. Here the physical consequence informs the wariness of very sweet tasting foods.

5 DISCUSSION

We now discuss the key findings in relation to prior work and how they contribute to the study's research questions. With respect to circumplex model, our findings confirmed the previous lab-based ones [3,14,23,28,39] on sweet-positive and bitter-negative mappings. However, we found intensity to not be simply correlated with affective response, and found new mappings for sour and umami tastes to arousing and positive affective reactions.

While prior lab-based findings suggested a positive correlation between taste intensity and strength of affective response [12] our findings indicate that this applies only for the middle levels of taste intensity, but intensities that are too low or too high trigger a negative response. These findings are also supported by Yamaguchi and Takahashi's [39] study on the taste intensity of foodstuffs.

Physical response has been previously mentioned in relation to tastes supporting the idea of an embodied approach to mappings [6,8]. Our findings confirm this, with caffeine being identified to trigger fear as a result of digesting the compound. Similarly, the sour-surprise mapping is informed by the *'tingly and exciting'* physical sensation of the taste. This suggests that when designing experiences with tastes it is important to pay attention to the longer term affects as well as the 'in-the-moment' influences of embodiment. For example, the connection between highly sweet tastes and nausea could arise due to a single intense dose or an accumulation of doses over time, both potentially intended to represent or trigger positive responses but in fact entailing negative ones.

For sour and bitter tastes, findings indicate several prototypical natural foodstuffs. Evidence from rat studies has shown that such foodstuffs can generate a similar but more informationally rich neurological stimulation than pure tastants [30]. Prior findings support the claims of the multisensory flavor perception [32,33] because of the extra sensory activity experienced from a food compared to a taste. However, it also shows the possibility of using certain foods to create responses akin to those achieved through pure tastants.

Narrative was highlighted as a key method for interviewees offering an insight into food designers' means of experience construction. This method was particularly apparent in bitter and sour tastes where the main narrative described crossing the boundary from pleasant to unpleasant. The transgression of enjoying an initially unpleasant sensation opens a new design space for creating experiences of transformation. Salt provides an intriguing counter point to the other tastes by acting as a 'negative space', meaningful in its lack of specific emotional response

Obrist et al. [22] have previously highlighted the variable nature of affective response to taste over time. Temporality is an under explored quality of both food and taste experience. Tuters and Kera [34] offered a framework for understanding temporal possibilities via *metabolic interaction*, describing how food is involved in a long chain of interactions that form one, complete experience. For designers, this adds a depth to the way taste can be used, through operating on several temporal scales simultaneously.

6 DESIGN IMPLICATIONS FOR EDIBLE INTERFACES

We now discuss the implications of our findings for designing user experience in HCI through an increased awareness of ecologically valid taste-emotion mappings. We also discuss how intensity and temporality can be considered, together with the limitations of taste as a medium and its potential contribution of integration in multisensory interactive systems.

6.1 Awareness of Taste-Emotion Mappings

Our findings aim to sensitize designers of edible interfaces to the importance of the taste-emotion mappings in naturalistic settings, both across the circumplex and discrete model of emotions. While there are individual differences in people's mappings [24], our findings point towards some novel relationships such as that of sourness and surprise, and high levels of sweetness and negative affect. Findings also confirmed prior mappings for bitter and sweet. The agreement on these mappings in both abstract and naturalistic settings indicates these to be the best starting point for further exploration.

Designers of edible interfaces should also be aware of the nonlinear relationship between taste intensity and the arousal of positive emotions. Our findings open up the possibility of intensity as a variable of the taste experience, for example the change from pleasure to nausea (in the case of sweet) or refined maturity to disgust (in the case of bitter).

6.2 Design for Temporality of Edible Interfaces

Taste also affords the opportunity for experiences that transform over time. We have seen how narratives and memory can influence this at one level, whilst lingering tastes and digestion can have an impact on another. These compound timelines offer the tools for designers to create complex experiences that last beyond the tasting, connecting back to the user's memory but also creating an on-going experience into the future.

