# Understanding the Design of Ingestible Play

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# Abstract

HUMAN–computer interaction (HCI) is becoming increasingly interested in bodily play, as it has the potential not only to enhance health and wellbeing, but also to engage people with their bodies. This PhD research uses ingestible sensors – sensors that can be swallowed – to explore novel opportunities for bodily play that engages players with their interior body. To understand the design of ingestible play, a research through design approach was adopted, resulting in three interactive prototypes. The first, called the Guts Game, allows mobile phone users to play with their interior body temperature as sensed by an ingestible sensor. The second, HeatCraft, allows players to experience their interior body temperature via localised thermal stimuli generated by a waist belt. The third prototype, InsideOut, enables players to interact with a real-time video of their gastrointestinal tract filmed by an ingestible imaging capsule and shown on a wearable screen placed over their abdomen. For each prototype, an in-the-wild study was conducted to understand the player experiences. The result is a novel design framework for ingestible play in the form of a 4x3 table (rows: the material interior body, the functional interior body, the affective interior body and the social interior body; columns: the sensing ingestibles, the fusing ingestibles and the moving ingestibles) that articulates 12 design themes such as 'confrontation' and 'cultivation' as well as implementation strategies for the design of future ingestible play. Ultimately, this work advances HCI design by including the interior body, contributing to a more playful and humanised technology future.

# Declaration

This thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

Zhuying Li

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# Publications

Major portions of this dissertation have been peer-reviewed and published in academic publications. The complete list of publications is presented below.

## Long papers

1. **Z. Li**, Y. Wang, J. Sheahan, B. Jiang, S. Greuter, F. Mueller, "InsideOut: Towards an understanding of designing playful experiences with imaging capsules," in *Proceedings of the 2020 on Designing Interactive Systems Conference*, ser. DIS '20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 601–613.

2. **Z. Li**, Y. Wang, W. Wang, W. Chen, T. Hoang, S. Greuter, F. Mueller, "HeatCraft: Designing playful experiences with ingestible sensors via localized thermal stimuli," in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, ser. CHI '19. New York, NY, USA: Association for Computing Machinery, 2019, pp. 1–12.

3. **Z. Li**, R. Patibanda, F. Brandmueller, W. Wang, K. Berean, S. Greuter, F. Mueller, "The Guts Game: Towards designing ingestible games," in *Proceedings of the Annual Symposium on Computer–Human Interaction in Play*, ser. CHI PLAY '18. New York, NY, USA: Association for Computing Machinery, 2018, pp. 271–283.

## Short papers

1. **Z. Li**, Y. Wang, S. Greuter, F. Mueller, "Ingestible sensors as design material for bodily play," in *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, ser. CHI EA '20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 1-8.

2. **Z. Li**, J. Sheahan, Y. Wang, S. Greuter, F. Mueller, "InsideOut: Playing with real-time video images of the gastrointestinal tract via imaging capsules," in *Extended*

*Abstracts Publication of the Annual Symposium on Computer–Human Interaction in Play*, ser. CHI PLAY '19 EA. New York, NY, USA: Association for Computing Machinery, 2019, pp. 501–509.

3. **Z. Li**, W. Chen, Y. Wang, T. Hoang, W. Wang, M. Boot, S. Greuter, F. Mueller, "HeatCraft: Playing with ingestible sensors via localised sensations," in *Extended Abstracts Publication of the Annual Symposium on Computer–Human Interaction in Play*, ser. CHI PLAY '18 EA. New York, NY, USA: Association for Computing Machinery, 2018, pp. 521–530.

4. **Z. Li**, "Understanding the design of playful experiences around ingestible sensors," in *Extended Abstracts Publication of the Annual Symposium on Computer–Human Interaction in Play*, ser. CHI PLAY '18 EA. New York, NY, USA: Association for Computing Machinery, 2018, pp. 33–38.

5. **Z. Li**, F. Brandmueller, S. Greuter, F. Mueller, "The Guts Game: Designing playful experiences for ingestible devices," in *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, ser. CHI EA '18. New York, NY, USA: Association for Computing Machinery, 2018, pp. 1.

6. **Z. Li**, F. Brandmueller, S. Greuter, F. Mueller, "Ingestible games: Swallowing a digital sensor to play a game," in *Extended Abstracts Publication of the Annual Symposium on Computer–Human Interaction in Play*, ser. CHI PLAY '17 EA. New York, NY, USA: Association for Computing Machinery, 2017, pp. 511–518.

7. F. Brandmueller, **Z. Li**, "Guts Game: A game using ingestible sensors," in *Extended Abstracts Publication of the Annual Symposium on Computer–Human Interaction in Play*, ser. CHI PLAY '17 EA. New York, NY, USA: Association for Computing Machinery, 2017, pp. 625–631.

## Collaborative works on bodily interactions that contributed to furthering my work

1. F. Mueller, P. Lopes, J. Andres, R. Byrne, N. Semertzidis, **Z. Li**, J. Knibbe, S. Greuter. "Towards understanding the design of bodily integration," *International Journal of Human-Computer Studies*, vol. 152, 2021.

2. F. Mueller, R. Patibanda, R. Byrne, **Z. Li**, Y. Wang, J. Andres, X. Li, J. Marquez, S. Greuter, J. Duckworth, J. Marshall, "Limited bodily control as intriguing play

design resource," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems,* ser. CHI '21. New York, NY, USA: Association for Computing Machinery, 2021.

3. Y. Strengers, J. Sadowski, **Z. Li**, A. Shimshak, F. Mueller, "What can HCI learn from sexual consent? A feminist process of embodied consent for interactions with emerging technologies," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems,* ser. CHI '21. New York, NY, USA: Association for Computing Machinery, 2021.

4. F. Mueller, P. Lopes, P. Strohmeier, W. Ju, C. Seim, M. Weigel, S. Nanayakkara, M. Obrist, **Z. Li**, J. Delfa, J. Nishida, E. Gerber, D. Svanaes, J. Grudin, S. Greuter, K. Kunze, T. Erickson, S. Greenspan, M. Inami, J. Marshall, H. Reiterer, K. Wolf, J. Meyer, T. Schiphorst, D. Wang, P. Maes, "Next steps for human-computer integration," in *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems,* ser. CHI '20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 1–15.

5. F. Mueller, T. Kari, **Z. Li**, Y. Wang, Y. Mehta, J. Andres, J. Marquez, R. Patibanda, "Towards designing bodily integrated play," in *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction,* ser. TEI '20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 207–218.

6. F. Mueller, L. Matjeka, Y. Wang, J. Andres, **Z. Li**, J. Marquez, B. Jarvis, S. Pijnappel, R. Patibanda, R. Khot, "'Erfahrung & erlebnis': Understanding the bodily play experience through German lexicon," in *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction,* ser. TEI '20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 337–347.

7. F. Mueller, Y. Wang, **Z. Li**, T. Kari, P. Arnold, Y. Mehta, J. Marquez, R. Khot. "Towards experiencing eating as play," in *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction,* ser. TEI '20. New York, NY, USA: Association for Computing Machinery, 2020, pp. 239–253.

8. F. Mueller, **Z. Li**, R. Byrne, Y. Mehta, P. Arnold, T. Kari, "A 2nd person social perspective on bodily play," in *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems,* ser. CHI '19. New York, NY, USA: Association for Computing Machinery, 2019, pp. 1-14.

9. F. Mueller, **Z. Li**, T. Kari, Y. Wang, Y. Mehta, “Towards a coming together of transhumanism and play,” in *Proceedings of the 2018 Annual Symposium on Computer–Human Interaction in Play Companion Extended Abstracts*, ser. CHI PLAY ’18 EA. New York, NY, USA: Association for Computing Machinery, 2018, pp. 549–557.

10. F. Mueller, T. Kari, R. Khot, **Z. Li**, Y. Wang, Y. Mehta, P. Arnold. “Towards experiencing eating as a form of play,” in *Proceedings of the 2018 Annual Symposium on Computer–Human Interaction in Play Companion Extended Abstracts*, ser. CHI PLAY ’18 EA. New York, NY, USA: Association for Computing Machinery, 2018, pp. 559–567.

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# Chapter 1

# Introduction

THIS dissertation explores the design of bodily play with ingestible sensors. In this chapter, I will briefly present the research motivations and contributions. I will conclude by giving an outline of this dissertation.

## 1.1 A Possible Future: Interior Bodily Play

What is the future of bodily play? In this dissertation, I propose a possible future where play involves the player's interior body. Segura et al. [146] framed body games as 'games in which the main source of enjoyment comes from bodily engagement'. Inspired by this, I propose interior bodily play in which the main source of the enjoyment comes from the player's engagement with their interior body.

With the concept of interior bodily play, I use the term 'interior body' as an opposite term to the exterior body, with the skin being the boundary. Here, the exterior body refers to the body parts that can be seen and easily accessed, as they can be touched by ourselves and others without any tools. In contrast, by interior body I mean the body parts beneath our skin that cannot be seen or touched: we can only access the interior body using tools such as surgical knives, X-rays and functional magnetic resonance imaging (fMRI). I acknowledge that this distinction between exterior and interior is imperfect because the human body is continuously absorbing and excreting substances via body parts such as the mouth, skin pores and the anus [207]. I do not conceptualise the exterior body and interior body as a dualism, but use this as a pragmatic approach to distinguish between outside and inside characteristics.

The idea of interior bodily play is mainly inspired by the trend of human–computer integration (HInt), which highlights the interrelation between humans and computers [164]. HInt was first presented by Farooq and Grudin [63]. According to the authors, interaction refers to a stimulus–response paradigm whereas integration highlights the 'partnership or symbiotic relationship in which humans and software act with autonomy'. For example, in the case of semi-autonomous vehicles, the drivers work with the computers together to control the vehicles. Later on, Mueller et al. [164] expanded the concept of HInt to describe the recent trend where technologies are being closely interwoven with the human body. Mueller et al. [164] used the word 'symbiosis' to refer to the original meaning of HInt presented by Farooq and Grudin [63]. In addition, Mueller et al. [164] argued that there is another type of HInt called fusion, referring to the 'integration in which devices extend the experienced human body or in which the human body extends devices'. According to Mueller et al. [164], adopting human-compatible technologies to understand the user's physical and mental state can better support this fusion between computers and the human body.

The trend of HInt can be observed by the decreasing distance of computers to humans and the increasing computer accessibility over time. At first, we had mainframe computers that weighed several tons and occupied hundreds of square meters. Users had to travel around the computers to work with them. At this stage, because of the cumbrousness of mainframe computers, they were only used in the workplace for specific tasks. Then desktops which are significantly smaller than mainframes came around, allowing us to sit in front of computers and interact with them at home. Afterwards, we developed laptops that can be carried around, allowing us to use computers in broader contexts such as in a cafe or during a meeting. Next, we began to use mobile phones that can be put into our pockets, which further increased the computer accessibility and decreased their distance to humans. In 2019, there were about 3.2 billion smartphone users worldwide [210]. Then we had wearables that are on our body such as smartwatches, which were followed by the emergence of insertables such as implantable chips and smart contact lenses. This trend shows that our interactions with computers are becoming increasingly ubiquitous [239], e.g., insertables can interact with the users at any time and in any location.

HInt practices can also be seen in human–computer interaction (HCI) research. For example, MetaArms [195] augments the human body with two additional robotic arms controlled by the user's feet to support the user completing tasks that are difficult to handle with only two hands. Weigel et al. [238] explored skin interface and investigated a set of on-skin gestures such as pulling, pressing and squeezing as input modalities. Companies such as Dangerous Things are selling implantable chips, for example, for sensing biodata to replace keys, etc. [45]. In summary, the field of HInt is rapidly expanding and an increasing number of research and practices are being done to investigate how the trend of HInt can affect the way we engage with technologies.

