HeatCraft: Designing Playful Experiences with Ingestible Sensors via Localized Thermal Stimuli

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ABSTRACT

Ingestible sensors are pill-like sensors that people swallow mainly for medical purposes. We propose that ingestible sensors also offer unique opportunities to facilitate intriguing bodily experiences in a playful manner. To explore this, we present "HeatCraft", a two-player system that translates the user's body temperature measured by an ingestible sensor to localized thermal stimuli delivered through a waist belt equipped with heating pads. We conducted a study with 16 participants. The study revealed three design themes (Integration of body and technology, Integration of internal body and outside world, and Integration of play and life) along with some open challenges. In summary, this work contributes knowledge to the future design of playful experiences with ingestible sensors.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing design**; *Interaction design*;

KEYWORDS

Ingestible sensors, body temperature, play, localized sensation, thermal stimuli

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1 INTRODUCTION

Ingestible sensors are devices that perform sensing or actuating functions inside the user's body [11]. They have been used for medical purposes such as endoscopy, patient monitoring, and medical adherence assistance [3, 11, 29, 30]. We believe there is an opportunity to explore the experiential aspects of ingestible sensors since recent studies suggest that health professionals should consider their patients' lived experience in addition to the treatment [37, 62]. Studies in human-computer interaction also highlight that appreciating the technology's experiential aspects may help users deepen their understanding and engagement with their own bodies [45, 61].

We believe designing playful experiences with ingestible sensors could highlight the experiential aspects of ingestible sensors and help attain the full potential that the devices can afford [19]. Moreover, playfulness could add a positive feature to ingestible sensors that goes beyond entertainment by making the user experience more engaging [36]. For example, a game around an ingestible sensor for medical adherence monitoring might further promote the device's efficiency [13]. Furthermore, adding playfulness to ingestible sensors could let players engage with their own bodies and experience their body as play [46]. Such experiences also allow players to attain new levels of bodily mastery which is important for human development [7].

Meanwhile, ingestible sensors' characteristics could extend the possibility of play. Firstly, playing with ingestible sensors may bring about unique experiences because the play duration depends on players' bodily functions which cannot be determined by players in the traditional sense via "removing" the pill. Secondly, ingestible sensors may facilitate an *always-available* play since the devices always move with the users [24]. Thirdly, ingestible sensors might facilitate ubiquitous playful experiences by turning the user's daily activities into game actions since a variety of actions such as eating and exercising could influence the bodily information collected by ingestible sensors. In light of the above, we believe it is worth exploring the potential of ingestible sensors to facilitate playful experiences.

We present *HeatCraft*, a two-player system that generates localized thermal stimuli where the intensity is based

on the user's body temperature measured by an ingestible sensor. An in-the-wild study [54] with 16 participants was conducted to understand the associated user experience. The results showed that the overall experience was intriguing and playful. Our system increased players' awareness about their body, their daily activities, and the environment. Ultimately, *HeatCraft* stepped towards the integration of play and life. Based on the user experience and our design, we propose eight strategies which can serve as a starting point for designing playful experiences around ingestible sensors. The primary contribution of our paper is that we explore the possibility of combining ingestible sensors with localized sensations to facilitate playful experiences. Additionally, we articulate design themes and strategies to guide the future design of playful experiences with ingestible sensors. More broadly, we open up new possibilities of facilitating the integration of body and technology to blur the boundary between play and life.

2 RELATED WORK

Recently, ingestible sensors have been used by artists to challenge the body's traditional roles [58]. The artist Stelarc swallowed a self-built capsule containing a beeping device and flashing light to turn his hollow body into a space for exhibiting "sculptures" [4]. Similarly, Jan Poope designed an audio pill which allows the user to experience the music from the inside [53]. These works suggest that there could be a design space worth exploring around the ingestible sensors' experiential aspects.

To design the technology's experiential aspects, there is a trend in HCI that embraces the *first-person perspective* which means placing the user's lived experience at the center of the design process [25]. In body-centric design, this perspective emphasizes the users' *lived body* which means the body through which the users live their lives and experience the world rather than treating the body as an object (the *third-person perspective*) [41]. Similarly, Dourish [14] proposed the concept embodied interactions which emphasizes the importance of the physical and bodily aspects of interactions. Svanæs [59] suggested interaction designers design for the *lived body* since it offers new angles to approach design challenges and enables new design alternatives [59]. When it comes to play, Mueller et al. [46] used the German words *Leib* and *Körper* to represent the first- and the third-person perspective, and proposed that looking at the body through these two perspectives lets players not only use the body to control a game, but rather experience their body as play. In summary, designers may take a *first-person perspective* when designing playful experiences around ingestible sensors.

Meanwhile, ingestible sensors are always inside the human body and therefore may continually offer interaction experiences [38]. A prior study indicated that interactions related to *always-available* body-integrated technology could facilitate a symbiotic relationship between the human and the device, and even extend the human body [32, 57]. When it comes to play, Li et al. [33, 34] designed a smartphone-based game, supporting two players playing against each other by changing their body temperature measured by an ingestible sensor. However, the use of a smartphone forces players to stop any current task they are undertaking as part of their everyday life to play the game. Thus, the game does not highlight the fact that ingestible sensors support continuous play.

