

Material Food Probe: Personalized 3D Printed Flavors for Emotional Communication in Intimate Relationships

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ABSTRACT

Interactions with food are complex, integrating rich multisensory experiences within emotionally meaningful social contexts. Yet, the opportunities for food as material resource for emotional communication have been less explored. We describe a two-month project with 5 couples centered on the co-design of personalized flavors for emotional communication. These were experienced through a three-day preliminary study involving a 3D food printer in participants' homes. We discuss the value of our findings indicating preferences for both remembered and imagined positive flavors and their integration in *focal intimacy practices* to support emotional coregulation. We also discuss *material food probes* and their value for exploring and inspiring both design-with, and design-around food.

Author Keywords

Food; flavors; 3D food printer; design methods; probes; human-food interaction; emotions; intimate relationships.

CSS Concepts

• Human-centered computing ~Interaction devices • Human-centered computing ~User centered design

INTRODUCTION

Boxes of chocolates, oysters and, for the ancient Greeks, prunes. There is a long and storied relationship between food and romance, from foods seen as aphrodisiacs to the 'dinner date' as a courtship archetype. Previous work has shown the value of food for enhancing communication in romantic relationships by ensuring both increased awareness of one's own and partner's emotions [12], as well as impacting upon emotional responses [15]. The instinctive understanding of the connection between food and emotions is also reflected in everyday metaphors such as 'sweet love', 'bitter jealousy' [9], 'eating your feelings' and 'comfort foods' [15]. Evidence for the broader connections between food and emotions have been provided by research on the meaning of food in religious celebrations [16], fasting and feasts [33]. In HCI, the growing interest in food has focused mostly on

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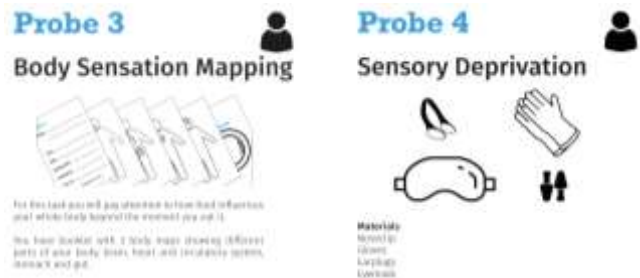


Figure 1 Probe Kit instructions for two of the probes, left – body sensation mapping, right – sensory deprivation

technologies and experiences *around* food consumption [25,49], but less so on the experiences of food itself [45]. The limited HCI work on technologies engaging directly with the making or eating of food has explored mostly universal basic taste experiences such as sweet, bitter and sour [20,22,45,64] rather than flavor-based experiences which are complex and idiosyncratic [59]. Moreover, making, sharing, and eating food, particularly with the ones we love, offers a sensory and experiential richness often less available in our interactions with digital technologies, even with those purposefully designed to foster intimacy [31]. We argue that the advancement of 3D food printing technologies is an opportunity to further explore food as material resource for communicating and regulating emotions. However, we know little in terms of how to work with food within the design process, and in particular in the context of intimacy. This paper investigates the feasibility of 3D food printing to support the design of personalized flavor-based experiences in the context of intimate relationships. We employed a co-design methodology [70] involving 5 couples who designed in total 50 personalized flavors of 3D printed food to support emotional expression and coregulation. The co-designed flavors were made in the lab and deployed with a 3D food printer as *food material probes* to be used over three days in participants' homes.

We found insights into the design of multisensory experiences, both using exemplar experiences and creating from scratch. We also uncovered how food was used in communication and coregulation and how this led to creative uses in which collaboration between partners accompanied solo use as part of gifting actions. The methods explored here include novel approaches to creating shared understandings of a user's bodily experience as part of co-designed *flavor*

experiences integrating *taste*- as the experience of sweet, sour, salty, bitter or umami by the tongue- with odor, texture, and appearance. This work sets out to answer the following research questions:

- What personalized flavors do people co-design for emotional communication in intimate relationships?
- How do people engage in 3D printing of such flavors in everyday lives?
- How does the 3D printed food support intimacy?

The main contributions of this work include (i) novel co-designed flavors supporting emotional expression and coregulation, (ii) understanding of how a 3D food printer and flavors are used for emotional communication in couples' homes; and (iii) the material food probe as a new method to explore both design-with and design-around food. In this paper we use the term *intimacy* to describe a close form of romantic relationship and *coregulation* to describe the intentional improvement of a partner's emotional state by interacting with them.

RELATED WORK

This work draws from the growing research in Human-Food Interaction (HFI) which has focused on two rather independent areas: “*around* food” and “*with* food”, as well as design research for romantic relationships in HCI.

Human-Food Interaction

Design around Food – Social Experiences in HCI

Work within this space has focused on social experiences around food consumption, particularly the sharing of food in domestic spaces for both collocated [17], and remote families [69], as well as broader community settings [25]. For instance, *Phototalk* tackles some of the disruptive impact of technology around dining through a shared digital photo frame to support prosocial interactions [17]. Technologies for remote connectedness facilitated by the sharing of meals include traditional video conferencing [69] through overhead capture and projection on tables [3,11], or food outputs for taste and smell experiences [69] to support conversations and sense of presence [54]. However, with a few exceptions [69], most such systems ignore food as a design resource for novel multisensory and embodied interactions.

Design with Food – Crafting Edible Experience

Attempts to harness the taste experience of foodstuffs have started in the context of designing for experience [48], and emerging HCI work has focused on leveraging taste experience to support users' communication and expression of emotions [22]. For instance, computer-aided manufacturing, such as transformative pasta [66] and laser cut foods [44] have been used to explore novel dining experiences. Food has also been integrated with text messaging printed onto edible biscuits [68]. However, such data representations printed on a food medium do not fundamentally change the eating experience, contrasting with taste-based experiences where the foodstuff is technologically mediated [22,45,64].