This dissertation contributes to HInt by exploring a possible future of digital play where technologies are closely interwoven with the human body. I envision that the trend of HInt can provide novel opportunities in the design of digital play. Similar to the development of computers, the advancement of entertainment technologies also make them closer to the players' body. For example, compared to the early years when we could only sit in front of desktops and played computer games with mouses and keyboards, wearables such as smartwatches enrich the way we can play by allowing us to use whole-body movements to play at any time in any place. Inspired by the HInt, I envision that technologies integrated with the human body might also be used for digital play, facilitating interior bodily play.

## 1.2 Ingestible Play

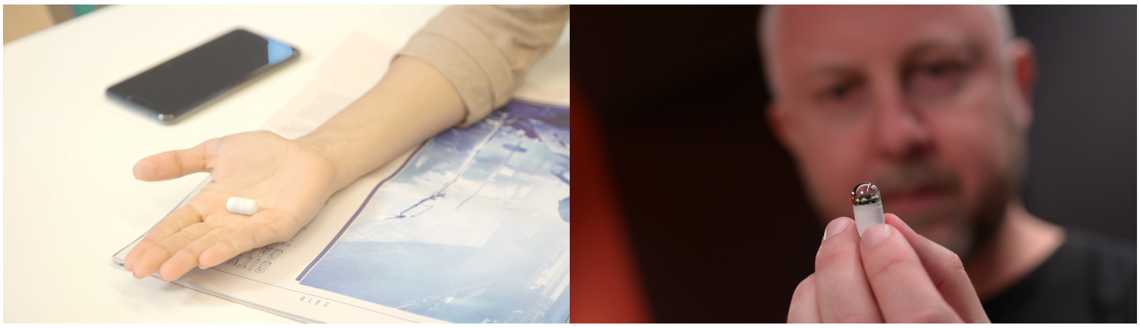
With the vision of interior bodily play, in this dissertation I explore the design of bodily play with ingestible sensors, a type of intracorporeal device that can potentially support players playing with their interior body. I define ingestible play as interior bodily play that involves ingestible sensors as the play technology.

### 1.2.1 What is an Ingestible Sensor?

Ingestible sensors (see Figure 1.1) are self-contained electronic microsystems with the capability of performing functions inside the body [34]. These sensors are usually similar in shape to standard pharmaceutical capsules. Examples of ingestible sensors include imaging capsules that incorporate small cameras to film the patient's gastrointestinal tract (GIT)[1] [105], temperature-sensing capsules [30], pH-monitoring capsules [79], GIT pressure-sensing capsules [225], medication-monitoring capsules [5], gas-sensing capsules [110] and vibration capsules that mechanically induce peristalsis in the GIT to aid the treatment of constipated patients [15].

Ingestible sensors are believed to have a great impact in clinics. According to Caffrey et al. [34], over 3 million people in the US suffer from severe gastrointestinal diseases every year. Current medical technologies used to examine the patient's GIT such

[1]The gastrointestinal tract (GIT) is a series of hollow organs joined in a long, twisting tube from the mouth to the anus. The hollow organs that make up the GIT are the mouth, esophagus, stomach, small intestine, large intestine and anus.



(a) An ingestible temperature sensor. (b) An imaging capsule.

Figure 1.1: Ingestible sensors.

as gastroscopy and colonoscopy are usually invasive and hence might cause stress [111]. However, with ingestible sensors, patients only need to swallow the capsule. Therefore, ingestible sensors can decrease both the physical discomfort and the mental stress during examination since such devices are usually perceived as 'non-invasive' [111]. Moreover, the locations that current medical devices can reach are usually limited; for example, they cannot access the patient's small bowel [220]. However, ingestible sensors can change this, since they could travel through the patient's entire GIT. Furthermore, different from traditional medical examination where patients passively wait for doctors to investigate their bodily condition, the data measured by ingestible sensors can usually be accessed by both users and physicians, providing an opportunity for patients to actively engage with their own interior body data. Therefore, ingestible sensors are quickly becoming more accepted and preferred by patients over invasive methods [111].

Most existing research focuses on the medical use of ingestible sensors. Kalantar-Zadeh et al. [111] reviewed the current and emerging ingestible technologies, providing a comprehensive overview of ingestible sensors from the functional aspect. Other research mostly uses ingestible sensors to investigate the user's body data in a given context. For example, Laursen et al. [124] used ingestible sensors to investigate athletes' core body temperature during an Ironman triathlon. Another study used ingestible sensors to record the core temperature of hot flashes in menopausal women [67]. However, there is limited research in exploring ingestible sensors' affordances outside the medical domain. This thesis fills this gap by exploring how ingestible sensors might be used as design materials in playful interaction design.

### 1.2.2 Why Choose Ingestible Sensors in this Dissertation?

I believe ingestible sensors are an appropriate technology for approaching the design of interior bodily play for the following reasons. First, I assume that ingestible sensors can be accepted by users more easily compared to other intracorporeal technologies such as implants. This is because ingestible sensors enter the user's body without cutting the skin. Moreover, many ingestible sensors can be excreted naturally and hence the use of ingestible sensors does not require any body modification. In addition, ingestible sensors travel through the user's GIT, providing an opportunity for players to engage with different parts of the interior body including the oral cavity, esophagus, stomach, small bowel and colon. Therefore, I chose ingestible sensors a design material to advance our understanding of interior bodily play.

## 1.3 Research Question

This thesis focuses on utilising ingestible sensors to design digital play that facilitates interior bodily play experience. Therefore, in this dissertation, I address the research question:

How can we design ingestible play to engage players with their interior body?

This dissertation addresses the research question from a design-oriented perspective and utilises a research through design (RtD) approach [247]: three prototypes that support ingestible play have been developed as case studies. For each case study, I first designed and developed a playful system around a type of ingestible sensor and then conducted a user study in the real-world setting [190] to learn about the player experience in a real-world setting.

To answer the research question, I have divided the overarching question into two parts. The first part focuses on the design of playful experiences with ingestible sensors. As an interactive technology, ingestible sensors are relatively new to the field of HCI and there is a lack of understanding of how ingestible sensors can be used as design materials for interaction and digital play. Therefore, it is important to take an explorative approach to understand the design affordances of ingestible sensors. This could help designers better understand ingestible sensors as design materials in playful interaction design.

In this thesis study, I understand the design affordances of ingestible sensors mainly through my hands-on experience in developing three interactive prototypes with ingestible sensors. I first engaged with prior works around ingestible sensors and communicated with experts from the medical and engineering fields to understand the functional perspective on the sensor. I also gained insights on the sensors' affordances in interaction via autobiographical studies [182], i.e., I experienced the use of ingestible sensors myself. Moreover, through the design and development of the prototypes with ingestible sensors and the associated user studies' results, I was able to identify the key characteristics of ingestible sensors that provide opportunities for designing engaging bodily play experience.

The second part of the research question focuses on facilitating players' engagement with their interior body. This part is important in designing ingestible play to support the interior bodily play. Designers can easily embed an ingestible sensor in game design even without much design knowledge about ingestible play. For example, designers can design a digital role-playing game where the virtual character's health can be improved when the player swallows an ingestible sensor. However, such a design fails to engage players with their interior body and misses out on the many opportunities ingestible sensors provide as a design material to support interior bodily play.

In this thesis study, the field deployments of three prototypes supported participants experiencing ingestible play in a real-world setting, which provided insights into the UX of ingestible sensors and how participants engaged with their interior bodies. The results of these studies shed light on how ingestible play differs from other bodily play genres. Leaning on prior works in phenomenology that investigates the bodily experience from the first-person perspective [81], I synthesised all the findings of the three studies, reflected on my hands-on experiences, and ultimately propose a framework to guide the future design of ingestible play.

## 1.4 Research Scope

I acknowledge that the research question of this dissertation is exploratory and could be answered from different perspectives. In order to ensure a concrete contribution, I have limited the scope of the thesis to the following aspects:

1. This work is the very first exploratory work in HCI investigating the design of ingestible play and has only investigated the design with two types of ingestible sensors: a type of ingestible temperature sensor and an imaging capsule that can film the user's GIT. Other types of ingestible sensors such as human gas-sensing

capsules [110] were not used in this work due to ethical considerations. As this work involved ingesting a digital sensor, I discussed the design and study extensively with the ethics committee of my university. For the sake of safety, the ethics committee suggested to only use commercial products. Many innovative ingestible sensors such as the human gas-sensing capsules [110] are still for laboratory only use and laboratory ethics approvals with these products were only allowed with associated medical studies. Considering my work uses ingestible sensors for entertainment purposes, the associated studies were not approved. This led to a very limited range of choices of ingestible sensors. Hence, I have focused my work on the above two types of ingestible sensors to explore the design of ingestible play.

2. This work approaches the design of interior bodily play by exploring the design of bodily play with ingestible sensors. I acknowledge that there might be situations where people engage with their interior body without technology. For example, people can become aware of their interior body when experiencing a stomachache or nausea. However, these sensory experiences are difficult to control, and so also challenging to induce as a result of design intervention. Furthermore, they are unpleasant or even painful experiences, and are often a sign that something is happening inside the body [199]. Hence I did not consider such situations in this work.

3. This work investigates the design of ingestible play and focuses on the experiential perspective of the UX, i.e., players' engagement with their interior body. Benefits around health were not considered in this work, However, I believe that this work can serve as a starting point and inspire designers to create ingestible nstems that benefit the health of users. For example, ingestible systems can be used to track users' interior body information and provide suggestions that motivate users to take care of their interior body.

4. This work investigates ingestible play in a daily-life context. Participants were asked to go through their daily routine during the study. Other specific contexts were not considered in this work. Designers could use this work as a basis to create future ingestible play systems for specific contexts. For example, an ingestible play system could be designed for patients who will go through a procedure involving the use of an ingestible sensor in the hospital.

5. Last, the ethical issues of ingestible play is not the primary concern of this work. I carefully considered the ethical issues during the prototype design and study de-

sign. All the studies were considered as 'more than low risk research' and had received ethics approvals from the university ethics board. However, my considerations related to the ethical issues mainly focused on the participants' safety and data privacy while the broad ethical issues at the level of society is not discussed in this work, although I believe this would be an interesting topic to investigate in future research.

## 1.5 Case Studies

To answer my research question, I conducted three case studies in order to explore the design space of ingestible play and identify the design framework. In each case study, I designed a prototype that facilitates ingestible play. For each of the prototypes, I invited participants to experience the system in a real-world setting. I used semi-structured interviews to collect the data and used thematic analysis to analyse the player experience. In this section, I briefly describe each case study and the framework.

### 1.5.1 Case Study 1: The Guts Game

The Guts Game is a two-player mobile game based on an ingestible temperature sensor. The temperature sensor is single-use and measures the user's core body temperature every ten seconds as it travels through the user's GIT, usually within 24–36 hours. During this time, it transmits the sensed temperature data wirelessly to a data recorder. The recorder then forwards the data to a smartphone.

In this case study, the Guts Game started by offering the two players some food. I then dressed up as a doctor and told the players a fictitious narrative: first, that a parasite hidden in the food had infected them and that the parasite was highly sensitive to environmental temperatures; and second, that the Guts Game application had been developed to assist with the treatment of the parasite. The game app offered a set of game tasks. By completing a task, the player weakened the parasite. The game then awarded points to the player. The Guts Game mobile app provided players with an animated flame to represent their temperature. The game had three different task modes. The 'general' mode required players to change their body temperature to reach the task's goal. In the 'feeling' mode, the game did not provide body temperature data to players; however, players needed to submit the task when they felt their body temperature had reached the task's goal. The closer the player's temperature was to the goal, the more points they obtained. In the 'challenge' mode, players could send a personalised challenge task to their co-player.

During the game, the players could send pictures to each other. There was no restriction on the content or number of pictures. Players could also discuss what they did to change their body temperature and their game experiences anytime via sending in-game texts. There were also no restrictions on the players' actions. Players could freely explore different ways to change their temperature, including eating hot or cold food and exercising. The game ended when one of the players excreted their sensor. The player who gained more points won the game. To understand the Guts Game's design and UX, I did a field study with 14 participants (7 pairs). The study resulted in three design themes and a set of design strategies for ingestible play.