Here we could see the manipulation of the functional properties of compounds that afford taste. Caffeine is a bitter tastant but also a stimulant, sucrose similarly for sweet. At this point taste extends into physical response and embodiment plays a role. A unique quality of edible interfaces is that computing is enabled to extend into the user's body in an ephemeral way, offering designers a bodily space for interaction that doesn't involve permanent or intrusive application of technology.

6.3 Exploiting the Limitations of Taste-Emotion Mappings

Findings also indicate that specific emotions such as sadness are difficult to be mapped to taste. This opens up the design space of co-creating tastes that people can identify with sadness, possibly leveraging the power of narrative. In an interactive system this could be constructed at a personal or interpersonal level. The development of culturally specific meanings for emojis [16] could provide some interesting insight into such a development. Anger also didn't map to taste, but our findings support the possibility of building on knowledge of multisensory integration [31], using touch or temperature to augment the taste sensation to create the required response.

7 CONCLUSIONS

This paper reports on interviews with 7 chefs and food designers to understand the validity of taste-emotion mappings for the design of ecologically valid user experiences. Sweet-positive and bitter-negative mappings were confirmed and a more nuanced understanding of to taste intensity on affective response has emerged. Sour, salty and umami tastes were found to exhibit mappings differing from lab-based findings. Findings have led to three design implications highlighting the value of sensitizing designers about the taste-emotion mapping, the role of temporality, and of opportunities of exploring currently unavailable mappings for sadness and anger.

7.1 Limitations

In the interviews, participants were relying on their memory of taste experiences and taste sensitivity as not accounted for. Further work is needed to explore these taste experiences in real time and to explore the influence of sensitivity.

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Gustatory Interface: The Challenges of 'How' to Stimulate the Sense of Taste

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ABSTRACT

Gustatory interfaces have gained popularity in the field of human-computer interaction, especially in the context of augmenting gaming and virtual reality experiences, but also in the context of food interaction design enabling the creation of new eating experiences. In this paper, we first review prior works on gustatory interfaces and particularly discuss them based on the use of either a chemical, electrical and/or thermal stimulation approach. We then present two concepts for gustatory interfaces that represent a more traditional delivery approach (using a mouthpiece) versus a novel approach that is based on principles of acoustic levitation (contactless delivery). We discuss the design opportunities around those two concepts in particular to overcome challenges of "*how*" to stimulate the sense of taste.

CCS CONCEPTS

• **Human-centered computing → User interface design**; *Interaction design*;

KEYWORDS

Taste; Taste Experience; Food Interaction Design; Acoustic Levitation; Food Delivery System; Taste Perception

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1 INTRODUCTION

The field of Human-Computer Interaction (HCI) has mainly focused on the use of visual and auditory modalities when designing user interfaces. This has changed through the proliferation of haptic technologies and will in the future be further transformed through the exploration of the sense of smell and taste [24]. The chemical senses are particularly of interest in the context of food-interaction design, linked to the study of food in everyday life (e.g., [3][5]), investigating the ecologies of domestic food consumption [6], product and package design [22], but also with respect to the exploration of novel interaction concepts (e.g., shape-changing food [26], edible screen/interface [2]).

When it comes to the design of food interaction and gustatory interface design, HCI is still facing various challenges related to the "how" of stimulating the sense of taste. Within HCI, taste stimulation is mainly achieved through the use of chemical stimulation (e.g., solutions for basic tastes [11][14]) or through electrical and/or thermal stimulation of the users' tongue (e.g., [12][18][19]).