We believe localized sensations can be used as feedback when playing with ingestible sensors. Localized sensations "mainly occur through touch, pain, proprioception, kinesthetic sensations and temperature perception" [56] and do not need the user's full attention. Therefore, such sensations may support *always-available* play [52]. Moreover, localized sensations have been widely used to facilitate lived body experiences since such sensations allow us to experience our body as ours rather than an object [46, 56]. For example, Schiphorst [55] developed an interactive tangible art installation *Soft(n)* using touch sensations to create a *lived body* experience. Byrne et al. [10] developed the game *Balance Ninja* that utilizes localized sensations of the vestibular sense to support players experiencing their body as play.

In light of the above, we acknowledge the opportunity of designing playful experiences around ingestible sensors. Designers may benefit from taking the *first-person* perspective and support *always-available* interactions in ingestible play. Meanwhile, localized sensations are *always-available* and may support *lived body* experiences. Therefore, this work explores the design of playful experiences around ingestible sensors via localized thermal stimuli.

3 HEATCRAFT

HeatCraft is a two-player system supporting users to experience their body temperature measured by an ingestible sensor via localized thermal stimuli. The system comprises a Cortemp sensor and a waist belt (see Fig 1b) which attaches an Elite receiver, an Arduino UNO, an XBee module, a MOSFET, a digital temperature sensor, two overlapping heating pads, a buzzer, and a switch for the buzzer. The Cortemp sensor [1] (Fig 1a) is a disposable sensor that measures the user's body temperature (T_B) once every 10 sec as it travels through the digestive tract within about 24-36 hours. The Elite receiver receives temperature data from the Cortemp sensor and sends it to the Arduino via XBee (see Fig 2a). If T_B is erroneous, the buzzer beeps. Otherwise, the Arduino calculates the temperature of thermal stimuli T_{HP}.

[1] http://www.hqinc.net/cortemp-sensor-2/.

(a) (b)

Figure 1: (a) A player is holding the Cortem sensor; (b) The two players are wearing the waist belt and running to change their body temperature.

If 36.2 °C $\leq T_B \leq$ 37.8 °C, $T_{HP} = -12.5 \cdot T_B + 500.5$. Otherwise, T_{HP} = 50 °C. The thermal stimuli is generated by the heating pads and adjusted by the Arduino and MOSFET via PID control. The digital temperature sensor measures T_{HP} and transmits it to the Arduino as the feedback in the PID control loop. The PID parameters were adjusted manually.

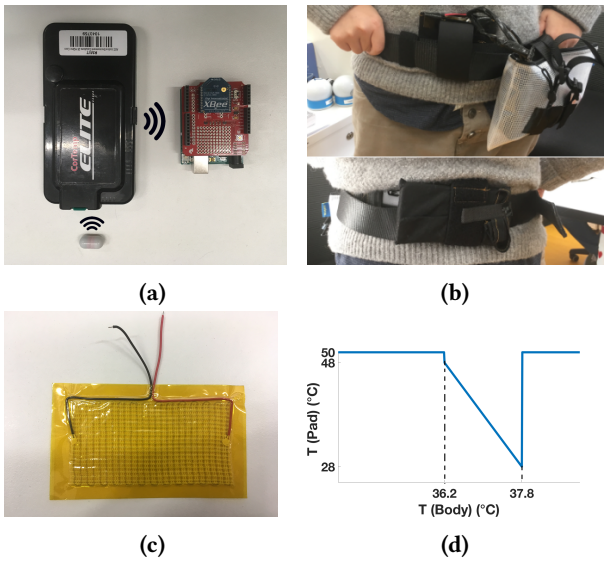
HeatCraft adopts open-ended gameplay. Players can freely explore how their actions affect their body temperature. They can also design specific rules around the system. For example, when the two players are physically together, they might agree that within the next hour, they must take various actions to change their body temperature. If they try an activity that does not change the temperature of the heating pads, they would be punished by the co-player.

4 DESIGN RATIONALE

In this section, we discuss four key design decisions and the rationale behind them.

Using Heat Sensations as Feedback

Section 2 introduced the opportunity of using localized sensations as feedback of playful ingestible systems. In *HeatCraft*, we chose the thermal stimuli as system feedback for five reasons. Firstly, it is intuitive for players to understand their body temperature via heat sensations. Secondly, the subtle heat can be used in everyday scenarios without the user's full attention [27], contributing to *always-available* play. Thirdly, thermal stimuli could bring about pleasant experiences since it can evoke the user's emotional response [63]. Fourthly, localized thermal stimuli could increase one's bodily awareness [26, 27], which may help users better manage their body [47] and increase body intelligence, leading to a healthy and vibrant life [21]. Lastly, the subtle and cosy heat gives space for players to reflect on their bodily experiences and turns their attention inwards, which positively influences their emotions and wellbeing [12]. We chose to locate the thermal stimuli on the player's waist because this allows



(a) (b) (c) (d)

Figure 2: (a) The Elite receiver receives the signal from a Cortemp sensor and transmits the temperature data to Arduino via XBee; (b) The anterio-posterior view of the waist belt; (c) The heating pad is made of flexible conductive yarn; (d) The mapping between the player's body temperature T_B and the heating pads temperature T_{HP}.

unobtrusive and unhindered body movement [22]. Also, the thermal sensation on the waist can strongly influence overall body sensations [2].