The Guts Game served as an initial exploration of the design of ingestible play. It helped demonstrate that ingestible sensors can be used as design materials to facilitate engaging bodily experience. I found that players became less engaged with the Guts Game over time as the novelty effect was fading. The smartphone-based game was not effective in attracting the players' attention back to the digital play as I expected. Therefore, in the second case study, I designed the play experience towards being always-available to fit the ubiquitous nature of ingestible sensors. Moreover, the design strategies I generated from this case study helped inform the design of the second prototype.

### 1.5.2 Case Study 2: HeatCraft

HeatCraft is a two-player system for users to playfully experience their body temperature as measured by an ingestible sensor via localised thermal stimuli. The stimuli are generated via two overlapping heating pads attached to a waist belt worn by players. The stimuli's temperature changes based on the temperature data sensed by the ingestible sensor.

HeatCraft adopts open-ended gameplay. Players can freely explore how their actions affect the sensed temperature data. I conducted a study with 16 participants (8 pairs of two players) to experience HeatCraft in the field. The two players in each pair were friends before the play. They were encouraged to spend at least three hours physically together during the study. The results show that HeatCraft facilitated ubiquitous and spontaneous playful experiences, augmented the players' bodily experiences and promoted awareness of their activities and surrounding environment.

HeatCraft took a step further to playfully engage players with their interior body by supporting always-available interactions and providing intimate sensory experiences that could better direct players' attention to their body compared to the Guts Game. With this case study, I also articulated three themes and presented design strategies for ingestible play, which can be seen as an add-on to the results I gained from the Guts Game. However, I still found that the findings were not adequate to answer the research question, for two main reasons. First, both the Guts Game and HeatCraft used an ingestible temperature sensor that senses one-dimensional temperature data. I believe that the design knowledge gained from the two studies might be easily used to design other ingestible play systems with ingestible sensors that also sense one-dimensional data, e.g., the intestines' pH value or pressure. However, for those ingestible sensors that capture multi-dimensional data such as imaging capsules that film the user's GIT, it is unclear whether the design themes are still adaptable. For example, designers could use thermal stimuli or other localised sensory stimuli like haptic experiences to support players experiencing their intestines' pH value, but it would be hard to let players experience their GIT video via the stimuli. Second, the player's bodily experience with different types of interior bodily data might be naturally different. For example, seeing interior body images might facilitate more intense bodily experience than knowing interior bodily data [207]. These reasons inspired me to design the next case study with an imaging capsule that can film the player's GIT.

### 1.5.3 Case Study 3: InsideOut

InsideOut is a playful wearable system based on a capsule endoscopy system. InsideOut supports players playfully interacting with a real-time video of their interior body shown on a display placed in front of their body. After players swallow the imaging capsule, they can watch the video as the capsule travels through their GIT. During this time, the players can explore various actions, such as eating, drinking and moving, to influence their GIT. In addition, I designed six play modes to enrich the play experience and engage players with their interior bodies. For example, a play mode called 'body balance' maps the video to the surface of a rolling ball placed on a springboard. Players need to move their body to balance the springboard in order to keep the ball from falling down. I investigated the player experience of InsideOut with 7 participants via a field study. The study results show that with InsideOut, players appreciated the experience of seeing, exploring and knowing their interior body. With this case study, I also identified key

Table 1.1: The design framework of ingestible play.

| | Sensing | Fusing | Moving |
|---|---|---|---|
| The material interior body | Confrontation | Compatibility | Ubiquity |
| The functional interior body | Exploration | Augmentation | Agency |
| The affective interior body | Ownership | Cultivation | Imagination |
| The social interior body | Resonation | Intimacy | Uncertainty |

themes and proposed a set of design strategies for ingestible play with a focus on imaging capsules. Although some of the design knowledge I gained from this study might only be suitable for design with technologies that capture the image data of the interior body, this study helped to gain a more complete understanding of ingestible sensors and moved towards the generation of the design framework of ingestible play.

### 1.5.4 The Design Framework of Ingestible Play

Through designing and studying the three case studies, I generated a design framework for designing ingestible play which is shown in Table 1.1. The first row of the table shows the key characteristics of ingestible sensors that might facilitate intriguing design opportunities. The first column of the table shows the four perspectives on bodily experience [81] that designers can consider when designing engaging experiences with the interior body. For the combination of each ingestible sensor's characteristics and the perspective on bodily experience, I present a design theme for ingestible play. In Chapter 7, I also present implementation suggestions that might support the corresponding design theme. I do not see the framework as a strict instruction for the design of ingestible play. Rather, I believe it can support the ideation and design process while giving space for designers to create diverse engaging ingestible play experiences.

## 1.6 Contributions and Benefits

This dissertation makes three main contributions.

### Artifact Contributions

I have created three playful interactive prototypes: the Guts Game, HeatCraft and InsideOut. These artifacts are all based on ingestible sensors, supporting players to play with their interior body. The three novel artifacts reveal the new possibilities of using intracorporeal devices such as ingestible sensors as design material in interactions, and in particular digital play. The artifacts could inspire designers to consider the role of the interior body in interaction experiences.

### Empirical Contributions

This dissertation also makes empirical research contributions by presenting the UX of the three designed prototypes. The UX were examined through field studies [190]. The findings on the UX with the three prototypes not only demonstrate the value of introducing ingestible sensors to interaction design, but also provide insights on the potential user behaviour and experience when engaging with the interior body. The empirical findings present practical design guidance that aims to support designers and developers in creating systems that support ingestible play and, more broadly, interior bodily play.

### Theoretical Contributions

Lastly, this dissertation also contributes to theory by presenting a design framework for ingestible play. By synthesising the empirical findings and craft knowledge gained through the three prototypes, I have identified a design framework to guide the future design of ingestible play. Such a framework provides a structured conceptual understanding of how ingestible sensors can playfully support players' engagement with their interior body, which may expand the future body-centric interactive experience.

I believe that this dissertation also potentially benefits a wide range of audiences. Here I present some of the potential benefits as follows.

1. **Increasing players' bodily awareness and bodily knowledge**

   Ingestible play might increase players' bodily awareness and bodily knowledge for two reasons. First, ingestible play can show players their interior body data, enabling them to become more aware of their interior bodies. Second, compared to standard procedures where ingestible sensors are used such as capsule endoscopy procedures, ingestible play can be designed to let players experience greater agency by supporting them to interact with their interior body data via bodily movements and actions. The experience facilitated by this increased agency could help players build a connection between the interior body data representation and the their own body. Prior studies suggested that increased bodily awareness and bodily knowledge can increase players' appreciation of their own body [99] and lead to various health benefits such as reduced stress, anxiety and depression [26]. These benefits can be found as outcomes in a variety of activities that increase bodily awareness, such as yoga and tai chi [150].

2. **Facilitating heightened engagement with health data**

   With ingestible play, players might engage with their interior body data. Prior research suggested that engaging with personal information can bring about various benefits such as increased physical activity, better health behaviours, and even a better understanding of one's own goals, values and desires [83]. However, it might be difficult to engage with interior body data as it might be challenging to build a connection between one's own body and the collected interior body information. For most people, their interior body is a matter of 'mystery and speculation' [187]. Consequently, people might not receive the potential benefits of accessing interior body data. Moreover, players might find the data unappealing and might interpret the data incorrectly, which might make them feel anxious (such as with capsule endoscopy). Ingestible play provides an opportunity for players to interact with their interior body data in a playful way, which might help them engage with their interior body data and encourage a healthier lifestyle related to the GIT, ultimately contributing to overall health and wellbeing.

3. **Engaging players with the ingestible sensor procedure**

   Ingestible play might help players engage with the ingestible sensor procedure. This engagement could facilitate acceptance of the technology [101]. Moreover, ingestible play might provide players with better access to their data, as well as facilitating communication with the medical professionals who interpret this data, improving the user's satisfaction and impacting on the perceived quality of care and possibly even clinical outcomes [112].

4. **Facilitating critical reflection**

   Prior research suggested that supporting user interaction with personal data may raise technological, ethical and regulatory concerns relating to how people make sense of, engage with and rely on this data [201]. Inspired by this, I believe Ingestible play might entice users to reflect on the role of modern technology and their resultant data in their daily lives relative to their health and wellbeing. Users might become more critical about how their lives are mediated by modern ingestible technologies, assumptions, values, ideologies and behavioural norms with ingestible play. For example, with imaging capsules that film their GIT, users might reflect on the role of contemporary imaging technologies in modern society, since the 'endoscopic gaze penetrates the user's skin' [204, 228]. Moreover, in current clinical settings, the interior body data collected by ingestible sensors is usually interpreted by a doctor. Usually the user only listens passively to the doctor's interpretations and conclusions. With ingestible play, the player can understand their bodily data and interact with this data. Therefore, this project could raise questions such as: Who should engage with one's personal interior body data? Who should review the data first? Who controls or has rights to the data? Etc.

## 1.7 Structure of this Dissertation

This dissertation is organized into eight chapters. After the introduction (Chapter 1), I will present the literature review as the research background (Chapter 2). Then, I will introduce the research methods of this work (Chapter 3). Chapters 4, 5, and 6 will introduce the three design case studies: the Guts Game, HeatCraft and InsideOut. In Chapter 7, I will present the design framework for ingestible play. Lastly, in Chapter 8, I will conclude the dissertation, proposing in detailed limitations of this work and presenting future research directions that could be extended from this dissertaion.

# Chapter 2
# Related Work

IN this chapter, I provide an overview of prior work around intracorporeal technologies in HCI, ingestible sensors for non-medical uses, body-centred interactions and play, and biofeedback system design.

## 2.1 Ingestible Sensors

Ingestible sensors are wireless medical devices that are ingested like medication, in the form of pills, tablets or capsules. In this section, I introduce the ingestible sensors that are commercially available and some of the ingestible sensors that were presented in academic papers based on their functions.

### Imaging capsules

Imaging capsules, also known as capsule endoscopy, are ingestible sensors that include cameras for filming the patient's GIT. Conventional endoscopy usually inserts a flexible fibre-optic tube that places a camera into the patient's GIT to perform an examination, for example, detecting bleeding or neoplasm. However, with conventional endoscopy it is hard to access the patient's small intestine. Imaging capsules can overcome this limitation as they naturally pass through the entire GIT [15].

Imaging capsules make up the most significant part of the global market for ingestible sensors [111]. Currently, there are several imaging capsules on the commercial market. PillCam, manufactured by Given Imaging (Israel), was the first commercially available capsule endoscopy system. There are different PillCam capsule endoscopy systems developed for various purposes: PillCam SB[1] for small intestine examination; PillCam UGI[2]

[1]www.medtronic.com/covidien/en-us/products/capsule-endoscopy/pillcam-sb-3-system.html
[2]www.medtronic.com/covidien/en-us/products/capsule-endoscopy/pillcam-ugi-system.html

for esophageal imaging; and PillCam Colon[3] for large intestine examination. There are also other commercially available imaging capsules, such as:

- EndoCapsule[4] developed by Olympus (Tokyo, Japan)
- OMOM Capsule Endoscopy[5] developed by Jinshan Science & Technology (Group) Co., Ltd (Chongqing, China)
- MiroCam[6] developed by IntroMedic (Seoul, Korea)
- CapsoCam[7] developed by CapsoVision (Saratoga, USA).

All these products were developed for small intestine examination. Recently, controllable capsule endoscopy systems have emerged, allowing health professionals to control the capsule's movement, posture and angle with a controller outside the patient's body. Examples of controllable capsule endoscopy include OMOM controllable capsule endoscopy[8] developed by Jinshan Science & Technology (Group) Co., Ltd (Chongqing, China) and MCE capsule endoscopy system[9] developed by Ankon Technologies Inc. (Wuhan, China).