3D Food Printing – Designing ‘with’ and ‘around’ Food

Besides 2D images printed onto food, the encoding of information into food has also been explored through 3D food printing technology [36,50] - an application of additive manufacturing using edible materials. This technology provides the opportunity to bring together the *design-with-food* and the *design-around-food*, while creating new experiences rather than merely automating existing ones [21]. Much HCI research on 3D food printing technology could be grouped into two categories, those prioritizing form, and those prioritizing flavor.

CoDine [69] is an application that prints images with jam onto bread. The system allows users to design their own drawings or write messages for dining partners. A similar “2.5D” form-based approach can be found in *Edipulse* [35], which prints out various predefined forms in chocolate, such as graph traces or emojis, in response to physical activity data. A different form of data edibility [67] can be found in *Data Jalebi Bot* [50] that provides an edible representation of a person's CV. Each of these systems use a single flavor (chocolate [35], sugary, deep fried jalebi [50] or jam on bread [69]), creating mostly visual experiences that can be eaten, similar to edible messages [68]. These are all appealing, sugary flavors. However only in some cases does the flavor support the interaction, for example, chocolate as a reward for physical activity [35], while for others, it is unclear how the flavor supports the intended user experience.

All food-based experiences described above contain food whose primary mode of interaction is visual rather than multisensory flavor-based. In speculating on how food outputs could be crafted in HCI, *edible interfaces* were proposed as the next step to GUIs or Tangible UIs [42]. To create such interfaces researchers should exploit 3D food printing technologies, to bring together design *around* and design *with* food, combining both the exploration of food for crafting new experiences such as social bonding [17] and for data communication [35,50]. In doing so designers could better address the challenge of designing for taste-, and flavor-based experiences [47], for instance by leveraging the connection between taste and emotion [19,48], which 3D printed foods have been already shown to support in HCI contexts [22].

HCI Research on Intimate Relationships

A rich body of HCI research has focused on intimate relationships and how they can be designed for to support “awareness, expressivity, physicality, gift giving, joint action, and memories” [28]. Awareness of each other's presence and joint actions underpins the *Lover's cups* [10], a pair of augmented, Wi-Fi connected drinking cups that use light and haptic feedback for intimate communication. Gift-giving, expressivity, physicality, and memories were captured in *Lovers' box* [61], a physical-digital repository for couples that required the creation and curation of multimedia content to communicate emotional experiences. Both projects [10,61] aimed to support connectedness, within

fleeting, quotidian experiences as well as enduring ones. Another strand of work has explored emotion co-regulation, or the ability to influence partner’s emotions such as calming down when stressed, or cheering-up when sad [23]. *Lightweight, vague* and *indirect interactions* were design principles proposed to support intimacy and coregulation [51], while these three support more reflective interpersonal experiences mediated by technology [7]: *re-pattern* (creating new behaviors to change engagement), *reflect* (considering past influences on the present relationship) and *re-story* (understanding the relationship from a new perspective).

Although HCI research on the value of food in designing for intimate relationships has been less explored, we can draw a link between the concerns. For instance, flavor experience is highly multisensory [59] and influenced by mood [14], while its idiosyncratic quality allows *vagueness* in exchanges. Foods themselves can be experienced as snacks for *lightweight interactions* [38]. By providing context for other experiences, food can also create an *indirect interaction* that contrasts with direct verbal communication. In addition, food is often *given as a gift*, and is *physical*, both in terms of the food itself and its bodily experience. Finally, *joint action* occurs in shared meals or cooking together, while the smell of food is strongly associated with emotional *memories* [37].

METHOD

For this study we worked with 5 couples employing a food-based probe methodology which consisted of three stages as part of a full design cycle: (i) a *visual food probe* kit for sensitizing participants towards food-emotion practices and self-documenting them, in preparation to collaborate on (ii) the co-design of personalized flavors with each participant to be used with a 3D food printer as part of a *material food probe* kit, in (iii) an explorative study over three days in couples’ homes which examined how the probe was used, within everyday contexts (Fig 2). We note the distinction between the visual food probe as cultural probe [18], and the *material food probe* as food printer with a set of personalized flavors as a hybrid of material probes [34] and technology probes [34]. While the exploration of flavor personalization can be explored in many domains, intimate relationships were particularly suitable due to a threefold rationale. First, a wealth of findings have shown the value of food for expressing and communicating about love [43,46]. Second, practices around food and love [4] are highly embodied [9,41], and third, emotional support is provided within trusted loving relationships thus enabling exploration of food practices for emotion co-regulation [26].

Visual Food Probe Kit - Stage 1B

Inspired by design probes [18] as ambiguous [56], and open-ended interpretive methods [6], we developed a visual food probe kit for exploring the multisensory food experience of participants’ *taste worlds* [5] in order to inspire the co-design of flavors in stage 2. The kit was completed over two weeks, a duration chosen to allow the capture of a breadth of food consumption activities, while allowing time for use of, and

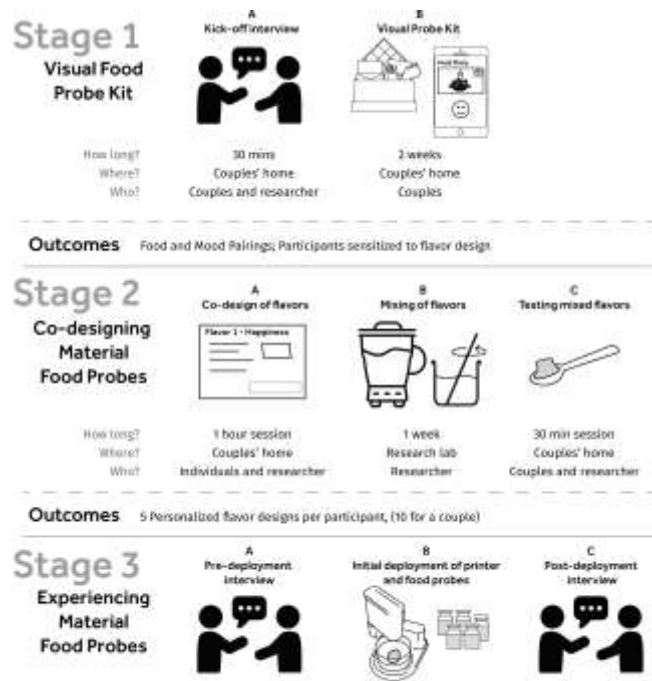


Figure 2 Overview of the three research stages, (Icons: ©Graphic Tigers and ©Adrien Coquet)