A systematic review and discussion of the possibilities and pitfalls around stimulating the chemical senses (taste and smell) was recently presented by Spence et al. [23], providing a solid foundation for future work. Here, we extend the discussion by reviewing the specificities of gustatory interfaces using both chemical and electrical/thermal stimulation approaches. We then move on and introduce two concepts of gustatory interfaces we were actively involved designing and developing. The first concept refers to a device that involves five basic tastes that can be flexibly controlled, and is inspired by LOLLio, a taste-based gaming interface [11]. The second concept presents a new interaction concept for human food interaction exploiting principles of acoustic levitation.

We conclude with a reflection on the emerging design opportunities around the sense of taste and discuss how particularly the two concepts we introduce could provide new approaches in food experience design.

2 GUSTATORY INTERFACES

Current gustatory interface developed within the field of HCI can be categorized into two main groups based on their ***stimulation approach*** to create a taste sensation on the users' tongue: (1) chemical stimulation, and (2) electrical and/or thermal stimulation. Below we review and classify prior works on gustatory interfaces (see Table 1 below for an overview) based on the following three criteria:

- Materials used in the specific gustatory interface (e.g., cartridges, pumps)
- Interaction method used for the human interaction with the gustatory interface (e.g., passive vs. active)
- Capability of the gustatory interface (e.g., how many tastes can be stimulated, combination of taste stimuli)

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Table 1: Overview on gustatory interfaces in HCI, divided by chemical and electrical/thermal stimulation, clustered along the 3 main criteria

Stimulation Approach	Gustatory Interface	Materials used	Interaction Method	Capabilities
Chemical (e.g., cartridges with flavouring agents or basic tastes)	TasteScreen [9]	A USB device contains 20 small plastic flavour cartridges, mounted on top of the screen.	Users lick the screen to sample the taste.	Deliver liquid in the cartridges (e.g., lemonade, milk, coffee, wines).
	BeanCounter [9]	Rods (made from transparent acrylic), each is filled with a flavour of jelly beans. The bottoms of the rods are sealed with electronically controlled valves.	Map information with the colour of jelly beans. Users can pick up and eat the jelly beans.	Tastes of jelly beans: cherry, strawberry, orange, lemon, liquorice, grape.
	LOLLio [11]	A small spherical handheld device and a spherical lollipop with a plastic stick. Hardware: tiny pump, taste compound, Arduino.	User tastes the actual lollipop. Small amounts of a sour liquid are pumped from the grip to the outlet of the candy.	Sweet and sour.
	EdiPulse [7]	A chocolate printer. A heart rate monitor device.	A message made of chocolate is printed based on the user's heart rate data. The user is free to taste or share the printed chocolate.	Chocolate.
	Meta Cookies [13]	Plain cookies with AR marker (printed using branding iron).	User select a type of cookie (chocolate, strawberry, tea, etc.) and have the scent dispensed to the nose.	Simulated taste of the cookie based on the olfactory scent.
Electrical and/or Thermal	Digital Lollipop [17]	Tongue interface (two electrodes) Control system (control and dispense an electrical current).	User holds the device to the tips of their tongues.	Sour, bitter, salty.
	Augmented gustation using electricity [12]	A positive and a negative straw inserted into two cups of electrolyte drink.	User drink the solution from both cups using the two straws.	Electric taste.
	Virtual Lemonade [18]	pH sensor, RGB sensor, LEDs. Mouth piece with two silver electrodes. Control module with Bluetooth communication.	User select the colour then have the lemonade taste electrically simulated.	Sour (800Hz, 160ÂţA current).
	Thermal Sweet Taste Machine [21]	An electronic controller circuit, Electrode that connects to the Peltier, and a software module.	User put the taste strip on the surface of their tongue to perceive taste.	Sweet, (possible) bitter, and (possible) umami

Chemical Based Stimulation Approaches

Traditionally, tastes are given to users through a chemical compound, either in a solid or liquid form. Example ingredients for the five basic tastes (sweet, bitter, sour, salty, and umami) are: glucose for sweet, citric acid for sour, caffeine/quinine for bitter, sodium chloride for salt, and monosodium glutamate for umami [14].