Mapping Body Temperature to Thermal Stimuli

We designed the mapping between the player's body temperature (T_B) and the thermal stimuli's temperature (T_{HP}) as shown in Fig 2d based on an autobiographical study [51] and prior works [15, 40, 44]. The rationale is as follows. Firstly, for safety and comfort reasons, we limited the stimuli's temperature to 50 °C. Secondly, to ensure the players could sense the thermal stimuli, T_{HP} must be significantly higher than the room temperature. We chose the lowest of T_{HP} as 28 °C. Thirdly, the inverse correlation between T_B and T_{HP} could bring about pleasant sensory experiences since one would feel pleased with the intense thermal stimuli when he/she is cold and vice versa [44]. Fourthly, this mapping can make players aware of their body temperature changes when T_B is within the normal range between 36.2 °C and 37.8 °C as shown in a prior medical study on 85 participants while reminding them when T_B is extremely low/high. Fifthly, with this mapping, when T_B changes 0.1 °C, T_{HP} is set to change 1.25 °C which can be sensed by the player. Based on our personal experiences, it takes at minimum 10 sec for the player to change T_B for 0.1 °C while it takes less than 2.3 sec for the

system to change T_{HP} for 1.25 °C. Thus, there is sufficient time for the system to adjust T_{HP}.

We do not see the designed mapping as a perfect way to represent the player's body temperature, but rather the outcome of benefit balance since the mechanism of how human body temperature changes and how we perceive thermal stimuli are complicated. For example, prior work [34] with 14 participants suggested that the temperature data measured by the Cortemp sensor ranged between 25.64 °C and 43.9 °C when the sensor was inside the user's stomach since the food and drink the user ingests might make contact with the sensor and significantly change the measured data. When the sensor entered intestines, the data ranged between 35.64 °C and 39.11 °C. Therefore, our designed heat pattern allows players to notice body temperature changes in most times but may miss some changes (e.g., from 39 °C to 40 °C).

Designing for Erroneous Data

We designed a buzzer to beep while kept the heating pads temperature invariant when the system received an erroneous body temperature data ($\leq$ 22 °C or $\geq$ 45 °C [34]). Such design has three benefits. Firstly, this design allows players to be notified by the beep and not get confused when the player's action and the system feedback do not match as the system receives erroneous data. Secondly, as the system may receive erroneous data since the quality of data transmission is susceptible to electromagnetic interference [5, 9], the beeps could also help players get to know more about their surrounding environment. Thirdly, the Elite would send out random erroneous data when the Cortemp sensor is excreted. Therefore, a player would know he/she has excreted the sensor if the buzzer beeps once every 10 sec regardless of the player's location. Moreover, erroneous data between 22 °C and 45 °C rarely happens and would not cause a dramatic change in the heating pads temperature as heat changes slowly.

Designing the Playful Experiences

We believe *HeatCraft* is intrinsically playful. Based on the PLEX model [36] that proposed 22 categories of playful experiences, the localized thermal stimuli could bring about playful sensory experiences while swallowing a digital sensor could facilitate the playful experience of thrill [34]. In addition, we adopted the open-ended gameplay to facilitate an experience of exploration and discovery by giving players space for freely investigating the relationships between body temperature and their activities, considering one's body temperature could be influenced by a variety of factors such as one's diet, environment and physical activities [34]. Also, the free exploration may help us better understand the affordances of ingestible sensors in interactions. Moreover, we designed *HeatCraft* as a two-player system and encouraged players to be physically together to create the playful experience of fellowship [36]. Social interactions may motivate players to actively play with the system [47], and ease their nervousness before swallowing the sensor [34]. Therefore, we believe *HeatCraft* could facilitate playful experiences.

5 STUDY

We conducted an in-the-wild study [54] with 8 pairs of participants (7 males and 9 females, age 27 ± 4.7 (mean ± S.D.) years) to investigate the user experience of *HeatCraft*. The two players in the same pair were friends who could spend at least three hours physically together during the play. The recruitment followed a combination of convenience sampling and snowballing method [8]. No compensation was provided.

We designed a questionnaire to evaluate the participants' eligibility: this included whether they were able to swallow the Cortemp sensor and do physical activities to change body temperature. We then invited eligible players to the lab. Since the player's perception of thermal stimuli might be affected by the thickness of clothing [27], players were required to wear an ordinary T-shirt to minimize this influence. The two players were then provided with an info sheet explaining the Cortemp sensor and offering guidance for potential first aid; and the researchers' contact details for technical support. Then the two players swallowed the sensor and wore the belt, and were allowed to leave the lab afterwards. We did not restrict the places they go and the activities they do. After the players excreted the sensor, they went back to the lab and were interviewed together. Each interview took about 45 min, was audio-recorded and semi-structured. The players were asked about their perceptions in regards to the ingestible sensor, the motivations to take part in the study, and the experiences with *HeatCraft*. We utilized thematic analysis [6] to analyze the interview data. Two researchers got familiar with the transcripts by reading them three times, then independently coded the data. Then the codes were discussed and extracted until the two researchers reached an agreement. After deriving a set of codes, we iteratively clustered them into higher-level groupings which are the themes in the following Findings section.