reflection on each of the kit’s component. The kit consisted of 6 probes to be used either individually or together with the intention of sensitizing participants towards the multisensory and emotional aspects of food experience. Figure 1 shows some items included in the visual probe kit; 2 sets of letter paper and envelopes to write a love letter recipe to the partner, and a recipe representing heartbreak, stimulating thinking about both positive and negative food-based emotions; a booklet to draw out the impact of a meal onto different body systems over time (Fig1.),’ sensitizing participants to the digestion of food and its impact on the body; 4 items for sensory deprivation to be used whilst eating a meal (blindfold, nose clip, earplugs, gloves) (Fig 1.), highlighting the multisensory nature of flavor experience; as well as instructions to capture the soundscape and photograph their dining context. Also part of the probe kit was an online individual food diary to further sensitize participants towards their food eating practices and their emotional aspects [13,15], individually and as a couple. The diary asked participants to photograph and briefly describe each snack or meal they ate, its source (cooked or bought, by oneself or others), social context (eating alone or with others) and associated feelings. All materials were collected at the end of the three days (1B, Fig 2) and analyzed to provide input into the co-design phase.

Flavor Co-design of the Material Food Probe – Stage 2

This stage involved an individual session with each participant to co-design 5 flavors to be used as part of the *material food probe kit*: three flavors to communicate emotions of happiness, sadness, and a neutral one such as saying “hi” to one’s partner; and two flavors designed to regulate partners’ emotions when sad or angry by cheering

them up or calming them down. We choose these purposes for the flavors based on findings showing that flavor and taste support the expression and understanding of emotional content in HCI contexts [22], that phatic communication (general purpose social communication without specific content) is important for supporting intimacy [24], and that food has been successfully used for emotional co-regulation in couples [51].

The flavor co-design sessions (stage 2A, Fig 2) started with a discussion of diary and visual probe data using visual summaries. Each flavor purpose was discussed to decide suitable flavors for each of the five purposes, and how the flavors could be re-created in the lab. To do this participants were asked to reflect on probe data, encouraged to creatively consider other flavors [22], as well as the texture of the printed food and temperature constraints. After being mixed in the lab, the designed flavors were piloted in stage 2C (Fig 2) through partners tasting each other's flavors to identify their intended purpose. Forty percent of the designed flavors were blindly identified (20/50). After disclosing the purpose of each flavor, participants ranked them on a 5-point Likert scale on their match to the intended flavor (1 – not matched at all, 5 – matched perfectly) leading to above average matching score of 3.5 (S.D. = 1.5). Then participants tried their own flavors and provided similar match rankings showing a high matching score of 3.8 (S.D. = 1.2). Feedback was provided on how each flavor match could be improved, by altering the recipe “*more coffee and less sugar would be good*” (P3, cheer-up), and its intensity: “*that is too intense, make it more dilute*” (P2, say hi). As a result, 18 out of 50 flavors were iterated in the lab before being used in participants' homes.

Material Food Probe Preliminary Study – Stage 3

This stage involved the use of the *material food probe kit* namely the 3D food printer with the 10 co-designed flavors, 5 by each couple's partner, for three days for their initial exploration in real-life settings (Fig 4). At the start and end of the preliminary study, semi-structured interviews were conducted with each couple which were audio recorded. Early interviews (Stage 3A, Fig 2), covered participant's expectations of the 3D printer regarding frequency, location and context of use. Then, each couple was introduced to the printer, shown how to use it, and given a smart phone with an app for controlling the printer and designing the shape of the printed food by drawing each droplet (Fig 3). This meant users could vary the volume of 3D printed food between 5ml and 15ml and select the type of flavor to be loaded into the printer to fit the couple's emotional or communication needs. The app was used alongside an online diary for documenting; each printed flavor, who printed it and time of printing. Participants were asked to use the material food probe kit during their daily intimate conversations or any other contexts they liked. A week later, participants took part in a final interview (3C, Fig 2) to reflect on the experience of using the material food probe kit. The study lasted three days, limited by the shelf-life of the food materials, which

participants kept refrigerated when not in use, ensuring food was safe to eat. We were cautious not to encourage false use of the printer, asking participants to engage with the printer as desired rather than on a predetermined schedule of use.

	Purpose	Co-designed Flavors
Expression	To express happiness to your partner	<u>Raspberry and blueberry</u> ; <u>Broccoli and seasoning</u> ; <u>Maltesers</u> ; <u>Meat</u> ; <u>Blueberry, strawberry and chocolate (2)</u> ; <u>Cheddar cheese (2)</u> ; Nutella; Spinach, potato and garam masala; <u>Egg and cheese</u> ; <u>Orange and cranberry</u>
	To express sadness to your partner	Mushroom; Watery tomato; <u>Burnt (2)</u> ; <u>Pastry</u> ; <u>Burnt pasta</u> ; <u>Plain pasta</u> ; Bland chili sauce; <u>Soggy bread</u> ; <u>Chocolate</u> ; <u>Sugar</u>
Regulation	To cheer-up your partner	<u>Dark chocolate and salt</u> ; <u>Strawberry and banana</u> ; <u>Salted caramel chocolate</u> ; <u>Oreo</u> ; <u>Middle Eastern spice (2)</u> ; <u>Chocolate</u> ; Tiramisu; <u>Chocolate and chai</u> ; <u>Chocolate and cream</u> ; <u>Lime Curd</u>
	To calm down your partner	Redbush tea; Water; <u>Chocolate</u> ; <u>Tomato, anchovy and olive</u> ; <u>Banana smoothie</u> ; <u>Orange</u> ; <u>Chamomile tea</u> ; <u>Breakfast tea with milk</u> ; Cream; <u>Chamomile tea</u>
Phatic	To say ‘hi’ to your partner	<u>Spicy chili sauce</u> ; Potato; <u>Tomato, anchovy and olive</u> ; <u>Salt and vinegar</u> ; <u>Zucchini and olive oil</u> ; <u>Pasta and tomato</u> ; Orange; Smoked cheese; <u>Rice and dahl</u> ; <u>Banana</u>

Table 1 Co-designed flavors by purpose, flavors used during the preliminary study (stage 3) are underlined, those used twice are marked with ‘(2)’

Participants

We recruited 5 couples (4 males and 6 females), (average age 32.5, S.D. = 4.2, range: 26-45), (6 white British, 2 non-British white and 2 of mixed ethnic background) from local communities in the UK. The couples had been in relationships for an average of 65 months (S.D. = 44.8, range 6-120) and spend an average of 47 minutes cooking and preparing food each day (S.D. = 17.7, range 15-120). All but one couple (P1, P2) lived together.