This chemical based approach was, for instance, used by Maynes-Aminzade [9], who delivered the taste in form of jelly beans with different flavours (e.g., cherry, strawberry, lemon, etc.), with potential applications of memory profiling and network monitoring. The author also presented TasteScreen, a set of small transparent plastic cartridges that can be placed on a screen [9]. These cartridges release a flavouring agent if a user lick the screen.

Additionally, Murer et al. [11] presented LOLLio, a taste-based game interface. The taste dispensing mechanism is inspired by daily objects that people put in their mouth, such as a lollipop or a baby milk bottle (in the first prototype). The metaphor of a lollipop is then further developed into a working prototype, where users can experience either sweet or sour throughout a gameplay experience depending on how well or bad they are playing. In a similar vein, Ranasinghe et al. [17] designed a device in the form of a lollipop, however used electrical stimulation to create taste simulations, which we discuss further below.

In another attempt, Narumi et al. [13] introduced the concept of MetaCookie, a system that creates customized tastes with the same plain cookie by dispensing an olfactory scent to user's noses. Users can select between different types of cookies (e.g., strawberry, chocolate, tea).

Electrical and/or Thermal Stimulation Approaches

It has been shown that people can perceive taste qualities without administering a chemical compound on the tongue, by stimulating the tongue papillae using electrical [15] or thermal [4] stimulation. Plattig [15] stimulated the sweet, sour, and bitter tastes in participants by placing a silver wire (0.4 mm tip diameter) on the tip of the tongue and a reference electrode on the left wrist of the subject. Cruz and Green [4] showed that a sweet sensation can be created by warming the anterior (front) edge of the tongue, and a sourness and/or saltiness can be evoked by cooling it. Recently, these findings have been harnessed by HCI designers who demonstrated how to design an application with electrical and thermal stimulation of taste.

Ranasinghe et al. [17] designed a lollipop shaped gustatory device that delivers electricity on the users' tongue. Users hold two electrodes on two sides of the tip of their tongue to perceive the simulated taste. Their results show that participants tasted sourness the most (90%), then saltiness (70%), bitterness (50%), and sweetness (5%). In a follow up design, Ranasinghe et al. [18][19] integrated this stimulation approach into a bottle that augments the taste sensation by: (1) superimposing virtual colours onto the drink using Light Emitting Diodes (LED) and (2) applying weak and controlled electrical stimulation on the tongue.

Similarly, Amira Samshir et al. [21] presented a concept that can create different tastes by thermal stimulation. Their design includes an electronic controller circuit, electrode that connects to the Peltier, and a software module. Users can perceive tastes that are thermally stimulated by the Peltier attached with a silver strip. This device was shown to create sweet taste in participants.

Opportunities and Challenges

In summary, each stimulation approach has its advantages and disadvantages. While the chemical approach is less invasive than the electrical and thermal stimulation of the tongue, it has the disadvantage of requiring continuous fresh preparation and refill of taste stimuli. Electrical and thermal stimulation allow for more control and replication of taste stimuli over a long period of time and over distance (e.g., such as in Taste/IP [16] or virtual lemonade [18]). However, the spectrum of potential taste sensations that can be stimulated through this approach are still limited. Hence, in the early stage of using taste as stimulation approach in HCI, chemical stimulation has the advantage of covering the broad range of taste experiences [14].

3 NEW CONCEPTS OF GUSTATORY INTERFACES

In this section, we introduce two concepts for gustatory interfaces employing a chemical stimulation approach. Our intention is not to present each concept in detail (specific technical or perceptual abilities) as each idea is worth a dedicated paper in itself. Our intention is to systematically reflect upon those two concepts in the context of the other devices from prior work. Thus, we will highlight how the complete spectrum of all five basic tastes can be covered (concept 1, we refer to as TasteBud) and how a totally new delivery mechanism can be exploited (concept 2, we refer to as TastyFloats, see [25] for more details).

