HeatCraft: Playing with Ingestible Sensors via Localised Sensations

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Abstract
Ingestible sensors are digital devices that can measure the user's body data after being swallowed and hence have great potential in medical use. Unfortunately, few studies have considered the playful experiences afforded by ingestible sensors. We believe that the use of localised sensations, such as those created by heat, to represent the data measured by ingestible sensors offers opportunities to support experiencing the body as play. To explore this opportunity, we introduce a two-player system called HeatCraft that uses an ingestible sensor to measure the users' body temperature and employs thermal stimuli to provide feedback. Similar to open-ended games, HeatCraft allows players to decide when and what to do in order to know more about their body, facilitating playful experiences of exploration and discovery. With this work, we aim to inspire game designers and HCI researchers to consider localised sensations when designing playful and engaging experiences around ingestible sensors.

CCS Concepts
•**Human-centered computing** → **Interaction paradigms;**
•**Applied computing** → *Computer games;*

Author Keywords
Ingestible games; body temperature; thermal; game design; play; localised sensations.

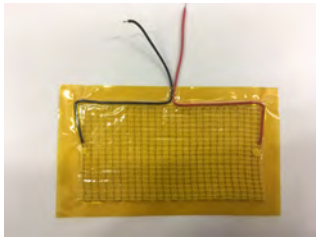

Figure 1: The DC powered heating pad is made of metal-polymer fiber composite conductive yarn. The pad is flexible and thus is suitable for wearable use.

Figure 2: This picture shows an early prototype of the waist belt containing all the components.

Introduction

Ingestible sensors are self-contained microsystems that perform sensing or actuating functions inside the body [6]. In recent years, ingestible sensors have become increasingly popular for medical use to support diagnosis and therapy. For example, capsule endoscopes allow medical practitioners to examine the conditions of people's gastrointestinal (GI) tract in a non-invasive way [14, 1]. Ingestible sensors are also believed to have great potential in biodata sensing, drug delivery, and measuring medical adherence [6, 15]. In addition, since ingestible sensors enable continuous measurements of the user's body data, they might offer opportunities in the field of pervasive health monitoring.

We find that most research around ingestible sensors focuses on the instrumental functions such as health benefits [14, 1, 5] while few studies have investigated the user experience around such devices. Considering that digital health technologies can bring about unique emotional and sensory experiences and influence people's understandings of their body and health [26], investigating the experiential benefits of ingestible sensors seems important. We believe that there are a need and an opportunity to explore the design considerations that go beyond the instrumental aspects of ingestible sensors. In particular, we believe there is an underexplored opportunity to make the experience of using such devices more engaging and playful.

Our earlier work [20, 22] explored designing a smartphone-based mobile game around ingestible sensors and showed that the use of screens might limit player's experiences. Therefore, this study explores the opportunity of using localised sensations, in particular thermal stimuli, to represent people's body temperature data measured by an ingestible sensor. This work presents a playful system called *HeatCraft* that uses a heating pad (see Fig 1) attached to a waist belt (see Fig 2) to generate thermal stimuli. The intensity of the heat depends on the user's body temperature data which is measured by an ingestible sensor. Two players are encouraged to experience the system together. We believe using localised (on the body), subtle (do not need much attention from users) and ongoing (always available) sensory feedback such as heat to represent the data captured by ingestible sensors can improve people's bodily awareness, support reflections on daily activity, and offer unique bodily experiences. In addition, designing playful elements in the proposed system might improve the overall quality of the user experience [25]. This paper describes our system along with the proposed study, aiming to inspire designers to utilise localised sensations when designing playful and engaging experiences around ingestible sensors.

Related Works on Intracorporeal Devices

Recently, an increasing number of people choose to use intracorporeal devices for non-medical purposes. For example, some people insert RFID tags into their body for opening doors, unlocking computers, and accessing public transport [10]. Unfortunately, there is not much work investigating the experiences of using intracorporeal devices. Warwick [38] recorded his experiences of implanting an RFID tag into his body to open his office door and switch the lights on. Later on, he explored the ethical aspect of using these devices. Based on Heffernan's interview with 17 hobbyists of implantable devices [10], people insert foreign devices into their body mostly for convenience or extending their senses. Moreover, many people who prefer implantable devices regard wearable devices as encumbrances. The skin contact with wearable devices may cause discomfort while intracorporeal devices do not have such problems. These works highlight that intracorporeal devices

might be intriguing to some people and offer interesting engagement opportunities.

Inspired by the above, many HCI researchers believe that intracorporeal devices have the potential to be integrated into people's daily life, which may make the vision towards pervasive computing come true [2]. For example, by proposing an implantable user interface, Holz et al. [11] suggested that we may interact with digital devices that are permanently inside our body in the future. Leigh et al. [19] also argued that such devices make us integrate with technology and provide opportunities to offer a direct interplay with our mind by extending our sensing capabilities. These works highlight the opportunities of introducing intracorporeal devices to the field of interaction design. Unfortunately, these works do not delve into practical design details on how intracorporeal devices can come together with play. Meanwhile, Mueller et al. [28] suggested that unique experiences can be generated when the interaction with technology involves our body, which can be utilised in digital play. Inspired by this, we believe that ingestible sensors can support players to experience their body as play, ultimately facilitating intriguing and innovative bodily experiences. To validate this, this research presents a design prototype around ingestible sensors to make the use of ingestible sensors more engaging and playful.