Apparatus

We decided to use nūfood (Fig 3), a commercial 3D food printer which previous research has shown to support taste-based emotional expression and understanding [22]. Unlike extrusion printers (working with solid food) which have a higher sensitivity to food viscosity, the nūfood printer can work with a wide range of flavors. Flavors were prepared by infusing in liquid, or liquidizing, the solid food identified as key for each designed flavor and removing any solid parts so that the remaining flavored liquid could be mixed with gelling agents. The printer's outputs are of gel-like texture and produced and eaten at room temperature.

FINDINGS

We report the insights from the food diary, visual probe kit, participants' co-designing and experiencing of the 3D printed food probes, and their impact on couples' emotional communication. The study involved over 10 hours of interviews with the couples, of which 4 hours 35 mins were

focused on the co-design of the flavors. All discussions were audio recorded and transcribed. Thematic analysis was undertaken using a mix of inductive and deductive coding, initially by the first author and then iteratively between authors until stability was achieved. We designated participants by number, with each pair of consecutive numbers being used for each, from, P1 and P2 for the first couple to P9 with P10 for the last couple. We used “n =” to report the total number of mentions for that reported finding.

Sensitizing Couples to their Emotional World of Food

In the stage 1 food diary, we collected 314 food experiences (Mean = 31.4, S.D. = 12, Range 17-56) with most foods being cooked and eaten with others (65.9%). Findings show that feelings associated with food experiences were predominantly positive (55%), with fewer negative (28%), and neutral (17%) ones. The rich insights gained from the probes include individual’s and partners’ favorite foods, newly crafted recipes with personally meaningful ingredients and foods associated with negative memories from past relationships.

Co-designing the Flavors for Emotional Communication

Findings indicate two broad approaches to the co-design of flavors for the purposes of expressing and regulating emotions in intimate relationships: recreating past flavors or creating new flavors. The broad exploration of these flavors has led to the identification of the 50 flavors to be 3D printed (Table 1). The first approach of recreating past flavors involves identifying a foodstuff that they or their partner have eaten, and which served one of the five target purposes to communicate or coregulate emotions. Unsurprisingly, flavors associated with happiness and cheering-up are foodstuffs that people enjoy, be they ready-made sweet snacks such as “Oreo” (P2, cheer-up) or “hazelnut chocolate [is a] happy flavor for me” (P4, happiness), or homemade food: “a nice Indian meal [...] quite hearty and filling, carbs, a warmth to it, not too spicy” (P3, happiness) or “he loves vegetarian meatballs [...] I would make that to cheer him up” (P5, cheer up). The value of known recipes (n=39) and of their ingredients (n=84) was much acknowledged for inspiring and refining the design of flavors.

An interesting outcome is that rather than being uniquely associated with memorable events [2] such as the first kiss, most of the explored flavors relate to frequently consumed everyday foods (7 flavors): “I always have the same thing at lunch for some reason, I always have granola for breakfast” (P2). These reflect participants’ habits of eating their preferred foods - both personal (n=14) and partner’s preferences (n=22) were used to support positive emotions happiness (n=9); or cheer-up (n=8). However, while the association of sweet taste to positive emotions is less surprising [22], its higher use in coregulation compared to expression of emotions is interesting, particularly in snack form. Indeed, participants selected snacks with a sweet taste (n=8) and chocolate flavor (n=6) for cheering their partner up, while the expression of one’s happiness was made not



Figure 3 nūfood printer and app showing design interface

only through sweet taste (n=5) and chocolate (n=3) but also through fruits and vegetables (n=3): “Yeah, I do love tomatoes, [they] are very important to me” (P5, happiness). These findings confirm previous ones on the value of such flavors for creating meaningful interactions [22], and extend them to lightweight interactions such as snacks.

Another important outcome is the limited use of carbohydrate-based food for coregulation, despite their acknowledged value as comfort food [30]. Even more interesting is the association of such food with sadness, albeit due to inadequate preparation: “tomato juice seeps into the bread and becomes very soggy over time [...] moldy pitta bread” (P5, sadness) or “white bread, soggy, without even the sides of the bread, super bland, nothing, like chewing on air” (P3, sadness). Other ways to communicate sadness were through a diluted version of preferred flavors: “I remember when I had a flight recently [a] really watery tomato soup, that was low in flavor and a really feint taste [...] it was really bad, that made me sad” (P5, sadness). In regard to the coregulation of negative intense feelings a significant outcome is the predominant use of drinks (n = 7) for helping partners to calm down; be those hot, such as tea (n = 4): “not that much milk [in the tea] just a hint of milk and no sugar” (P3, calm-down); or cold, such as fruit smoothies or even water (n = 2). Even when meals are suggested for this purpose, their less solid quality is emphasized: “curry, like a creamy coriander masala type thing” (P6, calm-down).