### Temperature-sensing capsules

The ingestible temperature-sensing capsules are usually developed for monitoring the user's core body temperature (i.e., the temperature of the internal organs located deep within the body). Such products are beneficial for physiology experiments and for people such as firefighters, soldiers and athletes who work in extreme environments. Examples of ingestible temperature-sensing capsules are CorTemp[10] developed by HQinc (Palmetto, USA) and the VitalSense Jonah capsule[11] developed by Phillips (Amsterdam, Netherlands).

[3] www.medtronic.com/covidien/en-us/products/capsule-endoscopy/pillcam-colon-2-system.html
[4] www.olympus-europa.com/medical/en/Products-and-Solutions/Products/Product/ENDOCAPSULE-10-System.html
[5] www.jinshangroup.com/en/solutions/omomhd.html
[6] www.intromedic.com/eng/item/item_010100_view.asp?search_kind=&gotopage=1&no=3
[7] capsovision.com/capsocam-system/
[8] www.jinshangroup.com/en/solutions/omomrobotic.html
[9] www.ankoninc.com.cn/official-mobile/productions
[10] www.hqinc.net/cortemp/
[11] bmedical.com.au/product/core-body-temperature-capsule-ingestable-jonah/

### Medication-adherence monitoring pills

Ingestible sensors can also be designed to monitor medication compliance. Proteus Discover developed by Proteus Digital Health (Redwood, USA) is a smart pill system to measure a patient's medication adherence [19]. The patient swallows the Proteus smart pill along with their daily medicines. The smart pill reacts with stomach acid and produces a voltage after being swallowed. The voltage then powers a circuit to transmit a signal to an external patch, indicating that the pill has been taken. The patch then sends the patient's medication-adherence information to a smartphone and also to their doctor.

### Other commercial ingestible sensors

There are also other commercial ingestible sensors. IntelliCap developed by Philips Inc. (Amsterdam, Netherlands) can measure pH value and core body temperature, and deliver pharmaceuticals [111]. Once the capsule reaches the target location in the GIT, the capsule receives an RF signal to release the pharmaceuticals. SmartPill[12] developed by Medtronic (Minneapolis, USA) can measure the pH value, temperature and pressure in the GIT. Bravo Capsule[13] also developed by Medtronic (Minneapolis, USA) can evaluate heartburn and reflux symptoms related to gastroesophageal reflux disease (GERD). During usage, it attaches to the patient's esophageal wall and monitors the pH value in order to understand the reflux symptoms. The Atmo gas-sensing capsule[14] developed by Atmo Bioscience (Melbourne, Australia) can measure the concentration of various gases in the GIT in real time. The Vibrant capsule[15] developed by Vibrant Ltd. (Israel) stimulates the colon to encourage digestive activity and relieve constipation.

Other types of ingestible sensors are currently not available on the market but have been reported in academic publications. Beardslee et al. [15] reviewed the current research around ingestible sensors and summarised the ingestible sensors under development, classifying these ingestible sensors into four groups based on their functions. The first group is ingestible sensors for sensing the user's GIT. For example, Caffrey et al. [33] presented an ingestible sensor that integrates an electronic tongue sensor to support real-time electrochemical sensing of the GIT, aiming to aid in the diagnosis of GIT diseases such as Crohn's and ulcerative colitis. Demosthenous and Pitris [50] presented an

[12] www.medtronic.com/covidien/en-us/products/motility-testing/smartpill-motility-testing-system.html

[13] www.medtronic.com/covidien/en-us/products/reflux-testing/bravo-reflux-testing-system.html

[14] atmobiosciences.com/

[15] vibrantgastro.com/

ingestible sensor that uses infrared fluorescence techniques to detect cancer in the small intestine. Mimee et al. [153] developed an ingestible sensor that can detect GIT bleeding based on biosensor bacteria and luminescence electronics that wirelessly communicate with an external device. Merino et al. [151] presented an ingestible glass sensor that can provide real-time location information inside the user's GIT for digestive motility tracking. Dagdeviren et al. [44] presented the design of a proof-of-concept ingestible sensor that senses mechanical deformation within the gastric cavity. This concept might benefit the future development of ingestible sensors that sense the GIT's mechanical variations and harvest mechanical energy inside the GIT. The second group of ingestible sensors is for biopsy. For example, Le et al. [126] presented a capsule endoscope that embeds a module that can perform a microsurgical operation to collect biopsy tissue in the GIT. The third group of ingestible sensors is for drug delivery. For example, Abramson et al. [1] developed an ingestible sensor that supports drug delivery by rapidly propelling dissolvable drug-loaded microneedles into intestinal tissue using a set of unfolding arms. The last group of ingestible sensors is GIT-indwelling systems that immobilise the sensor at a specific location in the GIT. For example, Nakamura et al. [170] developed an ingestible sensor for long-term GIT monitoring. The sensor includes an inflatable silicone balloon, which inflates in the user's stomach based on chemical reactions and can be deflated and excreted at any time via electrolysis.

I used CorTemp ingestible temperature sensors and the OMOM Capsule Endoscopy system in my three case studies in my PhD research. These choices wereas made mainly for reasons of technology availability and ethical reasons. As mentioned earlier (in Chapter 1), I have extensively discussed my work extensively with the ethics committee of my university. For the sake of safety, the ethics committee suggested that I only use commercial products. Therefore, the ingestible sensors found onlythat are in research labs were not considered when I was choosing ingestible sensors. Among the commercial products, I chose ingestible sensors based on availability. For example, similar to the CorTemp I used in this research, VitalSense developed by Phillips (Amsterdam, Netherlands) can also measure core body temperature. However, I did not find a dealer providing these sensors in Australia. Also, when I started working on the third case study, I contacted the dealer for EndoCapsule in Australia; however, they only provide these devices to hospitals and clinics.

I acknowledge that the choice of ingestible sensors might have limited the design. For example, both of the two chosen sensors pass through the user's GIT naturally and their motility cannot be controlled. This limits the potential interactions that can be designed.

In the future, players might be able to control ingestible sensors travelling around their GIT to explore their interior body playfully. Moreover, the technical limitation of the chosen sensors might have had an influence on the user experience (UX). For example, the CorTemp sensor's accuracy can be easily influenced by electromagnetic interference, which might cause negative experiences. In the future, with ingestible technology becoming less error-prone, better UX could be designed. Moreover, current sensors have a relatively long sensing interval. For example, the CorTemp sensor senses the body temperature every 10 seconds. Players might experience a higher sense of agency if thise interval is shortened in the future. However, I do not see this as a problem, as people naturally have a relatively low sense of agency over their interior body;, unlike a button that can respond immediately after being presseding, our body data changes slowly after one performing certain actions.

## 2.2 The Body in HCI

In recent years, the human body has played an increasingly important role in HCI research [137]. Before the third wave of HCI [22], the design of technology and interaction qualities was mainly assessed from usability perspectives [96]. As a result, the human body was usually understood by designers from an ergonomics perspective, a third-person perspective that treats the body as an object. Third-wave HCI focused more on the cultural levels such as aesthetics, emotion, experience and entertainment [12, 22]. At this stage, designers began to understand the user as an embodied being and to consider the role of the bodily experience in designing interactions. Designers borrowed phenomenological theories, especially the work on the lived body by Merleau-Ponty [152], in order to see humans as 'experiencers' of interactions. Dourish [56] proposed embodied interaction as a new interaction design paradigm that puts the bodily and social aspects of interactions at the centre of the design process. Designers began to also look at the users' lived body experience, or first-person experience of interactions. Svanæs [218] proposed that interaction designers should not overlook the user's lived body during the design process because the first-person perspective engenders new approaches to design challenges and enables new design alternatives.

Under this somatic turn in HCI [137], many design methods of body-centric design highlight the user's lived body experience. For example, Loke and Robertson [135] proposed seven concepts of the body (i.e., anatomy, physiology, knowledge, physical skill, expression, felt experience, social and cultural) to help designers develop body literacy to better articulate the felt dimension of bodily experience and to inspire designers to create novel interactions that put the lived body at the centre of experiences. Tholander et al.'s paper on design qualities for whole-body interactions highlighted the first-person experience [224]. It argued that whole-body interactions should help users engage with and appreciate both the interaction and their performance. Höök et al. [99] proposed somaesthetic appreciation design, which highlights the user's first-person bodily experiences in interactions and encourages them to turn their attention inwards, articulate their bodily experiences and increase their somatic awareness. Klemmer et al. [117] emphasised the physical body's central role in shaping human experience and understanding of the world. The authors proposed five themes, i.e., thinking through doing, performance, visibility, risk and thick practice, for interaction design based on embodiment theories. Alaoui et al. [64] identified first-, second- and third-person perspectives on how designers design with the human body in embodied design. The first-person perspective focuses on the designer's self-observation and the exploration of one's own bodily experience in designing and evaluating interactive technologies. The third-person perspective emphasises objective observation, for example, by gathering scientific data that removes the bias of the self. The second-person perspective includes observing others through kinesthetic empathy. Similarly, Svanæs and Barkhuus [219] presented a 3x3 matrix as a framework for body-centred design. One dimension of the matrix is the point of view, i.e., first-person perspective (lived body), second-person perspective (body of the other) and third-person perspective (body as object). The other dimension is tense, including past, present and future. There are also other design methods that use the lived human body as a tool, such as Bodystorming [176], which allows designers to be physically present in real contexts as a way to come up with and test novel design ideas; Moving and Making Strange [136], which utilises the moving body and its felt experience as the source for generating and evaluating movement-based interactions with technology; and Somatic Connoisseurship [197], which emphasises the role of somatic facilitation during the technological design process.

These works provided a solid foundation for how designers can engage with the human body when designing and evaluating technology. However, most of these works only emphasise the lived body experience and overlook the diversity of human bodies. This might be problematic when designing for certain user groups or with radical technologies. For example, with ingestible play different people might have different attitudes towards the activity, as some might feel uncomfortable swallowing a foreign object for entertainment. According to Homewood et al. [96], the concept of the body in HCI has moved from 'body' to 'bodies', aiming to highlight that designers should be aware that there is no universal body.

The datafied body is a conceptual lens under the concept of 'bodies'. Homewood et al. [96] proposed that with the development of body-centric technologies [158], one can better understand one's body as an individual rather than a 'standard' human body. According to Homewood et al. [96], this approach of viewing bodies as datafied is related to transhumanism, which envisions a future where people augment their bodies using technologies to enhance their bodily functions [96,167]. In HCI, the interaction paradigm Human–Computer Integration (HInt) adopts this view of the body as datafied [96], as discussed next.

## 2.3 Human–Computer Integration

HInt is an interaction paradigm that emphasises the intertwinement between humans and machines [164]. HInt was first presented by Farooq and Grudin [63]. According to the authors, interaction refers to a stimulus–response paradigm, whereas integration highlights a 'partnership or symbiotic relationship in which humans and software act with autonomy' [63]. One example is the semi-autonomous vehicle, where users and computers work together to drive. Mueller et al. [164] expanded the concept of HInt to describe the recent trend where technologies are being closely interwoven with the human body. Mueller et al. [164] used the word symbiosis to refer to the original meaning of HInt presented by Farooq and Grudin [63]. In addition, Mueller et al. [164] argued that there is an additional type of Human-Computer Integration called fusion, referring to 'integration in which devices extend the experienced human body or in which the human body extends devices'. According to Mueller et al. [164], adopting human-compatible technologies in order to understand the user's physical and mental state can better support the fusion between computers and the human body.

In this dissertation, I adopt Mueller et al.'s understanding of Hint [164]. An ingestible sensor is a type of human-compatible technology that performs functions inside the user's GIT. Therefore, ingestible sensors are part of the HInt trend and potentially facilitate fusion between technology and the user's body. The work of HInt inspired me to consider how ingestible play might extend players' experiential body and therefore I asked questions regarding participants' bodily experience with the designed bodily-integrated ingestible systems in my case studies.