First Concept: TasteBud

TasteBud is composed of six bottles of solution (see Figure 1), each contains one basic taste and one with water as neutral solution. The solution is pumped from each bottle using a peristaltic pump at a controllable speed. Out of each bottle is a tube for the taste solution to be transported. The six tubes for six bottles converges into a single tube (or straw), using a mouthpiece, making it convenient for the user to hold in the mouth during the interaction.

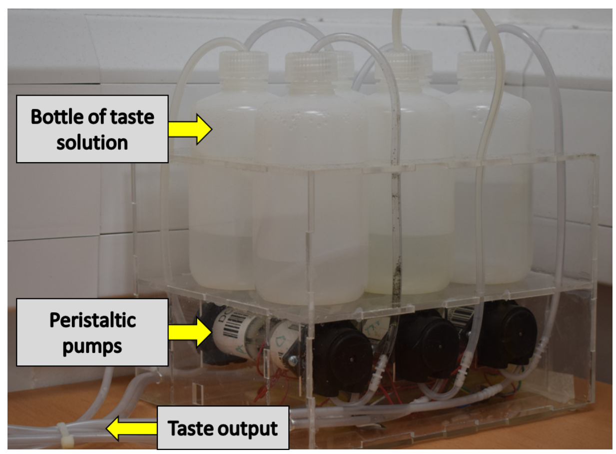

Figure 1: Overview of the TasteBud concept with bottles of taste solutions and six peristaltic pumps controlling delivery of five basic tastes and water.

TasteBud pumps taste solution from one or more bottles into the tubes connecting to participant's mouth. The taste delivery is controlled using an Arduino that allows the delivery of one or multiple tastes at a time, enabling an interactive and flexible gustatory interface. Compared to previous gustatory interfaces, TasteBud, as a standalone unit, offers the capability of delivering single or a combination of multiple taste in one trial. In addition, it offers a plug-and-play interface which allows interactive applications to send control commands to the Arduino board via a serial port to specify the taste delivery (a single or a combination of taste and the amount to deliver). This provides the flexibility and cross-platform ability necessary to stimulate taste in users.

TasteBud can deliver a customizable amount of taste stimuli to the user's mouth whilst they are interacting with the application (e.g., playing a game) on a computer connected to the device. The taste stimuli are in a liquid form delivered to the user's mouth. This minimizes the interaction required by hand allowing them to focus on the task at hand. This first concept aims to (a) provide a single taste or a mixture of five basic tastes though a single input device into participant's mouth and (b) can be interactively and flexibly controlled by a computer program. This guarantees a wide design space for potential applications in HCI.

Second Concept: TastyFloats

TastyFloats is a novel system that uses acoustic levitation to deliver food morsels to the users' tongue (see Figure 2). The technical implementation and first insights into its effect on users' taste perception are described in Vi et al. [25].

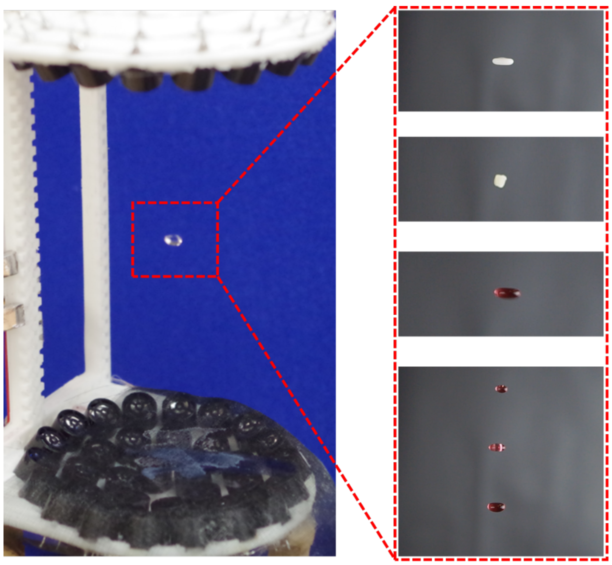

Figure 2: The pick-up unit using acoustic levitation with a drop of water (left) and (right, from top to bottom) milk, cheese, red wine (1 drop) and red wine (3 drops).