These outcomes suggest the specific value of *comfort beverages* for co-regulating high arousal negative emotions, in the context of their broader role in emotion regulation [62,63,71]. Findings indicate that the phatic communication has been associated with more diverse flavors, including favorite mundane ones, which are highly likely to elicit positive emotions. This suggests that in intimate relationships, even phatic communication is likely to be loaded with emotional undertones. If the flavors described before reflect individual preferences and partners’ intimate knowledge of each other’s favorite foods, and even consideration of their misalignment: “tomato is more something that I like, not that he doesn’t like it but seems a bit selfish to put tomato” (P5), other flavors are those that both partners enjoy together or couple’s preferred flavors: “anchovy, that is something that we both love” (P2) also



Figure 4 Designed flavor part of Material Food Probes

supported by his partner: *“he would definitely be like ‘yeah, that is a positive thing’, it is something we share together”* (P1). Couple’s favorite foods are also shared in everyday contexts, often in the form of rituals, either to support calming down: *“I think it would be something familiar [anchovy] for both of us, would calm us down a bit”* (P2), or for communicating happiness: *definitely I can put pancake; it is a ritual”* (P8).

If the above findings present the approach to the co-design by recreating specific flavors experienced in the past, we now discuss the second approach of creating new flavors for the purposes of expressing and regulating emotions. Findings show that almost one third of flavors (17 out of 50) consisted of such *newly created flavors*, most of them to communicate sadness (n = 6) and for phatic communication (n = 4), and fewer to calm down (n = 3), communicate happiness (n = 3) or cheer up (n = 2). In order to express sadness, participants engaged with the generic taste of burnt food: *“so what can I put here? burning? Sadness. Maybe some burnt thing? [...] let’s put burnt if I didn’t like, that is okay. [...] Burnt plus plain”* (P8). This outcome extends the link between negative emotions and bitter taste [14]; rather than raw bitter tastes, participants use burnt food to create a bitterness [13] and elicit the emotion of sadness.

Another way to express sadness is through lack of flavor which has not been experienced but imagined: *“lack of flavor [means sadness] [...] I think of sadness as a lack of arousal rather than high chili [which] would be a very strong emotion [so] watered down anything is a great idea”* (P4, sadness). This creative search for the best flavor is the hallmark of this approach, which often involves combining flavors in new ways: *“happiness for [my partner] is having something really sweet [...] I think very sweet chocolate as well as [...] nice chai taste, a sense of home and comfort [...] the treat chocolate is a pick me up [...] sweet chocolate and chai, quite hot with different spices”* (P3, cheer-up). They can also combine specific texture and odor in original flavors: *“something really quite moist, almost like if it was a bit lavender-y like edible water pods [27] you bite into it [and it] exploded in your mouth like cooling”* (P1, calm-down). Importantly, these outcomes indicate that beyond recreating existing flavors, almost one in three flavors were openly and creatively explored by combining flavors characteristics in unexpected ways. This approach was not only useful to creatively generate difficult flavors like the ones

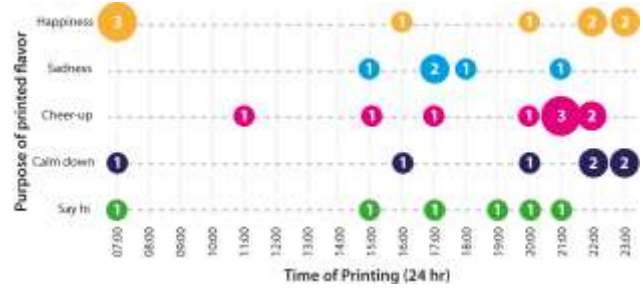


Figure 5 Frequencies of 3D printed food probes by time of day

communicating sadness which conflict with the sensorial pleasure elicited by food, but also to materialize imagined positive experiences of food leveraging preferred qualities beyond taste. This opens up an interesting design space of 3D food printing for such novel experiences difficult to otherwise access.

Interacting with the Material Food Probe Kit

Overall Experience

The overall experience of the material food probe kit during the three-day preliminary study in participants’ homes was perceived as highly creative, playful and enjoyable. An important quality of this experience was the creative experimentation mentioned by 5 participants as shown in this illustrative quote: *“It just seemed to be a really simple and easy tool to use, and fun to play with to create what we wanted”* (P7). Findings also indicate that although all couples engaged in experimentation, this was particularly enjoyed by three participants with an interest in tinkering (P1, P5, P8): *“I just like the process of making stuff that was what I really enjoyed [because] I am a making type person”* (P1). This finding indicates surprising making qualities of the 3D printer use, which appears to integrate hedonic qualities of DIY such as watching the 3D printer and trying to understand its workings [57], with cooking practices [39] such as “preparing” ingredients. P8 describes how this differed within the couple: *“I stayed around because I wanted to see if it was still working and which shape I would have out of it. [My partner] was more like: launch it and just come back when it is done.”* A key part of this experimental engagement with the material food probe kit was the creativity enabled by opportunity to mix different flavors, *“[It was] enjoyable to create a unique taste, because we [could] actually mix taste with it. The creation, the creativity [were] enjoyable for me”* (P8). One participant highlighted how open exploration could be generative: *“we can easily picture that we can try to make more fancy things [...] mixing the [flavors from the two tanks in the printer to make] different tastes”* (P8). Although a future possibility, the printer’s functionality during the study did not allow the mixing of flavors.

Patterns of Use

During the three-day preliminary study, 37 separate uses were recorded with 7.4 average uses per couple (S.D. = 2.9, range 5-11). Logged data indicates the probes were printed mostly in the evenings from 7 pm to 11pm (49%), and also

in the afternoons from 3pm to 7 pm (35%, all during weekends) with fewer uses on weekday mornings (13.5%) including no printing before 7am (Fig 5). Interviews also indicate participants' attempts to integrate the 3D printer in their daily routines, with the most frequent use around the evening meal as part of, or following, the couples' end of day ritual: "we were mainly using it at the end of the day, as a reflection. I think in the weekends we did in the afternoon [3pm], sometimes the morning [11am] and we will chat" (P3, P4). While attempts have been made to use the printer at breakfast time "I could do that lime curd on toast in the morning. Yeah, that might be quite nice." (P9) few such uses occurred as "breakfast was a rushed time of day, trying to get everyone out the house, [using] it was definitely an evening thing." (P10).