6 FINDINGS

Overall, our findings suggest that *HeatCraft* facilitated ubiquitous playful experiences, augmented the players' bodily experiences and promoted the awareness of their environment. We identified three design themes: *Integration of body and technology*, *Integration of internal body and outside world* and *Integration of play and life*.

Theme 1: Integration of Body and Technology

This theme explains the players' lived body experiences, and how players perceived the relationships between *HeatCraft* and their body.

HeatCraft extended players' capabilities. Participants reported that *HeatCraft* extended their sensing capabilities and might influence their self-identity. For example, P7 said:"*I felt like I had a new skill. I could tell the temperature of my intestines.*" P8 also said:"*I felt I was a cyborg having superpower!*". Similarly, P14 said:"*I felt like I was an agent or superhero. I was the only one with a digital sensor in the body and a belt containing so many electronics!*". The extended capabilities further influenced the ways how players used their body. For example, P13 said:"*I enjoyed the heat since the weather was cold. At a moment, the heating pad cooled down. I really missed that heat so I drank a cup of ice water to heat me up. After several hours, I suddenly realized it was so weired to heat my body up by ice water. But at that moment, it was intuitive for me.*"

Players appreciated HeatCraft to be symbiotic with the body. Ten participants mentioned that they liked the fact *HeatCraft* was attached to their body. For example, P5 said:"*I usually feel anxious with my phone and always touch my pocket to see if it is there. But with this, all the devices were either in or on my body. I didn't need to worry about losing it.*" The integration of body and technology allowed the device to be always available and facilitated a symbiotic relationship with their body. For example, P5 said:"*With a Fitbit, I would only look at the number when I remember. But with this, I can know my body changes anywhere and anytime. It is like my partner reminding me of my body changes actively.*" Similarly, P8 said:"*The feedback voluntarily came to me, which was very different from checking my phone to see the number. It was like an extension of my body and something symbiotic that relies on my body information and in turn gives me more information.*"

The intimacy between HeatCraft and body facilitated "body scan" activities. Participants reported that *HeatCraft* made them think about their internal body, which is similar to the body scan exercise [27]. For example, P13 said:"*It made me think about my body from the inside and think about my organ as a separate thing rather than the body as a whole. It made me think about my inner body structure and how things traveling through my body.*" P8 also said:"*It let me think about the size of my organs. I was imagining this sensor going through my stomach and entered the intestines. It made me think about how my body acts like a processing machine.*" Moreover, players reported that the sensor could be a reference point to help them focus on their inner body. For example, P7 said:"*Everyone gets small random pains in their body. When that happened, I was wondering what the sensor was doing. Maybe it was turning a corner, pushing my intestines' wall. Also, when I thought about the sensor periodically, I always imagined it was tumbling over in my intestines like a small rock. The sensor was a reference point to help me focus on my inner body.*" Meanwhile, this theme was particularly pertinent when players were alone. P6 said:"*When I was with P5, we focused more on the difference of heat between ours. When I was alone, I was more likely to think about my internal body.*"

Ingesting the Cortemp sensor increased players' bodily awareness. Fourteen players reported that *HeatCraft* increased participants' bodily awareness through providing information of their body temperature and digestion rate. For example, P1 said:"*It increased my bodily awareness by giving me a constant update of my body temperature from the heating pad.*" In addition, P12 said:"*Now I know it takes about three days for the pie I eat to travel through my body.*" Similarly, P5 reported that:"*I expected to excrete the sensor when I first went to the toilet after swallowing the sensor. But I didn't. My digestion rate is slower than I thought.*"

Heat as an embodied feedback further deepened the integration between the system and body. Participants reported that they liked the thermal feedback as it is embodied and easy to be experienced. For example, P2 said:"*Heat is better than the number. It might not be precise but it makes you feel different. A thermometer might show you the number of* 37 °C*. But this system allows you to actually feel your temperature through your body.*" Similarly, P4 said:"*I think heat is more interesting. When [the system is] attached to you and heats up, it has some phenomenological thing to it. You can connect that to what's happening inside you much more easily.*"

The subtle thermal stimuli did not interrupt players' daily lives. Participants appreciated that the thermal stimuli notified them of their body temperature changes in a subtle way. For example, P6 said:"*Heat is interesting. This sort of ambient feeling of having the heat pad on and off, not telling you things specifically, but in a subtle way to draw your attention.*" Similarly, P4 reported:"*The sensor is similar to other recording devices like Fitbit. But what makes the system interesting is that the heating pad is touching you that it's on all the time. You can feel it even if you're not paying attention.*"

Theme 2: Integration of Internal Body and Outside World

This theme includes how the system helped players gain bodily knowledge, and be aware of of the interplay of their internal body, body surface, bodily actions, and the environment. Players reported that *HeatCraft* made them aware of how their actions and environment influence their internal body through heat sensations. For example, P2 said:"*it's interesting to expose everything to the sensor these days and*

knowing more about my body and environment." P5 also explained:"*The whole experience is like a loop. The environment and actions I take makes my body changes. I feel this change via my skin and this sensation affects my mind. Ultimately, this influences my behaviors again. It's amazing.*"