Prior attempts of levitating food have been made by chefs such as Fernando Canales at Etxanobe (Bilbao) [1] and Anthony Martin at Morimoto (New York) [10] who are serving dishes on top of a levitating plate. In these examples, magnetic levitation is used and food is placed on a levitating but static dish where customers have to take the foods using cutlery. TastyFloats is using acoustic levitation that not only allows to levitate the food item itself, but also facilitates a contactless delivery of food into users' mouth without the need for cutlery. Such an approach has been demonstrated in prior attempts to levitate water [8] and salad ingredients [20]. The TastyFloats concept takes those ideas a step further and not just allows static but also dynamic levitation of food items. This type of food delivery has the hygienic advantages as the whole process of food pick-up and delivery is in mid-air. In addition, this mechanism enables rich and interactive user experience by manipulating the combination of food items being levitated and transported into the users' mouth in a pre-defined order (e.g., chefs could specify which food item(s) is released first to user).

4 DISCUSSION AND DESIGN OPPORTUNITIES

When using a taste delivery device in an HCI application scenario, one important question is "*how*" it will affect users taste perception and interaction experience. When using novel technologies, such as acoustic levitation, there are still a lot of unanswered questions on how the size of a stimulus, choice of stimuli (be it a basic taste stimulus or a food item, such as cheese or wine) would influence a users' perception and can ultimately be used in an interaction scenario. Both concepts we presented in this paper, on top of reviewing prior gustatory interface approaches, are using a chemical stimulation approach, covering the whole spectrum of basic taste stimulation. The first concept TasteBud is inspired by LOLLio [11], but extends the previous design by allowing for the stimulation of all five basic tastes. Moreover, TasteBud is designed for a single-user interaction, with one mouthpiece, however, can be extended to multiple users by multiplying the mouthpiece to deliver the same or different tastes to more than one user at time. This system can be integrated into a variety of interactive applications (e.g., notification system, gaming).

The second concept, TastyFloats is a novel approach with high relevance for food interaction design, as it does not only allow the delivery of food morsels (liquid and solid items) from one place to the users' tongue but also opens up new design opportunities for HCI, such as enhance gaming experiences for single and multiple users (see [25] for more discussion on application scenarios). Moreover, TastyFloats has the potential to change user's taste perception and dining experiences. For example, food items being levitated may change their properties (e.g., heating up while transported) due to the continuous induced energy and offer inspiration for chefs, you are interested in creating surprising new food serving experiences. Moreover, chefs can explore new food and flavours combinations (e.g., non-existing menu creations). In summary, our concepts can be used in combination with other senses to enhance user experiences while interacting. However, designers should consider the moment of when to deliver the taste to create an optimal experience. Moreover, different taste have different temporal properties, making the synchronisation crucial [14]. Further research with the sense of taste can explore this cross-sensory integration.

5 CONCLUSION

Gustatory interfaces are fascinating and challenging for HCI in general and for food interaction design research in particular. The success of such interfaces depends ultimately from the end user, and if they are willing to accept the stimulus to be delivered into their mouths. In contrast to any other sensory stimulation, the sense of taste is best stimulated inside the human body, in a user's mouth. Hence, the question of "how" to stimulate taste sensations is extremely important to discuss, study, and investigate with respect to the various stimulation approaches and purposes of a stimulation. Only if it is made meaningful and implicitly integrated into an interaction and application, the likelihood that users will accept it and enjoy it, will increase. Here we only started to review existing efforts and directions for gustatory interface designs hoping to inspire future research that will transform we will eat, experience food, and interact with technology in the future.

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Author Index