The printer logs indicate an interesting distinction between isolated (10 times) and sequential use (27 times) of the printer, where participants took turns in printing. Although sequential use may be due to participants' desire to sample as many probes during the three-day study, it still offers an interesting view into how such exchanges become orchestrated. One such orchestration is for emotional expression and coregulation as shown in the following sequence between P1 and P2: P2 expressed sadness (pastry), followed by calm down (tomato, anchovy and olive) to which P1 replied by printing cheer up flavor (Salted caramel chocolate), and concluded with the greeting flavor (tomato, anchovy and olive). The repeated flavor of tomato, anchovy and olive was previously highlighted as a mutually enjoyed recipe. The other orchestration is participants' taking turns to print different probes to express happiness, upregulate (cheer up), or both. This is an important finding suggesting a flavor-based dialogue which may lead, or be led by people's emotional responses in the moment, and the possible cumulative effect that a diverse succession of flavors may have for increasing the expressiveness of partners' nonverbal communication.

3D Printed Flavors: Broader Support for Intimacy

The 3D printed food probes appear to broadly support intimacy through expressivity, physicality, joint action and gift giving, four of the six strategies identified as key in supporting technology mediated connectedness between loved ones [28]. Less supported were *memories* related to 3D food probes and *awareness* since for all interactions with the printer participants were collocated; however envisaged scenarios of remote use were mentioned, which future work could further explore. *Expressivity* consisting of mediated opportunities for diverse expression of emotions [28] and was the most emphasized strategy in our findings. This is reflected in the diversity of personalized flavors as part of the material food probe kit and their ability to enable non-verbal, flavor-based emotional communication: "I think it was nice to have a flavor [during our conversations] to try and express a feeling. And I think [the flavors] fit [with the emotions] as well [...] it was useful to have a flavor to try and communicate an emotion" (P3). As this quote indicates,

expressivity of 3D printed food probes contributes to verbal communication through novel and intuitive ways to express the richness of, and as shown below, the tacit aspect of emotional experiences: "I was like 'How are you feeling right now?' and we were like we should probably go [use the printer] to print off how we are feeling as opposed to actually talking to each other about it [...] like non-verbal communication [to] portray an emotion that we weren't actually saying out loud. [It was] very good in terms of being more open" (P2). This non-verbal usage offers a lightweight and indirect method to express the negative experience of the day, echoing qualities previously identified as supporting intimate interactions [51]. The personalized quality of the probes also offer potential for an exclusive flavor-based language between the couple. Participants also suggested how shapes or texture could further support expressivity: "I think if you were able to print shapes that were more evocative of different emotions as well [that would be good]" (P6); "like a heart shape" (P7).

Findings indicate support for *physicality* which consists of mediated physical intimacy [28]. This was supported through the embodied quality of the food probes as they got shared and eaten, however not for nourishment purposes: "not to make stuff when I am hungry" (P6) but experiential ones through delightful bite-sized treats or a relaxing mouthful of drink: "maybe the way to use it will be to create something different but in small quantities, like an amuse-bouche more than a big meal" (P8). We have also seen indications of *joint action* [28] through participants' engagement in collaborative use of the printer and sharing of food probes: "we use it together most of the time, we took turns with choosing a flavor that the other person had designed" (P3), often as part of dining experiences: "after dinner we sit down and use it together" (P5). Not least, personalized flavors can be *gifted* [27] as acts of labor and care via their preparation to help one's partner cheer up or calm down: "It is a nice way of doing something for [my partner] because it is set-up for you. It has told you what that connection is" (P6).

Specific Support for Emotional Communication

We now discuss the specific impact of the material food probe kit on the emotional communication within couples. Findings show that half of printed probes were to either cheer one's partner up (n=9), or to express happiness (n=9), followed by calming one's partner down (n=7), saying "hi" (n=7) and expressing sadness (n=5). This outcome suggests a strong preference for emotionally positive flavors (50%) with limited use of negative or neutral ones (both 19%).

Coregulating Emotions

Cheering up was the most common reason for using the printer, with 8 of 10 such printed flavors being chocolate-based. It is unsurprising to find a strong preference for chocolate, a typical comfort food known to induce pleasure [13] was effective in enhancing participants' mood: "I would say it did connect [with how I was feeling], one time I was feeling down, and we were like let's print the chocolate one

[dark chocolate and salt]” (P5, cheer-up). Opportunities to print cheer-up flavors were often provided as part of dining experiences, with 6 out of 9 flavors being printed between 8pm and 11pm: “*we want to be full first, and then we use the printer [for] a dessert [chocolate]*” (P7, cheer up), to which the partner added: “*maybe we can have a taste of chocolate or we just talked about our days [and] I think we did [print more] sweeter than savory, because we used it as a dessert related to the emotion*” (P8). This quote is particularly interesting as it illustrates an additional value of cheer-up flavors, to be used *instead of dessert*, which given their bite-size form, may regulate sweet food intake.

In contrast to the printed cheer up flavors, calming down ones were diverse, and predominantly drinks such as juices (2) and tea (3). While cheer up flavors are used mostly during the dinner, calming ones tend to be used after as part of the end of day ritual, most likely before going to sleep, with 4 of 7 such flavors printed after 10pm: “*we were mainly using it [chamomile tea] at the end of the day for a reflection on the day*”(P4, calm down), a flavor which in the design stage was anticipated as helping distress: “*it will be good to have opportunities to use them when you are [...] getting frustrated*”. An interesting quote illustrating the actual tasting of tea flavors designed for calming down indicates embodied experience: “*quite bitter, like sour, my mouth is watering but not very strong flavor*” (P5 tasting P6’s Redbush tea flavor). An important outcome is the use of herbs such as chamomile known for their beneficial impact on mild or moderate anxiety [1]. The following quote illustrates how calming down and cheering up flavors can be printed in sequence: “*he was going through a lot at work, so I was printing him the nice ones [tomato, anchovy and olive to help] calm down, and [then to] cheer him up [salted caramel]*” (P1). P2’s experience of pastry is particularly evocative of the embodied qualities of the material food probes: “*that just tastes like flour, so dry as well, it has really dried my mouth out as well, sadness, that is horrific*” (P2).