## 2.4 Culturally Grounded Human–Computer Integration

Before the concept of HInt was 'officially' presented in HCI academic publications, the envisionment and practices of HInt had already emerged in other fields. According to Mueller et al. [164]:

> Tracing back the precise origins of the concept of "integration" is outside the scope of our work as we intend to focus it on the direct challenges this concept poses for the field of HCI. Yet, we briefly illustrate how this concept originated in various shapes and in a wide variety of knowledge fields. The concept itself can be seen in science fiction, in concepts, such as "man-machine mixture" in Edgar Allan Poe's writing in 1843 or the humanoid-"robot" in Karel Capek's 1920s play; in neuroscience where Manfred Clynes and Nathan Kline coined the term cyborg in the 1960s; philosophy, as echoed in D. S. Halacy's 1965 essay on the Cyborg; art, for example in Stelarc's 1990s work.

HInt is also related to other cultural movements. Transhumanism aims to enhance human capabilities through bodily-integrated technologies [24, 223]. For example, Oscar Pistorius, a running athlete whose legs had been amputated, took part in the Olympic Games using prostheses. The situation of Pistorius also raises ethical issues in transhumanism. For example, should the use of HInt technologies such as prostheses be considered gaining unfair advantage or cheating [39]? Another cultural movement related to HInt is the Do It Yourself Biology (DIYBio) movement, which enables hobbyists to experiment with organic materials. Within the DIYBio movement, the subgroups Body Hacking and Grinders are more relevant to this dissertation. The concept of body hacking overlaps with transhumanism to some extent. Body hacking usually uses technology to make functional and physiological modifications to the body [181]. For example, the biohacker Meow-Ludo Disco Gamma Meow-Meow removed the chip from a travel card and implanted it into his hand. However, this raised ethical discussions as he was later fined for violating the travel card's terms of use [80].

Besides cultural movements, body art is a field that can be seen to manifest the culture of HInt to some extent. Stelarc[16], a body artist, has done a variety of projects envisioning the future extension of the human body. Stelarc regards the natural human body as

[16] stelarc.org/

'obsolete', both in form and in function. With this perspective, Stelarc uses his own body as a design material to express his views on the human body: emerging technologies might help transcend the limits of our bodies [232]. For example, Stelarc's early work *Third Hand* attached a mechanical human-like hand to his right arm and this additional hand was controlled by the electrical signals of the muscles from the wearer's abdominal and leg muscles [211]. Similarly, Chris Burden presented a radical art performance called *Shoot* showing the artist being shot in the arm at close range with a rifle. According to the artist, this body art performance expressed the idea of breaking down bodily limitations by engaging in extreme actions such as body modifications that put one's body in a state of pain, ecstasy and transgression [222].

Considering that there are many body art projects related to HInt, here I only give examples about art projects involving intracorporeal technologies, as they are more relevant to the topic of this dissertation (i.e., ingestible play). Intracorporeal technologies are technologies inside the human body. Examples of intracorporeal technologies are implantables (i.e., devices that are implanted inside the human body such as pacemakers), ingestibles (i.e., devices that are ingested like regular pills such as imaging capsules) and injectables (i.e., devices that are injected into the human body via needles such as an injectable oxygen sensor[17]) [116]. Stelarc has also played with intracorporeal technologies. *Ear on Arm* is a project presented by Stelarc [213] where the artist implanted an artificial ear onto his forearm. The idea behind the project was that Stelarc believes that prosthetic attachments and implantables should not be simply viewed as replacements for a part of the human body, but rather that they can also augment and extend the human body. Other artists are engaging with implantables to enhance their bodily capabilities as well. For example, Neil Harbisson implanted an antenna into his skull. The antenna can measure electromagnetic radiation, phone calls, music, videos and images, then translate the information into audible vibrations and send them to the artist [241]. ORLAN is an artist who has undergone nine plastic surgeries to turn her body into an artwork [242]. ORLAN sees her face and body as malleable design materials for shifting her identities [8]. ORLAN's works question body boundaries, as the films of her surgeries show the radical difference between the inside and the outside of the human body, and can be confronting to watch [74].

Ingestible sensors have also been used in artworks. For example, the artist Stelarc inserted an ingestible sensor containing a beeping device and a flashing light into his body to express his understanding of the human body [212]. He argued that the body is

[17] profusa.com/lumee/

'hollow' and useable as a public exhibition space. Poope [106] designed *Audiopill*, which allows the user to experience music from their insides after swallowing an ingestible sensor. The pill vibrates inside the user's GIT with musical beats for about 10 hours. To highlight the use of internal body images beyond their medical applications, Warnell [237] swallowed an imaging capsule (an ingestible sensor containing a camera) and showed audiences the captured video of his GIT. Mona Hatoum exhibited *Deep Throat*, an art installation that projected the GIT's inner appearance on a plate placed on a fine dining table [119]. Another of Hatoum's works, *Corps étranger*, used an imaging capsule to film the artist's exterior and interior body in turn, and then projected the film on the floor of a cylindrical structure that viewers entered. A soundtrack broadcasting a heartbeat accompanied the film [14]. Hatoum's works aim to show audiences the unknown parts of the human body and facilitate reflections upon the 'violent appropriation on the human body' of contemporary imaging technologies [204].

These prior works suggest that the trend of HInt can be culturally grounded. Moreover, related art projects highlight how intracorporeal devices might influence one's bodily experience and identify the potential for using ingestible sensors as a raw material for interaction design.

## 2.5 From cultural movements to HCI practices

The cultural movements such as transhumanism and related body art projects presented above have inspired many HCI researchers to consider what a body-centred interaction future could be. For example, Stelarc's early work *Third Hand* inspired Saraiji et al.'s project MetaArms [195] to some extent. MetaArms augments the human body with two additional robotic arms controlled by the user's feet and extends human capabilities when tackling tasks that are difficult to perform with only two hands. Moreover, Stelarc's project *Third Hand* is one of the first applications of electrical muscle stimulation (EMS) for non-medical purposes. It informed later projects in HCI using EMS for interactive purposes. For example, Lopes et al. used EMS to actuate the user's wrist as output [138].

Similarly, the subculture of using intracorporeal devices for non-medical purposes has also inspired the design of novel interfaces. Inspired by the Grinders movement, Strohmeier and McIntosh [216] explored the design of implantable magnets as input devices for on-body positioning and as output devices that provide in vivo haptic feedback by actuating the implanted magnets to vibrate for body-centric interactions. Similarly, Holz et al. [95] investigated subdermally implanted user interfaces that embed a pressure sensor, a tap sensor, a button, a capacitive sensor and a brightness sensor as input devices, and an LED and a vibration motor as output devices. Other research focuses on the motivations behind the voluntary use of intracorporeal devices; for example, Heffernan et al. [90] interviewed people who voluntarily inserted digital devices into their bodies to understand the motivations for the non-medical use of implantables. This research suggested that hobbyists may choose to use implantable devices mainly for convenience or to extend human senses. The discomfort caused by wearable devices also seems to boost the popularity of implantable devices. In summary, implantable devices appear to be used for reasons including 'desiring a new body modification', 'wanting to be a part of the next big thing', 'extending human function and capabilities' and 'tiring of wearables'. Compared to Heffernan et al.'s work, Homewood and Heyer's work was more focused on the design of intracorporeal devices and explored a speculative design space of controllable implanted contraceptives for females [97].

These emerging HCI works around intracorporeal devices motivated me to consider the following: As ingestible sensors have been used in body arts, can these devices be used in HCI and in particular digital play design?

## 2.6 Bodily Play

This work is situated in the field of bodily play. I believe the context of play can allow for a broader understanding of the potential UX and interactions, as play naturally encourages players to explore. As Gaver [71] said:

> Play is not just mindless entertainment but an essential way of engaging with and learning about our world and ourselves—for adults as well as children. As we toy with things and ideas, as we chat and daydream, we find new perspectives and new ways to create, new ambitions, relationships, and ideals.

The early work in bodily play took a more third-person perspective, that is, seeing the body as an object and focusing on body movements and social interactions. For example, Benford et al. [18] proposed a design framework 'sensed, expected and desired' for sensing-based interactions. This work distinguished between users' movements that were expected, those sensed by the sensing technology and those desired and required by the system. Segura et al. [146] identified a design space for body games and argued that technology affordances are important design resources in bodily play design. Rogers and Muller [191] presented a sensor-based play framework to assist designers when considering the sensor properties and the couplings between player actions and system feedback when designing player experiences. Buruk et al. [29] presented a design framework to explore wearable devices' full potential in digital play.

Influencing by the third wave of HCI and the somatic turn in the field [137], an increasing number of researchers took a more first-person perspective on bodily play design. Mueller et al. [159] used the German words *Leib* (i.e., lived body) and *Körper* (i.e., physical body) to highlight the first- and third-person perspectives on the human body when designing bodily play. Later, Mueller et al. [168] suggested that the bodily play experience can also be understood from two perspectives, *Erfahrung* referring to an experience where one gains knowledge and *Erlebnis* referring to a tacit experience or 'lived experience'. The perspective *Erfahrung* is more third person, while *Erlebnis* takes a more first-person perspective. In Mueller et al.'s early work [160], the authors used phenomenological theory [231] to propose that, in exertion games, designers can view the body through four lenses: the responding body, the moving body, the sensing body and the relating body. There are other researchers' works exploring bodily play from a first-person perspective. Segura et al. [144] proposed embodied sketching, an approach enabling designers to design and understand bodily experiences early in the design process. Matjeka and Mueller [148] distinguished bodily play by providing four different combinations of bodily 'playing/gaming' a 'play/game'.

Together, these works aimed at providing a generalised design vocabulary or framework to guide the design of bodily play. Therefore, most of these works did not consider the affordances of interactive technologies. With the trend of HInt, technologies are becoming more integrated with the human body, which might change how people experience their body and therefore bring about novel design opportunities, along with design challenges, to the field of bodily play.

While there is a lack of design knowledge of bodily play within HInt, there are still projects that take a HInt perspective on game experiences. For example, Byrne et al. [31] used galvanic vestibular stimulation (GVS) to create vertigo experiences as a digital game design resource. Kunze et al. [122] proposed superhuman sports that use human augmentation technologies to surpass human bodies' physical and cognitive restrictions and enable superhuman abilities. For example, Skeletonics[18] uses mechanical exoskeletons to

[18]www.skeletonics-us.com/

facilitate an intriguing and entertaining superhuman sports experience. By wearing the system, users can experience themselves as a giant. However, Bryne et al.'s work [31] limited their findings to vertigo experiences, which are hard to use directly by designers to create other playful HInt experiences. Kunze et al.'s work [122] took a practical perspective and mainly made an artefact contribution. There is still a lack of systematic understanding of how bodily play can be designed in the era of HInt. Mueller et al.'s work on bodily-integrated play [162] can be seen as an initial attempt to fill this gap, aiming to provide insights into bodily play design with bodily-integrated technologies. The authors suggested that designers should:

1. support playful explorations of the bodily integration to learn more about players' bodies;
2. highlight opportunities for play resulting from the bodily and temporal availability;
3. facilitate self-expression through bodily integrated movement;
4. initiate playful social interaction through bodily integration technology;
5. facilitate reflection on both having and being an integrated body;
6. challenge cultural norms around the body through bodily integration.

These strategies for bodily integrated play can provide insights into the design of ingestible play considering that ingestible sensors are integrated into the human body. However, Mueller et al. [162] approached the design from a technical perspective, i.e., considering how bodily-integrated technologies can be used as design resources for digital play. There is still a need to understand how the design of digital play can support players to engage with their interior body.