HeatCraft made players aware of their daily activities. Players reported that *HeatCraft* made them aware of their activities. For example, P4 explained:"*It's fun to think about what I eat may change the sensor reading like whether the food is hot or cold or how much I eat.*" P13 also said:"*It is interesting to think about the thing I am doing because it may change thermal stimuli.*" Six participants reported that *HeatCraft* made them aware of their behaviors including those unrelated to body temperature. For example, P3 said:"*I felt bad when I had junk food although I knew the sensor was not measuring the fat I ate. I felt it was monitoring. Then I decided to go swimming. Exercising was probably a thing in my head that was already there but it was accentuated by the game.*" Similarly, P14 said:"*I felt the sensor started dictating my movements in the physical space and the food I ate.*" P11 also said:"*It made me realize the exercise I didn't do because I knew the pads would change if I have done physical exercise. It made me think I should do more exercise.*" Moreover, the player's awareness of activities further contributed to the awareness of the environment. P13 said:"*The activity I could do was limited by the environment. When I entered a new place, I might try to figure out what can I do here to play with the system.*" Some players reported that *HeatCraft* influenced their behaviors even after the play and therefore they were interested in the long-term effect of *HeatCraft*. For example, P6 said:"*After the play, I still ate more vegetables to speed up my digestion. I guess I subconsciously felt worried that the pill might be still in my body although the beep sound told me that I have excreted it.*" P3 also said:"*I had a small concern that if I wore it for a year, it might influence my decisions. Is this a good thing?*"

The ambiguity of the system offered space for reflection. Participants reported that they liked the ambiguity of heat since it gave them space for reflection on the relationships between their actions and body temperature. For example, P9 said:"*Heat is ambiguous. It gives you more space to think. You can reflect on your activities according to the temperature.*" Similarly, P13 said:"*If it is the number, I would focus on the changes of my temperature. But with this, every time when I was doing something and suddenly felt the heat, it was like a surprise and I intuitively began to explore the reasons for the heat.*" Some players reported that the ambiguous game duration might motivate the player's reflections. For example, P2 said:"*The ambiguity of the excretion time is an interesting thing. It made me periodically think about my body and my activities. This also slightly influenced my daily behaviors.*"

HeatCraft increased players' awareness of the outside world. Twelve participants mentioned that *HeatCraft* made them more aware of the environment. For example, P14 reported that:"*I enjoyed knowing more about the environment. When I heard the beep, I thought there was a wave traveling beside me and connecting to someone's mobile phone. Also, it made me observe the number of digital devices in my space.*" P3 added:"*The beep sound made me aware of the overwhelming technology around me. So I went to a bush walk. I felt so good to feel the nature.*" Similarly, P2 reported:"*The system indicated the environment temperature. One time when the heating pads temperature increased, I realized I was in a cold space.*" The awareness of the outside world might affect the player's perceptions of a certain place. For example, P3 said:"*When I played the game, I went to an electronic shop. I felt bad because of the continuous beep. After I excreted the sensor, I went back to the shop but I still felt that place was noisy even without the system.*"

Increased awareness of the outside world facilitated players treating their bodies better. The increased awareness of the environment motivated players to reflect on their interactions with the outside world, making them treat their bodies better. For example, P13 said:"*Now I know my office has a strong electromagnetic field. I think I should not stay there for too long.*" P14 added:"*The system connected me and the environment. I can know informations of the environment which I would not know. It also made me think about how I can actively influence the environment to benefit my health, and more broadly, the society and natural environment.*" Similarly, P5 said:"*I think it is important to be attune to nature. This system definitely helped me towards this. For example, it made me aware of I should adjust my clothes based on the environment temperature.*"

Theme 3: Integration of Play and Life

This theme illustrates how *HeatCraft* facilitated ubiquitous playful experiences. For example, P15 said:"*The system turns daily activities to potential game actions and turns all the objects around me to game resources. For example, I can eat food to play with the system.*" P3 also said:"*Everything feels unusual with the system and I tried to discover it in 24 hours.*"

HeatCraft motivated spontaneous play. All the players played spontaneously during the study. For example, P5 said:"*When I was with P6, we drank ice water together and touch each other's belt to see who can raise the heat faster.*" P3 said:"*The buzzer sound made me feel like playing hide and seek with the system. I tried to avoid modern technology to stop it.*" P9 and P10 reported that they prepared food for each other to change the co-player's temperature. P11 and P12 said they raced against each other to see who excretes the sensor first. P1 and P2 reported that they compared the heat feedback of

different activities. P13 and P14 said they exchanged their belt and tried to influence the heat felt by the co-player.