Expressing Emotions

We now describe the use of material food probes intended to express emotions. The printed flavors communicating happiness were the most diverse, from sweet, fruit-based ones to dairy flavors, umami flavors and vegetable flavors. Unlike other probe flavors, happiness ones were printed throughout the day, (7am to 11pm). Arguably some of the specific textures of foodstuff inspiring flavors designed for the happiness probes made it challenging to “translate” them into gel-like bites while preserving their experiential qualities. Findings indicate the 3D printer’s texture limitation, and how a happiness flavor became less appealing: “*[making Nutella] with the printer into this gelatinous thing [...] made it less appealing*” (P3).

The printed flavors for expressing sadness were more homogenous including burnt or bland foods (3) and were mostly printed between 5pm and 7pm (3 out of 5), as participants got home and discussed their days. Indeed,

participants’ challenge to design flavors for negative emotions: “*that stuff will taste really bad*” (P5), was mirrored by their reduced desire to consume them: “*the ones used least were the burnt and pastry [expressing sadness], [we] printed with it but neither of us tried it because we knew it was disgusting*” (P1), or “*pasta burnt, burnt bread. I think we didn’t use it at all*” (P8). There was also skepticism about the intention to create food for negative emotions compared to positive ones, “*[the thought that] if he cooks something I hate, he must hate me. I don’t think I’ve ever thought that there’s negative connotations to what you cook. I think just spot the positive connotations and that’s really sweet*” (P9). Flavors for *phatic communication* were printed throughout the day, similar to happiness ones, albeit within a reduced window from 7am to 9pm. These probes were again diverse including both preferred flavors (3) as well as mundane ones (6). This means that the former could have been used for other purposes such as calming down, like in the case of tomato, anchovy and olive (P1), or were rather mundane, and less exciting to use: “*I don’t know if the middle ground ones [neutral: saying hello] would be used as much*” (P1).

DISCUSSION

In the light of our outcomes, we now reflect on the initial research questions.

Designing Emotionally Positive Flavors

The first question focuses on what specific personalized flavors people co-design for the purpose of emotional communication. While previous work has explored food as a visual medium on which informal messages can be printed [35,50,68,69], our findings contribute to the less explored research space [22] where food itself can be 3D printed. Key insights from our study emphasize the recreation of flavors related to positive emotions informed by individual and couple preferences as well as everyday food sharing practices, with a strong preference for sweet treats for cheering up, and drink flavors for calming down. Previous work has looked into comfort food and sweets as a medium of communication [35,50,68], albeit not for supporting intimacy in terms of the type of 3D printed foods that could regulate emotions. Our participants also created new flavors for the more challenging to express, negative or neutral emotions; in part explored through burning or diluting preferred flavors. However, given participants’ limited appetite for less appealing flavors, we argue that there is more value in exploring positive flavors, both those that are familiar and those that are creatively imagined to surprise, delight, and improve both one’s own and partner’s mood [15] by cheering up or calming down. Thus, the identified creative approach to designing flavors from scratch, can open up design opportunities for emotionally positive flavors. Here we can think of flavors for coregulation such as “*chocolate and chai*” for cheering up, or “*lavender-y like edible water pod*” for calming down. For the former, we can imagine innovative caffeine-based flavors leveraging preferred tea, chocolate or even spice flavors as *pick me up* stimulating bite-sized treats. For the second, we can think of

nervine herb-infused flavors [1] such as lavender, chamomile or lemon balm as a *calm me down* relaxing mouthful. Both nervine herbs [1] and comfort beverages [71] have been shown to be beneficial for down regulating arousal in mild or moderate anxiety.

Our outcomes also advance the edible interface research [42,64] by highlighting the distinction between idiosyncratic and more generic types of flavors. Indeed, while those for cheering up and expressing sadness tend to be consistent among participants, i.e., sweet or burnt and plain, those communicating happiness, saying hi, and calming down are more idiosyncratic. This in turn suggests stronger benefits from personalizing flavors which can take two forms. First, research on HCI design around food should be responsive and considerate to the range of food being eaten whilst the ‘around food’ interaction takes place, considering how favorite foods could align with the content being delivering through the digital experience. Second, HCI research with food could benefit from personalization and combination of flavors, moving away from single flavors predominantly used in previous work [21,42,59]. Moreover, flavors can be designed both to recreate previous experiences, and also crafted from scratch for novel experiences beyond emotional communication, for instance for creating food-based memory cues for older adults.

Integration of 3D Printed Flavors in Focal Intimacy Practices

We now turn to the question regarding how people engage with and use in-situ, the flavor-based probes, while being mindful of the reduced duration of our preliminary study, and therefore on the claims that our findings support. Although much HCI research has explored connectedness in intimate relationships [28] the emphasis has been mostly on remote awareness and presence, mostly through visual or multimedia interfaces [61]. Thus, our focus on flavor as an interface for supporting collocated intimacy is particularly novel, allowing us to understand the value that material food probes or printed flavor may take in two important intimacy rituals where they have been mostly used: the end of day, and the evening meal. To further reflect on our findings, we frame these two rituals as *focal intimacy practices*. Here we build on Borgmann’s [7] conceptualization of *focal practices*: essential for connecting people to what matters most or their “significant realities”. Focal practices such as hands-on ones of cooking, gardening, or exercising, or those of connecting, such as family meals, require attention, commitment and skills; they are also at risk of becoming increasingly unfocused or fragmented [29] through the distraction of technology [8].