## 2.7 Body-Centred Interactions that Focus on the Interior Body

There are concepts of body-centred interactions that might involve the interior body. Pataranutaporn et al. [178] proposed 'living bits' to highlight the opportunity of integrating living microorganisms with computers. For example, Mushtari is a wearable integrated with synthetic microorganisms that can augment one's biological functionality [10]. Similar to 'living bits', the gut–brain computer interface [234] detects gut changes via abdominal electrodes to see how one's digestive activity is synchronised with eating, sleeping, emotion, etc [65]. Prior projects have used gut biofeedback for various purposes such as affect detection [235] and emotion regulation [154]. These concepts take a more third-person perspective on the interior body, while the concept of inbodied interaction looks at the interior body from a more first-person perspective. Schraefel [198] proposed a model of inbodied interaction highlighting that designers could consider tuning the quality, quantity, time and context of one's fundamental processes, i.e., movement, eating, engagement, cogitation, sleep, to increase how one feels, which benefits health and wellbeing. Ingestible play might involve all these five fundamental processes as interior bodily data might be affected by various activities such as eating, moving and sleeping. Therefore, this work is in line with inbodied interaction, e.g., designers could consider supporting players' reflections on how these fundamental processes may influence their entire bodies and engage players with their interior bodies.

There are also projects on body-centred interactions aiming to increase the understanding of the interior body, which can shed light on how the interior bodily information can be externalised via design. For example, Fujisawa et al. [69] presented a virtual reality (VR) system called A Body Odyssey to simulate the journey of food digestion. Viewers wore a head-mounted display to see their food travelling through digestive organs while getting digested from a first-person view. Tactile and auditory sensations were also designed to simulate the senses of touch and hearing. From this work, I learned that adding more sensory experience might better engage players with their interior body and enrich the overall interactive experience. Boer et al. [23] presented the design of Loupe and Lightbox to externalise the user's gut microbiota for closer examination, aesthetic appreciation and reflection on the self. This work is in line with our work to consider supporting players' experience of bodily cultivation rather than mere self-tracking.

## 2.8 Biofeedback System Design

Biofeedback games incorporate players' biometric information [49]. Most biofeedback games use bodily data to understand the players' emotional or physiological states in order to either adjust gameplay for increasing game immersion [49, 169] or change the game difficulty to keep the player in a state of 'flow' [38, 221]. However, although these works in biofeedback games may involve the player's interior body, they do not put it at the centre of the experience.

Unlike exterior body parts such as the legs and arms, humans usually experience low agency over their interior body since our internal organs operate mostly independently without us consciously controlling them. Given the importance of agency in facilitating positive play experiences [221], this low agency makes it challenging to design engaging interior bodily play experiences. In biofeedback game design, Nacke et al. [169] suggested that where we can directly control biodata, such as eye movement and muscle flexion, the design should use it to drive quick and visible in-game responses. Biodata that can only be controlled indirectly, such as galvanic skin response and heart rate, should be designed to influence features that alter the game world such as in-game weather. Building on these works, my design process has considered players' low agency over their interior body. For example, when developing the case study systems, I employed ambiguity [72] around the system's feedback as a strategy to dampen any frustration caused by low agency.

Although most biofeedback games see the player's interior body as a 'game controller', some biofeedback interactions aim to facilitate somaesthetic experiences, directing the user's attention inwards and increasing their body awareness [115]. For example, Eloquent Robes is a wearable system that aims for increased somatic awareness and self-cultivation by visualising the user's heart rate data and projecting it onto their body [173]. However, this work focuses on the 'inner feeling' rather than the interior body. In other words, if we adopt Slatman's understanding of body intimacy [207], these biofeedback loops evoke the user's psychological intimacy with their own body while the physical intimacy remains underexplored. I believe that penetrating the spatial interiority of the player's body will help facilitate a fuller understanding of interior bodily play.

## 2.9 Summary

In this chapter, I have presented an overview of the design practices and theories that I believe are related to this thesis study.

The review showed a lack of understanding of ingestible play, both on practical and theoretical levels. On a practical level, ingestible sensors as interactive technology have rarely been explored in the field of HCI. Thus, the interactive affordances of ingestible sensors remain unknown. Even with other intracorporeal devices such as implants, related research in HCI primarily takes a technology-driven perspective. This thesis study considers ingestible play design from a more experiential perspective, aiming to engage players with their interior body. On a theoretical level, there is limited design knowledge of ingestible play. Current design concepts and frameworks in relation to bodily play are not adequate for understanding the design of ingestible play, since these design knowledge was mostly generated based on bodily play projects focusing on the exterior body. In summary, the design of ingestible play is still an underexplored topic in HCI and current related works are not sufficient to understand the design. Therefore, there is a need to conduct research to understand the design of ingestible play. In the next chapter, I will introduce the research methods I have utilised.

# Chapter 3
# Research Methods

THIS thesis study aims to understand the design of ingestible play through the design and evaluation of three design prototypes that serve as research vehicles. In this chapter, I will elaborate on the research methods used in this work.

## 3.1 Concept-driven Design Research

Concept-driven design research is a method for generating new design knowledge by creating design artifacts [214]. Traditional design methods such as user-centred design and participatory design mainly focus on seeking solutions for specific user needs; however, these methods are not always be suitable to advance design theories. According to Stolterman and Wiberg [214]:

> Concept design illustrates how cutting-edge technology can be used as a design material in the realization of new ideas. To find new ways to use these materials is a sign of a creative and inventive designer and a sign of interesting design research that pushes the field ahead, at least if it is done in the name of the common good. In interaction research this means that concept designs are a way to explore and experiment with new technology in ways that would not be asked for or wished by any user. The challenge is, of course, to do this with an intention to develop a theoretical understanding and not just to create anything that is possible because 'we can'.

Interior bodily play is a rarely explored area in current HCI design research, and few works have investigated ingestible sensors as a design material. Therefore, I believe that rather than, for example, aiming to satisfy specific user needs, conducting concept design research is more appropriate to understand the design of interior bodily play.

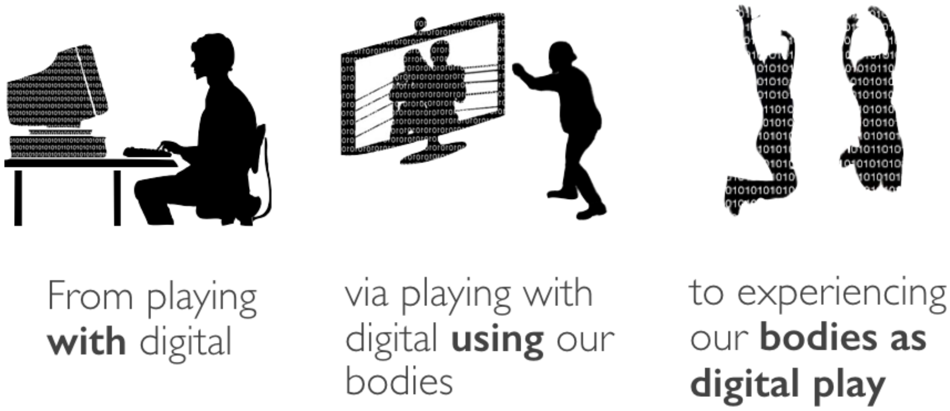



Figure 3.1: A vision of experiencing the body as play (image from [159]).

Concept-driven research does not present an arbitrary belief about the future. Instead, it should be grounded conceptually and historically [214]. My belief that interior bodily play is an emerging area worth exploring is based on how playful interaction has changed. Figure 3.1 shows how Mueller et al. [159] summarised the evolution of bodily play and envisioned a future of play. Humans progressed from playing games in front of computers in a seated position with a mouse and keyboard to playing games utilizing sensing technologies capable of engaging our whole bodies. For example, with popular game consoles such as Microsoft Xbox and Nintendo Switch, we can play body games via motion-sensitive cameras or wearable game controllers that embed motion sensors. Based on these developments, Mueller et al. [159, 162] envisioned that in the future, the digital content might integrate with the human body so that players can experience their bodies as digital play. As such, players no longer experience their bodies merely as 'game controllers', but as 'digital play'. This vision presented by Mueller et al. [159] provided the conceptual and historical ground for the concept-driven design of interior bodily play.

## 3.2 Research Through Design

A common approach to developing a theoretical contribution via concept-driven design is research through design (RtD) [247]. In design research practice, RtD generates new knowledge through the development of artifacts via the 'methods, practices and processes of design practice' [248]. This approach enables designers to reflect on their design and research results through prototyping, leading to the evaluation and examination of the design process, invention, relevance, and extensibility of their design [247].

Similar to most design research methods where the design knowledge is constructed via designing novel interactions and evaluating the interactions empirically through user studies [100], in RtD, the designed artifacts also play a central role. In RtD research, the designed artifacts are important because they: 1) enable experimetation; 2) provide a way to experience a future situation; 3) provide a way to connect abstract theories to experience; 4) serve as a carrier for interdisciplinary discussions; 5) serve as a prop to carry out activities and tell stories; and 6) provide a landmark for reference in the process of a project [209]. According to Grocott [82], artifacts can be important as part of a larger, emergent process that moves towards a more complete understanding, and that this understanding is perhaps one that only design processes and artifacts can reveal and address.

In this work, I have adopted the RtD approach to explore the design of ingestible play. I built three playful interactive prototypes that use ingestible sensors as design materials. I evaluated their use in a real-world setting through qualitative studies. By gathering the hands-on design experience of creating the three prototypes and the results of qualitative studies, I was able to generate a design framework for ingestible play.

### 3.2.1 Design Methods

This dissertation addresses the research question: How can we design ingestible play to engage players with their interior body? I acknowledge that this is an open-ended question and, therefore, unlike research thatfor tacklesing a specific problem, this research is more exploratory in nature. As this studyresearch is the first attempt in HCI to introduce ingestible sensors into the design of digital play, I believe it is important to gain a general understanding of potential UX. In the future, more research can be done to investigate more specific research questions, for example, how can weto design ingestible play to promote better health behaviours? How can weto design ingestible play to improve the

UX of ingestible sensor procedures in hospitals? How can weto design ingestible play to teach children medical knowledge about their GIT? Etc.

As exploratory research, I have loosely followed the design methods of gamification and playification [51, 145] along with my design intuition as a game designer. The first case study can be seen as a gamification of the ingestible sensor procedure, as I applied some game design elements to a non-gaming context [51]. For example, I designed the experience to be social and competitive, and I designed game tasks and added rewards, which are all common design elements in gamification [189]. After the case study of the Guts Game, I found playification was more suitable when designing my case studies. Playification can be seen as a generalisation of gamification. According to Nicholson [172], playification is all about play engagement, rather than goals and rewards. With the Guts Game, I found that rather than positive emotions gained from completing tasks and winning the game, players were more satisfied by exploring their interior body and engaging with the novel ingestible technology. Therefore, intrinsic motivations might play a greater role in ingestible play experiences. This motivated me to consider using a playification approach to encourage players' engagement and exploration. Following the design strategies of playification presented by Segura et al. [145], I designed HeatCraft and InsideOut to be open-ended, as playification suggests systems should provide players with space to create their own play activities.

## 3.3 Field Study

To understand the player experience, I conducted three field studies, one per prototype. According to Koskinen et al. [121], design research can be conducted in the lab, field or showrooms. A lab study provides researchers with a controllable environment and therefore provides the researchers with an opportunity to focus on one variable at a time. Studies in a showroom are usually set up for radical designs in shop windows, exhibitions and galleries to provoke critical reflections. A field study is a method of investigating the use of a system in a real-world situation with real users, enabling researchers to evaluate the design in the context of use [190]. A field study, therefore, helps researchers to generalise the findings to the real world rather than a study environment by bringing the system to real users.

In my work, I conducted field studies to understand the UX of ingestible play in an everyday context. I believe doing field studies can provide a richer understanding of how users interact with the technology and how users will adopt, use, or abandon the technology in a real-world context compared to a lab study [113]. Moreover, as the ingestible sensors used in this work usually stayed in a user's body for 24–36 hours, conducting field studies over several days allowed for the full use of the ingestible sensors and thus enabled a more comprehensive understanding of ingestible play over the period. Thefore I have decided to conduct field studies to understand the player experience in my three case studies.