Players appreciated the playful experience of exploration and discovery. Participants reported that they enjoyed exploring how to affect their body temperature. For example, P3 said:"*The first thing I did after swallowing the pill was eating food. It was fun to add new information to our body system and imagine what would happen.*" Similarly, P13 reported that:"*I am curious about the technology and my body. Before I swallowed the sensor, I planned to do some physical activities, try different food and drink like some spicy food and icy coke.*" Through the exploration, participants gained new knowledge about their body, which facilitated a playful experience of discovery [36]. For example, P5 said:"*It is interesting to know that I could quickly change my temperature by drinking water but surprisingly, ice-cream did not change my temperature.*"

Players appreciated the playful experience of thrill. Thrill means the excitement derived from risks and danger [36]. Participants reported that they experienced thrill during the play, especially before swallowing the pill. Thirteen players reported that they felt a bit nervous about swallowing the sensor which also facilitated a playful experience. For example, P9 said:"*I felt a tiny bit nervous but that's why I like it.*" Four players reported that they had thrill experiences when they periodically thought about the fact of having a sensor in the body. For example, P1 said:"*Before I went to bed, I thought about the sensor. It was scary but still interesting.*" Meanwhile, players regarded the experience as a safe adventure for several reasons. Firstly, the device would not be inside the body permanently. For example, P8 said:"*I think this would be the future of play but swallowing a sensor is a commitment. I liked to do it because I know it would leave my body.*" P14 also said:"*I felt it interesting and it would just stay in my body for three days. It's better than implantable devices.*" Secondly, the study procedure such as the screening protocol and guidances for first-aid dampened their nervousness. For example, P6 said:"*I felt a little bit nervous but the first-aid document made me feel safe.*" P4 also said:"*At first I was thinking is it safe? But after completing the assessment questionnaire, I think researchers know what they are doing. Also, I was told that the sensor has been commercialized for 10 years.*"

Players appreciated the playful experience of subversion. Participants reported that they enjoyed experiencing the subversion during the play as they thought it challenged social norms to swallow a digital sensor and wear a belt with wires and electronics. For example, P6 said:"*I was excited since I like doing anything that is a little bit out of the average experience.*" P3 also said:"*If you do something different, you start to realize how normal things are. In that regard, this game definitely caused me to have this feeling. Like my hairdresser is a cool guy but I still have trouble explaining this idea to him. It made me think I am weird but I enjoyed this.*"

Players appreciated the playful experience of fellowship. Participants reported that the system promoted intimate social interaction with their co-players. We did not ask how long players were together but from the activities they did, we inferred that they spent about 3-22 hours (M = 9) together. For example, P11 laughed:"*Now we are very open. I never thought about updating information to her every time when I went to the toilet.*" Similarly, P13 said:"*Exchanging our belt and feeling the other one's body temperature created the feeling of empathy. We were in the same room and the heat made me know he was doing something even when I was not looking at him.*" *HeatCraft* also motivated conversations between players and non-players. For example, P3 said:"*Throughout the day, I texted my friends all around the world in a messenger group, telling them what was happening. I usually don't want to text them and say I have just woken up and now I am eating breakfast or whatever. This experience became an excuse to update them about my life.*"

Players appreciated the playful experience of sensory stimulation. All participants reported that they enjoyed the localized thermal feedback as it brought about a pleasurable experience of sensory stimulation. For example, P8 said:"*Heat can make me happy or sad. It has an emotional effect. For me, I felt nice when the heating pad was getting hotter.*" Similarly, participants' expressions indicated that they kept the sensory experiences in memory. For example, P5 said:"*Yesterday when I did not have that belt on me, I felt cold and I missed that heating pad.*"

Issues with HeatCraft

Players expected to be able to check if HeatCraft was running. Participants reported that they were not sure if the system was running properly when they could not feel the heat. For example, P7 said:"*Sometimes I could not feel the heat. I was not sure if it was broken or just my temperature was that.*" P8 further explained:"*I always wanted to confirm whether it was working. I guess it is because I didn't trust the device at this stage since it is a prototype. It would be great to have some feedbacks that are easy to learn to indicate the system is working, like an LED.*"

Players expected the combination of numbers and sensations as feedback. Five participants said they would like a combination of localized heat and digital number as feedback. For example, P9 said:"*The heat is telling us the temperature is rising, not giving a specific number. Numbers on the screen could tell how much the temperature changes. But I don't want to replace the heat with the number.*"

7 DISCUSSION

This study highlighted the opportunity of using ingestible sensors to facilitate playful experiences. This section discusses our findings in the form of design strategies. This is not a complete list, but a starting point to guide designers in creating playful experiences around ingestible sensors.

Design for the Partnership between Human and Ingestible Systems

Theme 1 shows that players appreciated that *HeatCraft* acted as their partners reminding them of body temperature anywhere and anytime. Similarly, Farooq and Grudin [17] introduced the theory of *human-computer integration* [18] which moves beyond the command-response interaction paradigm and highlights the partnership between human and computers: users and computers construct meaning around each other's activities instead of simply taking orders. *Human-computer integration* is believed to bring about novel design opportunities and theoretical assumptions [18]. The theory could also be applied in the field of play. For example, embracing this theory in exertion games could offer new opportunities to engage with the active human body [1]. Thus, we suggest a partnership between the system and users when designing ingestible systems for play.

HeatCraft stepped towards the *human-computer integration* mainly because the thermal feedback kept interacting with players rather than waiting for instructions, indicating that the system was operating without players' full attention and invited players to play in an unobtrusive way. Inspired by this, we believe implicit interactions could be designed for ingestible systems. Implicit interactions do not require the user's explicit awareness and therefore are employed when the user is not focused on the interactive device [28]. Well-designed implicit interactions will make technologies more effective and appreciated, and integrate technologies into everyday life [28]. Thus, we believe design knowledges of implicit interactions might benefit the ingestible system design to facilitate *human-computer integration*.