Opportunity of Playing with Body Data

Prior work around biofeedback systems suggests that playful elements can make the experiences of affecting body data more engaging and enjoyable. Many systems have already adopted a biofeedback loop that transmits the player's psychological data measured by the sensors back to the game systems [18]. For example, Liu et al. [24] measured the player's extent of anxiety through wearable sensors to adjust the game difficulty dynamically. Stach et al. [35] built a racing game in which the car speed is determined by the player's real-time heart rate. Patibanda et al. [30] developed a VR game that measures the player's breathing to control the growth of an animated tree. These studies highlight that playful elements can enrich the experiences of controlling the body to be more engaging and pleasant. Inspired by the above works, this study extends related work on biofeedback interactions by designing playful experiences around the body data measured by ingestible sensors.

Opportunity of Using Localised Sensations

To design playful experiences around ingestible sensors, how to design engaging and meaningful feedback seems to be important. Prior work explored different methods to create engaging experiences around the sensed body data. Lin et al. [23] designed an animated fish which can grow based on the user's daily step count. Consolvo et al. [7] utilised the users' activity data to nurture the virtual flowers in a garden. However, most of these works used on-screen numbers and graph to represent the body data while Khot et al. [17] argued that designers should consider material representations to enrich the user experiences when designing data visualisation. For example, the author developed a playful system called *TastyBeats* that creates a fluidic spectacle of mixing sports drinks based on the user's heart rate [17]. Inspired by these works, we ask, what if we use localised sensations to represent the users' body data?

We find the combination of localised sensations and ingestible sensors intriguing because localised sensations allow players to experience their measured body data directly through their body, which might help increase bodily awareness. Prior work suggests that the increase of bodily awareness might make individuals be more perceptive and aware of the physical world, leading to novel, playful and engaging experiences [12]. Meanwhile, prior research

Figure 3: The Cortemp sensor is about 22mm in length and passes through the body in 24-36 hours depending on the user's rate of motility.

Figure 4: The Cortemp sensor transmits a signal to the Elite receiver every ten seconds. The Elite receiver then transmits the data to the Arduino.

showed that body-centred technologies can increase the user's bodily awareness by showing users' real-time body data [36]. These works and our previous study [21] suggest that there is an opportunity to design playful experiences around ingestible sensors for increasing players' bodily awareness. Meanwhile, we note that localised sensations such as touch, pain, proprioception, kinesthetic sensations, and temperature sensations could increase our bodily awareness and help us experience our body as ours [33]. Mueller et al. also suggested that designers should consider designing with the experiential perspective in mind by engaging with these localised sensations [28]. Therefore, we find it intriguing to explore what happens if the feedback device of an ingestible sensor provides localised sensations to users.

As a starting point, we choose thermal stimuli to represent people's body data as feedback for the following reasons. First, heat has been used in bodily awareness exercises as it can attract one's attention to the body [13]. Second, body temperature data usually changes slowly [5]. Similarly, heat generated by a heating pad changes gradually [13] as well. We therefore believe that it may be suitable to represent body temperature through heat. Third, since players might play with the system for 24-36 hours as the sensor travels through their GI tract, a feedback in the background which does not need the user's continuous attention seems to be suitable. Heat can range from subtle to intense and therefore might be appropriate for background feedback [32].

In light of the above, we identified the design space to design playful experiences around ingestible sensors. In this work, we ask, how to design playful and engaging experiences around ingestible sensors via localised sensations? To answer this question, we developed a system called *HeatCraft*, which we explain below.

HeatCraft

HeatCraft is a playful system that enables players to experience their body temperature measured by an ingestible sensor via a localised sensation of heat.

Measuring temperature data

The temperature data is measured by an ingestible sensor called Cortemp. Cortemp is an FDA-cleared pill-like device (see Fig 3) measuring the user's core body temperature for approximately 24-36 hours as it travels through the digestive tract. The sensor transmits a signal to a data receiver called Elite every ten seconds. In this study, we use an Arduino UNO with an XBee wireless module to receive the messages from the Elite receiver (see Fig 4) and then extract the temperature data to control the intensity of the thermal stimuli.

Using thermal stimuli to represent body temperature

To generate thermal stimuli, we use a heating pad attached to a waist belt worn by the players. We note that the sensitivity and experience of the thermal stimuli might be affected by the thickness of clothing [13]. To minimise the influence of clothing, we suggest players wear a T-shirt. During play, the Arduino reads the player's body temperature data every ten seconds to adjust the temperature of the heating pad accordingly.