## 3.4 Qualitative Research

I used qualitative research methods to understand the UX of engaging with the three prototypes. Following the RtD approach, the studies remained open to serendipitous discoveries providing unexpected but valuable insights. Moreover, the studies of the three prototypes focused primarily on UX, which is exploratory by nature. Qualitative research methods are often used to address exploratory and open-ended questions in HCI, such as understanding users' needs and behaviours and evaluating situated uses of technology [20]. Researchers generally use a qualitative research method to understand the UX of certain technologies in contexts where the events occur. Therefore, I used qualitative research methods to collect and analyse data in order to understand the UX of my three prototypes.

### 3.4.1 Participant Recruitment

In all three case studies, I conducted research with participants. In contrast to quantitative studies where large numbers of participants are essential to generalize results, this qualitative study uses the depth of the interview data as a key measure of quality. I recruited 14 participants to experience the Guts Game, 16 participants for HeatCraft and 7 participants for InsideOut. The number of participants is similar to other qualitative studies in HCI usually involve small numbers of participants, occasionally as few as one [133], but more commonly 10–20 [20]. I believe that the participant number is appropriate in my three case studies as long as enough qualitative data has been collected to construct meaningful design knowledge.

In HCI, the participant recruitment in qualitative research is usually conducted in three ways: 1) convenience sampling where the system is deployed within one's own convenient social networks such as family, friends and lab mates; 2) semi-controlled studies, where most participants who know the research team and those who are unknown to the team become familiar with time; and 3) deploying the prototype with participants unknown to the research team [202]. In my three case studies, I followed a hybrid of the first and second methods. I began recruiting participants within my personal and the lab's social networks (e.g., Google groups). I also put posters on the campus to recruit voluntary participants. I also adopted the snowballing method [27], asking participants whether they could recommend this study to other potential participants. In all the case studies, no compensation was provided.

### 3.4.2 Qualitative Interviews

Following qualitative research methods, I used semi-structured interviews to collect participants' responses to the three interactive prototypes during field studies. Interviews can provide rich subjective data and help understand a user's interactions with a given system, providing insights on the user's experience with the system. During interviews, users describe their experiences with the system. This data assists researchers to reflect on different aspects of the system and can further support designers generating higher-level design knowledge. In this thesis study, all the conducted interviews were semi-structured: I followed a set of questions to guide the interviews, while also following up with participants on the interesting topics that emerged during the conversation [21]. I believe semi-structured interviews can leave sufficient room for topics to emerge, supporting a deeper elucidation of participants' responses and thinking processes [200].

The interview questions were designed based on prior studies that investigated UX [87,233]. UX with a product usually depends on the users' motivation to achieve specific goals with the technology, how they anticipate using a technology, and later how the technology fulfils their expectations. UX is the result of a user's internal state (such as perceptions, expectations, motivation and mood), characteristics of the product (such as usability, functionality and purpose), and the context (such as organisational and social settings) within which the interaction occurs [89]. Inspired by the above, I respectfully asked questions focusing on the participants' expectations, motivations, feedback on the system, feelings and experiences, and use contexts. All the semi-structured interviews were audio-recorded.

### 3.4.3 Thematic Analysis

Data analysis was conducted to interpret the data meaningfully based on the context [25]. Qualitative analysis usually includes analysing the data to form coherent themes, and finally linking different themes together to derive the story [226]. A theme refers to a label that represents something important about the data related to the research question. In this thesis study, the qualitative data gathered in all the case studies was analysed by another researcher and me. After the interview, I first transcribed the interview data from the audio-recording and shared the transcript with the other researcher. The process of transcription also helped me familiarise myself with the data. Next, the other researcher and I became familiar with the transcripts by reading them three times, then coded the data independently. The codes we labelled described important aspects that each of us observed. Then the codes were discussed and extracted until the other researcher, and I reached an agreement. After deriving a set of codes, we iteratively clustered them into higher-level groupings as themes. The themes and my hands-on experience in designing each system led to practical design strategies to guide the future design of ingestible play.

## 3.5 Ethics Considerations

Interior bodily play raises several ethical questions. Although there is no research in HCI discussing the ethics of interaction design around ingestible sensors, there are works from other fields discussing the use of ingestible sensors for medical uses [118]. Klugman et al. [118] discussed the ethical challenge of digital medicine, which was defined as 'medical treatment that combines technology with drug delivery'. The authors argued that from the patient's perspective, ingestible sensors raise ethical issues including informed consent and autonomy, therapeutic misconceptions, external influences on decision-making, data privacy and device dependability [118]. From the provider's perspective, ingestible sensors might change the relationship between patients and doctors, and change patients' expectations of clinicians. Moreover, with ingestible sensors clinicians might be monitored by the device manufacturers. Also, there exist new liability risks [76]. Other societal ethical questions include third-party monitoring of health treatment, affordability and transparency to the public for adverse events [76]. I believe that such research can provide a basis for designers to consider the ethical issues of ingestible play.

This thesis certainly does not discuss all ethical considerations, I believe that it is important to start a conversation about ethical issues as bodily-integrated technologies become more common in HCI. Some people might regard using invasive technologies for non-essential purposes as unethical. In this dissertation, I have an optimistic view towards ingestibles and advocate that besides the risks, there are also various benefits including entertainment, education, health, reflections, etc. as I discussed in Chapter 1. In all my case studies, participants were fully aware of the potential risks of ingestible play. They were willing to participate in the study without compensation. This indicates that players might regard ingestible play as worthy of engaging in despite considering its potential risks; however, future research in this area is certainly needed.

Although I have an optimistic view regarding the ethical issues related to ingestible play, I acknowledge that designers of ingestible play need to be more mindful of the ethical issues compared to conventional bodily play. According to Benford et al. [16], designers should concern themselves with informed consent, the right to withdraw, privacy and anonymity, and managing risk when designing uncomfortable interactions. Here I discuss the ethics of ingestible play from three perspectives: informed consent, privacy and anonymity, and managing risk. I do not include the right to withdraw, as I see informed consent as an ongoing process where the right to withdraw is part of the consent [215].

### 3.5.1 Informed Consent

In a paper I co-authored with Strengers et al. [215], we discussed the potential ethical challenges and solutions regarding consent in ingestible play. In this paper, we adopted the FRIES model [183] to discuss consent in HCI. The model consists of five themes: 1) Freely given, which highlights that consent is a choice one makes without pressure, manipulation or under the influence of drugs or alcohol; 2) Reversible, which highlights that anyone can change their mind anytime; 3) Informed, which refers to the fact that one can only consent to something if they have the full story; 4) Enthusiastic, which highlights that one should only do what one wants to do; and 5) Specific, which highlights that saying yes to one thing does not mean saying yes to other things. This model was first developed for sexual consent and later introduced to HCI [215], discussing consent when using interactive technologies. According to the FRIES model, consent to ingestible play can be complex. Regarding the Freely Given perspective, one might experience peer pressure when making decisions if the ingestible play is a social game. For example, if the player's friends show a strong desire to play, the player might choose to participate due to peer pressure. From the Reversible perspective, the design of ingestible play can be challenging as the sensor can only be removed by surgery after being swallowed. The theme Informed might be challenging to follow as it could be difficult to evaluate the potential extent of discomfort in ingestible play. For example, it might be challenging to have a sense of the discomfort of swallowing. Also, one might not be fully aware of the extent to which one might feel uncomfortable with confronting interior body data. The Enthusiastic perspective is usually not a big problem for ingestible play, as play is voluntary in nature [104]. The theme Specific might also bring challenges in ingestible play design. For example, my three case studies were conducted in real-world settings and the researchers were not physically present together with the players. As a result, it was challenging for the designers to predict how participants might interact with the system.

In my studies, all the participants were given a Participant Information Sheet where I informed them about the technology they would use and the potential activities they might do. Potential risks were also reported. Moreover, players were informed that they could withdraw from the study at any time. Also, although the sensor could only be removed by surgery, the other parts of the ingestible systems such as the wearable parts could be removed anytime. Participants were also informed that they could contact the research team if they felt any discomfort during or after the study and the researchers would try to help. The design of ingestible play can also create different levels of experiences so players can adjust the level of potential discomfort. For example, players could choose from tasks with different levels of difficulty with the Guts Game: easy, medium and hard. InsideOut provided players with different play modes with different levels of abstraction of the GIT video.

### 3.5.2 Privacy and Anonymity

The ethical issues of privacy and anonymity should also be considered, as people often regard interior body data as a private medical record. Interior body data such as the core body temperature and video images of the GIT, as captured in my studies, are generally only collected in medical and clinical contexts. With ingestible play or any other non-medical purposes of ingestible sensor-based interactions, ethical questions might arise, such as, who should have the right to access the user's interior body information? Who owns the data? Moreover, in some cases, ingestible play might be designed as social games. If so, should the co-players have access to eachthe player's data? Should the game support the player sharing the data on social media? Etc.

In my case studies, I requested permission from players before using their anonymous data in our publications. All three studies weare small-scale research projects, which only involved a small number of participants. As interior body data becomes more pervasive in the future, data privacy risks require further consideration.

### 3.5.3 Managing risk

In ingestible play, the most important risk that designers might need to manage is the issue related to health. Designers should clearly be aware of the health risks of integrating digital technologies with the human body. With ingestible sensors, the primary risk is the sensor's retention in the player's GIT. This risk is low, as prior research suggested that ingestible sensors have been widely recognised as safe for healthy people to use if smaller than 11 mm in diameter and 28 mm in length [111]. I reduced this risk by screening potential players and excluding participants who had any obstructive disease of the GIT. To do this, I established a screening procedure which required players to complete a short questionnaire about their health conditions. In the third case study, I invited a health professional to further evaluate each player's suitability for the study, as the imaging capsule has rarely been used outside the medical domain. Details of the screening procedure can be seen in Appendix A.

Once a player was deemed eligible to participate, I provided them with preparatory instructions, including information on what they should and should not do based upon the product manual's directions and health professional advice. For example, in my third case study InsideOut, players were not allowed to take iron tablets for at least seven days before the study. They were also warned not to go near functional magnetic resonance imaging (fMRI) machines while the imaging capsule was inside their body.

On the day of the study, I provided each player with a printed document listing all the researchers' contact numbers, guidance for first aid in case of emergencies, and a copy of the study do's and don't's. For example, following health professionals' advice, I recommended players not engage in strenuous physical exercise. During the study, researchers were contactable via mobile phone to clarify any queries.

In some cases, ingestible play might cause risks associated with social interactions. For example, players might experience negative social interactions during interior bodily play, such as sharing their interior body data or talking about the study to others. I informed players that they could share any aspects of this research with potential spectators, including motivation, technology, design and experience. If players found spectators' questions too hard to answer, they could provide the researchers' contact phone numbers. Moreover, I informed players that they could stop the study at any time if they felt uncomfortable.

With InsideOut, I also considered the risk that a public video display of the interior body could offend bystanders. I suggested that players show the video only at home and in the workplace to manage this risk. The system also features a button to hide the video. Additionally, prospective players were required to inform potential spectators such as housemates and workmates about the study before the player became involved. I instructed players to continue with the study only where these potential spectators felt comfortable.

## 3.6 Summary

In this chapter, I have presented the methods that I have used and my ethics considerations in this thesis study. Following an RtD approach, I have designed and developed three interactive prototypes that support ingestible play. For each prototype, I conducted a field study to understand the associated UX. Qualitative data on the participants' experience was collected in semi-structured interviews and was analysed via thematic analysis.

In the next chapter, I will introduce my first case study – the Guts Game.