We also acknowledge that *HeatCraft* is not a perfect integration since the system is not able to acquire the player's context and provide different interactions based on it. In the future, designers might consider using context-aware technologies in ingestible systems to enrich the user experiences and facilitate the *human-computer integration*.

More broadly, this work opens up new opportunities of embracing *human-computer integration* to facilitate ubiquitous play. For example, intelligent systems might offer different gameplay based on the user's context to support ubiquitous playful experiences. Moreover, the *human-computer integration* indicates that smart technologies may not only be designed as play interfaces, but as the users' co-players to support better play experiences.

Design Always Available Interactive Systems to Facilitate Symbiotic Relationships

Theme 1 shows that players regarded *HeatCraft* as a symbiotic partner since *HeatCraft* extended the players' capabilities and was *always-available*, which influenced how players perceived and used their body. Theme 3 shows that the symbiotic relationship further facilitates the ubiquitous play by integrating play into user's everyday life. Prior work suggested that augmented human (AH) technology is *always-available* and symbiotic with the human body. It could improve human abilities and has the potential to change the way we perceive ourselves and body's functionalities, and might be perceived as an extension of ourselves [32]. AH technology could augment our experience, and help us to realize ourselves [39]. Therefore, we believe designing ingestible systems to facilitate a symbiotic relationship with the human body may bring about novel experiences, augment our bodily perceptions, and provide ubiquitous playful experiences.

To facilitate the symbiotic relationship, Theme 1 and 2 highlight the importance of designing the ingestible systems to be *always-available*. Prior work proposed that *always-available* health technology would turn any place the user is in into a therapeutic landscape [38]. Thus, we argue that designing playful experiences with *always-available* technology such as ingestible sensors might turn any place the user is in into a playground and therefore facilitate ubiquitous play. Moreover, such *always-available* body-centric technologies could make users aware of their bodily state at any time and therefore support self-discovery and self-development [48]. *HeatCraft* supported *always-available* interactions by a belt with always-on thermal feedback, making the whole system more pervasive than technologies such as smartphones. However, we acknowledge that the *always-available* affordability of *HeatCraft* is limited since the waist belt needs to be taken off in specific scenarios such as swimming. Since ingestible sensors are naturally ubiquitous as they are in the human body, we recommend designers to design the rest of system towards being *always-available*. For example, *always-available* feedback systems such as localized sensations, interactive clothing, and skin interfaces can be considered when designing playful experiences with ingestible sensors. More broadly, for designers who aim at creating ubiquitous play experiences, *always-available* systems such as AH technology could be considered as a design resource.

Embrace the Functional and Affective Perspective to Facilitate Body Extensions

Since the ingestible system could be designed to form a symbiotic relationship with the player as an extension [32], we believe designing playful ingestible systems may learn from prior work around body extensions. For example, Slatman [56] argued that whether one perceives a transplanted organ as part of the body is influenced by the functional limits and affective limits [56]. Functional limits refer to the transplanted organ's usability. Nunez-Pacheco [48] also suggested that in biofeedback projects, the user's trust of the data helps create a sense of ownership towards the system feedback, which further motivates the user for self-exploration. *HeatCraft* stepped towards being the user's body extension by providing reliable body temperature data. We also acknowledge that the ingestible sensor technology is still in its infancy and therefore the collected data might not always be reliable. In *HeatCraft*, the unreliable data were designed to indicate the intensity of the surrounding electromagnetic interference. Therefore, the data did not afflict the player's experience but added another layer of playfulness. Thus, we suggest designers design a reliable ingestible system while turning the unreliable aspects of the system into features which players can play with.

Affective limits refer to whether the transplanted organ can be accepted psychologically. For example, the transplanted organ may be regarded as a strangeness rather than an extension as it is not appreciated [56]. When it comes to ingestible sensors, users might feel uncomfortable for ethical issues such as safety, cultural effects, and data security [23]. Theme 3 shows that ethical design choices such as evaluating player's eligibility before the study and providing first-aid guidances could dampen the players' discomfort with the sensor. Therefore, we suggest designers keep a safe atmosphere for players when designing ingestible system. Prior work [31] already explored the ethics of ingestible sensors from both the patients' and the providers' perspective, from which we know that designers should notify players of all medical aspects of the ingestible sensor before play, for example. Future works around designers' ethical choices and possibilities might further benefit the design of playful ingestible systems.

Overall, we suggest designers embrace the functional and affective perspective when designing playful ingestible systems.

Consider Ambiguity to Facilitate Playful Experiences

Theme 2 suggests that ambiguous aspects of *HeatCraft* motivated players to reflect on their daily activities and environment. Prior work [20] suggested that pointing out things without explaining the reasons could encourage people to consider the personal significance of things, behaviors or events in their environment. With *HeatCraft*, players were only aware of their body temperature change but did not know the exact causes. This ambiguity evoked players to reflect on the reasons of their body temperature changes and facilitated playful experiences of exploration and discovery [36]. Prior work also suggested that ambiguity is an important factor in creating playful systems integrating with users' lives to facilitate ubiquitous play [50]. Therefore, we suggest designers consider ambiguity as a design resource to create playful experiences around ingestible sensors. Moreover, this work indicates that ingestible sensors might be a design resource to facilitate reflections.