To design the intensity of the thermal stimuli, we utilised the autobiographical research method [31] to understand the experience of thermal stimuli: two of the researchers experienced the heat with different intensities. Both of the researchers are female (age 24 and 30). Researcher A changed the temperature of the heating pad which was attached to Researcher B's T-shirt and asked researcher B to report her real-time sensation. Then the two researchers swapped their roles. This process was repeated five times. Results showed that the lowest heating pad temperature

that can be sensed was 28 °C on average and there was an unpleasant sensation after temperature reached 50 °C. Therefore, we designed the temperature of the heating pad between 28 °C and 50 °C. The researchers also reported that they felt the heat stimuli to be pleasant when they were cold (skin temperature was about 23 °C). Similarly, previous work suggests that thermal stimuli is perceived as very pleasant in hypothermia [27]. Therefore, we designed the heating pad to be hotter when the player's body temperature is lower and the heating pad to be cooler when the body temperature is higher (see Fig 5). In addition, previous work showed that the temperature data measured by a rectal thermometer and an ingestible sensor is very similar [8] and the normal rectal temperature is between 36.2 °C and 37.8 °C [29]. We therefore assume the normal temperature data range in this study is between 36.2 °C and 37.8 °C.

In light of the above, we designed the heating pad temperature as follows: if the body temperature data is lower than 36.2 °C or higher than 37.8 °C, the heating pad temperature is 50 °C to remind players of the extreme high/low body temperature; if the body temperature data is between 36.2 °C and 37.8 °C, the heating pad temperature gradually decreases from 48 °C to 28 °C (see Fig 5).

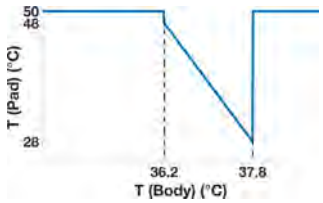

Figure 5: The picture shows the mapping between the user's body temperature and the temperature of the heating pad.

Open-ended play

In our system, the two players swallow a sensor at the same time and experience their body temperature via the thermal stimuli generated by the heating pad.

We adopted the open-ended gameplay, which means players can explore and approach their objectives freely [34]. Similar to Poker cards that allow players to invent different kinds of gameplay, *HeatCraft* supports players to generate their own play rules. Based on the PLEX framework proposed by Lucero et al. [25], we believe such an open-ended play can help facilitate the playful experiences of exploration, discovery, and sensation. To inspire the players, we propose some play ideas to them but highlight that we encourage them to create their own playful experiences by inventing new gameplay.

When designing the play ideas, we mainly aimed for helping players gain more body knowledge, increase their bodily awareness, and make the experiences of using the system more engaging. This is inspired by the three pillars of bodily intelligence [9]. The authors argue that one's body intelligence can be promoted by increasing his/her somatic awareness, body knowledge and the level of engagement, contributing to the self-attunement. Here are some examples of the play ideas:

The play ideas for increasing players' body knowledge:

- Where and What: The two players make two dices together. One dice lists six locations such as campus and restaurants on each side while the other one lists six activities such as running and drinking hot water. Players roll the dices and do the activity in a certain place followed by the dices. We believe this game could help players understand how their daily activities can affect their body in order to increase their body knowledge.
- Scientific Diary: When the two players are not physically together, we advise them to write down the moments when their attention moves to the thermal stimuli and reflect on the potential reasons for the change of body temperature. We believe this game also helps players understand the relationships between difference activities and body temperature, leading to an increase of body knowledge.

The play ideas for increasing players' bodily awareness:

- TransHeat: The two players exchange their heating pad to experience the other player's body temperature. The player can try to increase the temperature of the heating pad worn by the co-player. For example, the player can drink ice water to decrease his/her body temperature in order to increase the heating pad temperature. We believe this game could increase players' bodily awareness by experiencing the other's body [37].
- Escape: The two players guess when they will excrete the sensor before swallowing. The player wins if his/her answer is closer to the truth than the co-player's. We believe this game can help players be more conscious of their digestion rate and be more aware of the sensor's existence, leading to an increase in bodily awareness.

The play ideas for increasing players' level of engagement:

- Being together: The two players set a time duration and then exchange their heating pad. They need to ensure that the Arduino they wear can receive the data from the other player's Elite receiver during this period of time (the transmission range is about 100 meters). We believe this game can motivate players to be physically together and therefore provide more opportunities for social play.
- Feed Me: The two players prepare a meal for each other. The player is required to tell the co-player his/her requirements for the meal. For example, a player may want some yellow food which can increase his/her body temperature. Then the co-player might cook some yellow curry for the player. We believe that this game could facilitate a playful co-experience, making the experiences of using the system more engaging.

Proposed study

At this stage, the system design and hardware development are completed. To help understand the design of playful systems around ingestible sensors, we will recruit 14 participants (7 groups) to play with the *HeatCraft*. Participants will be required to write down the gameplay and their experience during the play. After the play session, participants will be asked about their experiences in semi-structured interviews [4]. Thematic analysis [3] will then be used to analyse the interview data to generate design themes. The themes will be utilised to articulate design strategies that future designers may consider when aiming to develop engaging experiences around ingestible sensors. The results of this study will guide us towards a better understanding on the design of playful experiences triggered by localised sensations around ingestible sensors.

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