Our findings however indicate a more nuanced view, as the 3D printed flavors used by participants in their homes, not only did not disrupt couples’ patterns of interaction but augmented them in subtle new ways. For the end of day rituals taking place after people arrive home in order to share and reflect on their daily experiences, findings suggest a strong emphasis on the need for calming down, often after

expressing negative feelings such as sadness or stress. Here we have seen the most often use of drink related flavors based on herbs or fruits. While some resembled the traditional cup of tea, others were creatively designed with great care and skill such as the *lavender-y water pod* offering only a mouthful of precious drink to be mindfully enjoyed. Although embodied experiences in the context of intimacy have been previously described, supporting for instance remotely drinking together [10], the drink itself has not been technologically mediated. We argue that technologically mediated food experiences such as those enabled by our co-designed 3D printed flavors can open up novel design opportunities. The evening meal ritual usually starts after the end of day ritual with people preparing and sharing the meal. The 3D printed flavors most often used in this context were those for cheering up, which contributed to the meal in an interesting way: not by adding to, but by replacing the dessert course, through chocolate-based flavors, which may offer the additional benefit of regulating sweet intake through their limited size. This ritual can also continue later in the evening when people printed more idiosyncratic flavors expressing happiness.

Experiencing and Crafting Emotionally Positive Flavors for Coregulation

The third research question focused on how the 3D printed food probes can support intimacy. Findings indicate that through their qualities, the 3D printed flavors support intimacy in two important ways. The first is more broad through expressivity, physicality, joint action and intentions of gift giving [28], while the second one is more specific through the probes’ direct support for emotional coregulation. The preference for positive flavors from the co-design became even stronger while experiencing the printed flavors in situ. Initial findings also suggest higher use of probes for emotional regulation compared to emotional expression, as arguably the former not only builds on the latter but supports increased connectedness. Moreover, the pleasure of exploring the flavors and their right combination, as well as the anticipated delight of their partner experiencing them, not only strengthens the craft quality of the practice around the 3D printed flavors, but also contributes to couple’s emotional communication. Although couples often engage in affectionate exchanges mediated by food such as cooking a dinner or making a cup of tea, these tend to be either laborious like the former or immediate like the latter. We argue that 3D material food probes allow both; 3D printed food as *immediate* tokens of affection through lovingly and *laboriously* crafted flavors. The approach of decoupling the design and the delivery of the flavors is key for enabling such meaningfully rich, personalized exchanges responding to partners’ emotional needs at the present moment. We argue that there is potential for novel intimate experiences mediated by material food probes to be not only lovingly crafted for personal meaning but also lightweight communications tools [51] through their quick and easy delivery as needed in the moment. More can be understood

around how the use of the 3D printer remakes such meaning, and about the values expressed via food. By crafting the flavors themselves users reframe the interaction into one which better represents the value a loved one's effort.

Material Food Probes

We now discuss our approach to the exploration of food mediated intimacy through what we call *material food probes*, which we define as consisting of 3D food printer and co-designed flavors, allowing the exploration of food's material properties for the specific purpose of inspiring novel design. This concept bears similarities with both material probes [34] and technological probes [32] much used in HCI. Technology probes [32] are open ended digital artifacts with a single, simple functionality, deployed in situ, early in the design cycle, not to be evaluated but to inspire the design of future technologies. Material probes [34] on the other hand, enable the exploration of the physical artifacts' material properties such color, shape or texture and how these may support specific functions that could then inspire design of digital artifacts. The co-designed flavors within material food probes are excellent illustrations of less explored material probes, namely those focusing on flavor-based material properties such as taste, texture or color, which in our study were explored for the specific purpose of supporting emotional communication. This extends previous findings on food experiences in HCI relying on just one modality [35,48,50,65] towards multisensory experiences that material food probes can inspire. Material food probes also resemble qualities of technology probes as they are materialized through participants' in-situ interaction with the 3D printer, its app, and the personalized co-designed flavors, mixed and ready to print. Thus, the functionality of the 3D printer is simple, yet the 3D printed flavors carry strong personal meaning and are open for users' interpretation.

Preliminary outcomes also indicate important qualities of the material food probes shared with both the craft and DIY practices, facilitated by the decoupling of the flavors' earlier co-design in the lab, from their printing in situ. While, the co-design of flavors - through the creative, enjoyable and playful exploration of personally meaningful flavors [2] - resembles many qualities of crafts practice [8,52], it also echoes design *around* food through the crafting of new social experiences [3,11,17]. Independently, the printing of flavors resembles qualities of DIY practice [57,60], through the "assembling" the flavor probes and the 3D printer "components", getting them to work together through the printer app, which carried forward the enjoyable and playful exploration [8] from the co-design stage. However, it is now enriched with the experiential qualities enabled by the shared consumption of 3D printed food probes. The printing of flavors is similar to design *with* food research [22,45,64] albeit extended towards richer multisensory experiences that integrate the benefits of design-*around*, with the personalized flavors for emotional communication. Also related to DIY practice, the value of personal labor invested in the making of complex electronics has been shown to shift

their status from unremarkable objects to things of significance ensuring attachment and long term adoption [55]. Through creative appropriation [53], the craft quality of the designed flavors may offer similar benefits that future work could unpack. As 3D printed flavors become integrated in couples' focal intimacy practices [7] they may also gain the status of *focal things*, authentically contributing to these focal practices which in turn may foster strong long term engagement.

Bodily-actuated Emotional Regulation through Food

Given the potential of material food probes for emotional regulation, which emerging affective interfaces also support [57], we could also explore integrating together such technologies. For instance, we can think of novel interfaces for remotely actuating the 3D printer based on tracked changes in user's emotional arousal. This would allow one's bodily emotional responses to directly drive the 3D printing of flavors. By complementing the current tentative interaction [58] described in our work, the affective interface would ensure a hybrid interaction with the printer that integrates both automatic and active printing of emotionally adaptive flavors. Future work should consider how to balance immediate responsive contexts, tailored towards sweet treats, with the long-term maintenance of physical and emotional wellbeing, if food is to further support the emerging interest in emotional regulation in HCI [40].

CONCLUSION

This study introduced a novel *material food probe* design method to uncover opportunities for both design-with, and design-around food in the context of intimate relationships. We reported on the design of personalized flavors for expression and coregulation, highlighting how they drew from both remembered flavor experiences and new ones creatively generated. These flavors, and the experiences of engaging with them, were explored through a three-day preliminary study in couples' homes, where they became integrated into everyday intimacy rituals. Our findings open up design opportunities for novel food-based interactions via the further development of *material food probes* including bodily-actuated emotional regulation through food.

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