Consider the Environment Perspective in Ingestible Systems

We suggest designers consider engaging players with their environment when designing ingestible systems. In *HeatCraft*, a buzzer functioned as an environment sensor, making players aware of their surroundings. This contributed to ubiquitous play experience since the player continuously entered new places during the play. The buzzer also made the player engage with the outside world [35]. Similarly, prior work [16] indicated that a key attribute of pervasive games is that they could influence the player's experience of their environment, invoking emotions that affect the player's perceptions of the real world. Therefore we recommend designers to consider additional environment sensors in ingestible systems. For example, designers could complement their game design with location sensors, temperature sensors, or humidity sensors. This strategy might be generalized to other body-integrated systems to engage users with the environment.

Consider Body Boundaries to Facilitate Playful Experiences

Our body boundaries are not strictly outlined. The pores of the skin, our mouth, and anus are absorbing and excreting things in and out of our body [56]. In *HeatCraft*, the Cortemp sensor crossed the player's body boundaries twice during the play, bringing about novel play opportunities. According to Theme 3, players appreciated ingesting a foreign object, or guessing when the sensor would come out. In addition, Theme 1 suggests that players enjoyed the experience of fantasy [36] when an foreign object entered their body boundaries since they regarded the Cortemp sensor as a reference point to imagine their inner body structure, leading to the body scanning activity which might further facilitate mindfulness [49]. Therefore, we recommend designers to highlight the experience of ingesting and excreting the ingestible sensor when designing ingestible play. Moreover, there is an opportunity to design fantasy experiences by utilizing the player's inner body as a resource since we are

usually unfamiliar with our inner body. More broadly, designers could consider this "crossing of the body boundaries" as a design element to facilitate a playful experience.

Embrace the Körper and Leib Perspective to Facilitate Lived Experiences

Theme 1 indicates that participants enjoyed the lived body experience with *HeatCraft*. Our findings confirmed the theory proposed by Mueller et al. [46] (see Section 2) that players could experience their body as play by 1) highlighting the interplay between Körper and Leib; and 2) shifting the focus between Körper and Leib. For example, players tried to first be active with their body (Körper) and then feel the bodily change through the localized thermal stimuli (Leib). Moreover, when participants were interacting with each other, they were physically active (Körper) to form social interactions but when they were alone, they felt themselves from the inside (Leib). Therefore we suggest designers embrace the Körper and Leib perspective and learn from the related design knowledge [46] to facilitate lived experiences when designing for ingestible sensors. For example, designers may consider shifting between Körper and Leib by allowing sensors to measure what the Körper does, and turn this data into a localized sensation to support the Leib. More broadly, we believe the Körper and Leib perspective would be used to facilitate lived experiences when designing playful experiences around body-integrated technology.

Design Social Play for Ingestible Systems

Theme 3 shows that players enjoyed social interactions during the play. Prior work also suggested that designing social interactions in ingestible games could enrich game experiences and help players relax before swallowing ingestible sensors [34]. Our findings show that 1) like other games [60], social interaction is a key element to facilitate positive game experiences when playing with ingestible sensors; 2) *HeatCraft* could promote the connection between the two players when they exchange the belts and let the co-player feel their temperature; 3) *HeatCraft* provided a topic for players to start a conversation with both the co-player and outsiders. Prior research also showed that sharing biosignals could support a feeling of intimacy between people [42]. Moreover, ubiquitous play usually encourages spontaneous interactions with outsiders which enriches the game experiences [43]. Therefore, we suggest designers consider social play when designing playful experiences around ingestible sensors. Meanwhile, designers should keep in mind that social interactions might distract players from feeling themselves from the inside (Theme 1).

8 LIMITATIONS

This study has several limitations. Firstly, we only looked at the Cortemp sensor that measures the player's body temperature. Investigating the playful experiences afforded by other types of ingestible sensors might strengthen the work. Secondly, we did not consider how the subversive nature of ingestible sensors may affect the results. Future work may explore the attitude of people who would have not volunteered for the study on ingestible sensors. Thirdly, due to experimental platform limitations, we did not log data such as players' game duration, the frequency of error data, and the temperature of heating pads. An analysis of the relation between these data might reveal more findings. Lastly, we did not consider the novelty effect of the ingestible sensor. All players were not familiar with an ingestible sensor, therefore their play experience might be influenced by their interest in the new technology. However, we consider novelty as an intriguing element of playful experiences and therefore propose that our work provides a valuable starting point for future investigations.

9 CONCLUSION

In this paper, we offered the first conceptual understanding of designing playful experiences around ingestible sensors via localized sensations through our system *HeatCraft*. Our study showed that this system can increase the user's awareness of their body, daily activities, and environment. This awareness further contributed to the integration of the system and the user's body, the integration of the internal body and outside world, and ultimately the integration of play and life.

This work contributes knowledge to the design of future playful experiences with ingestible sensors. Furthermore, we inspire designers to use ingestible sensors as design resources and highlight how ingestible sensors can be used for play. We also highlight the opportunity to use localized sensations as feedback to support players experiencing their body as play. Moreover, we open up new possibilities to help designers facilitate the integration of body and technology to blur the boundary between play and life.

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