# Chapter 4

# Case Study 1: The Guts Game

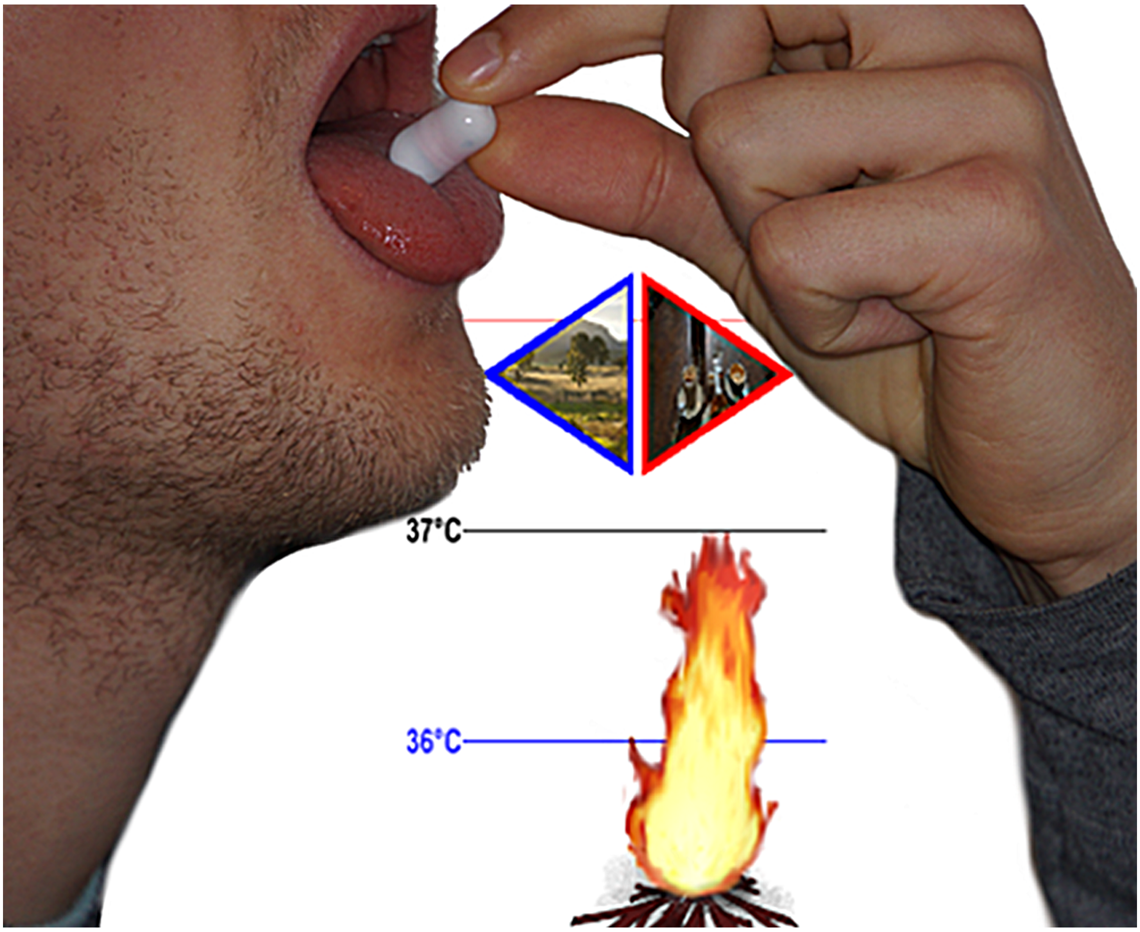



Figure 4.1: The Guts Game.

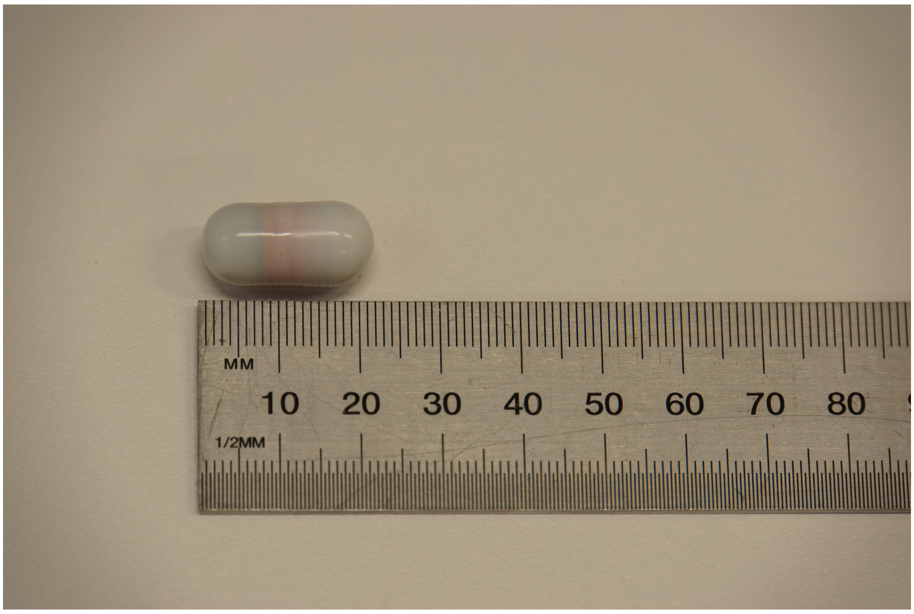



Figure 4.2: The CorTemp ingestible temperature sensor.

## 4.1 Introduction

IN this chapter, I present the first case study: the Guts Game, a two-player smartphone-based game around an ingestible temperature sensor. This case study serves as the initial exploration of the design of ingestible play.

To understand the design and UX of the Guts Game, I also conducted a user study with 14 participants, from which I derived three themes and a set of design strategies to guide future explorations around interior bodily play with ingestible sensors.

## 4.2 First Insights on the Ingestible Temperature Sensor

The Guts Game uses an ingestible temperature sensor called CorTemp (see Figure 4.2). The sensor is a single-use FDA-cleared sensor that measures the user's body temperature and transmits the data wirelessly to a data recorder every 10 seconds as it travels through the user's GIT. The data recorder can send the real-time temperature data to a smartphone via Bluetooth. The ingestible sensor system is illustrated in Figure 4.3. The ingestible temperature sensor was originally produced for people such as athletes, soldiers and firefighters to monitor their temperature in extreme environments.

Most work involving ingestible sensors are situated in the health and medical domain


Figure 4.3: On the left is the data recorder and on the right is the ingestible temperature sensor placed on a smartphone.

and hence the experiential perspective of the sensor is unclear. I conducted a pre-study to understand the UX of ingesting the sensor before engaging in the game design process. Another researcher and I swallowed an ingestible temperature sensor and performed a series of activities such as drinking water of different temperatures and physically exercising with various intensities until we excreted the sensor. During the study, I recorded the time and notes about how I felt for each activity (see Figure 4.4). The data recorder saved the body temperature data that can be later downloaded to see how the activities influenced the body temperature changes.

I adopted an autobiographical approach in this pre-study as this allows for the fullest account of the experience [98]. Moreover, bodily experiences are best understood by going through them oneself [182].

The results of the pre-study showed that there were delays between the activities and the temperature change. The delayed time might depend on the sensor's location. When the sensor was in the stomach, the temperature usually changed 20–40 seconds after drinking or eating. When the sensor entered the intestines, drinking water might

| Date | Time | Data | Activity | Note | Feeling |
|---|---|---|---|---|---|
| 9/5/17 | 9:30:09 | 19.79 | | | |
| 9/5/17 | 9:30:19 | 19.86 | | | |
| 9/5/17 | 9:30:29 | 19.91 | | | |
| 9/5/17 | 9:30:41 | 19.98 | | | |
| 9/5/17 | 9:30:51 | 24.28 | Swallow the sensor | | Before I swallowed it, I felt that it might be hard to swallow. However, it is easier to swallow it than I thought. |
| 9/5/17 | 9:31:01 | 21.02 | | | |
| 9/5/17 | 9:31:11 | 20.47 | | | |
| 9/5/17 | 9:31:21 | 24.73 | | | |
| 9/5/17 | 9:31:31 | 30.13 | | | |
| 9/5/17 | 9:31:41 | 34.17 | | | |
| 9/5/17 | 9:31:51 | 47.09 | | | |
| 9/5/17 | 9:32:01 | 30.04 | | | |
| 9/5/17 | 9:32:11 | 31.22 | | | |
| 9/5/17 | 9:32:21 | 32.1 | | | |
| 9/5/17 | 9:32:31 | 32.74 | | | |
| 9/5/17 | 9:32:41 | 33.21 | | | |
| 9/5/17 | 9:33:44 | 34.68 | | | |
| 9/5/17 | 9:33:54 | 62.48 | | | |
| 9/5/17 | 9:34:14 | 34.9 | | | |
| 9/5/17 | 9:34:24 | 34.98 | | | |

Figure 4.4: A screenshot of some of the notes I logged during the pre-study. I found some abnormal data and marked it in red as it was outside the range of possible human body temperatures. According to the manufacturer, the sensed data might be erroneous due to an electromagnetic field's interference.

only affect the temperature data if the stomach was empty and there might be a delay of 3–5 minutes to see the change. Additionally, the intensity of exercises also affected the delayed time. For example, during the pre-study my body temperature began to rise 8 minutes after starting to walk at normal speed, but only one minute after starting intense exercise.

## 4.3 The Guts Game

With the Guts Game, each of the two players swallows an ingestible temperature sensor and is provided with a smartphone running the Guts Game app. The game app can release game tasks, requiring players to change their body temperature as measured by the ingestible sensor. During the game, the players can freely explore how they can change their body temperature to complete game tasks.

As players might be nervous about swallowing a sensor, I developed a game story to help players relax during the initial stage of gameplay. This design was inspired by the fact that game narratives can encourage good behaviour around players' medication intake [11]. With the Guts Game, players are firstly provided with some food. Then a non-player (in the study of the Guts Game, the non-player was me) dresses up like a medical doctor and tells the players that they have been infected by a parasite that is

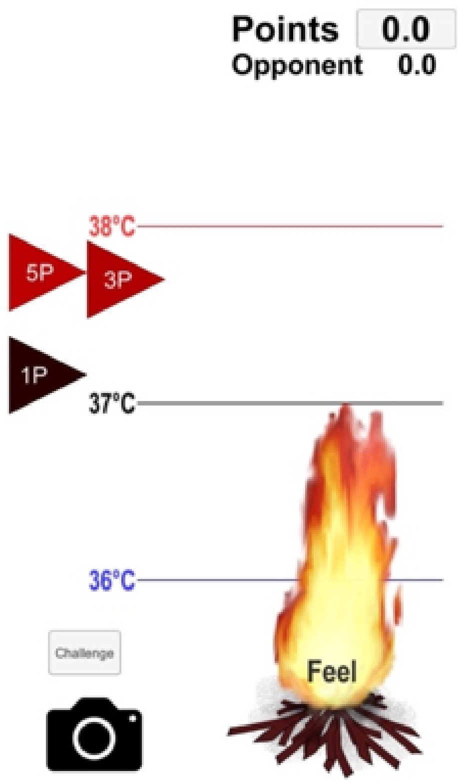



Figure 4.5: The interface of the Guts Game. The three temperature lines (36 °C , 37 °C and 38 °C) are the temperature reference lines for the flame's height. By clicking one of the three triangles, players can receive a general mode task. The numbers 1, 3 and 5 shown in the three triangles refer to the points the player can get after completing this task. The three triangles are colourized and their height (y-position) is arranged according to the task's goal temperature.

sensitive to its environmental temperature, i.e., the body temperature of the player as measured by the sensor. I told the players that the parasite would be hurt if the environmental temperature reaches a certain value. The crafty parasite might also adapt to the environment so that the target temperature might change once being reached. The more often the player reaches the target temperature, the greater the possibility the player will 'survive'. To aid the treatment, the 'doctors' developed a mobile app called the Guts Game. Players need to swallow the sensor to measure their body temperature, and the application will guide players to change their body temperature. During the study, all the participants were made aware that the parasite story was a fictional game narrative. The reason is so that all of them clearly knew what they would be doing before the study began, when signing the Participant Information sheet.

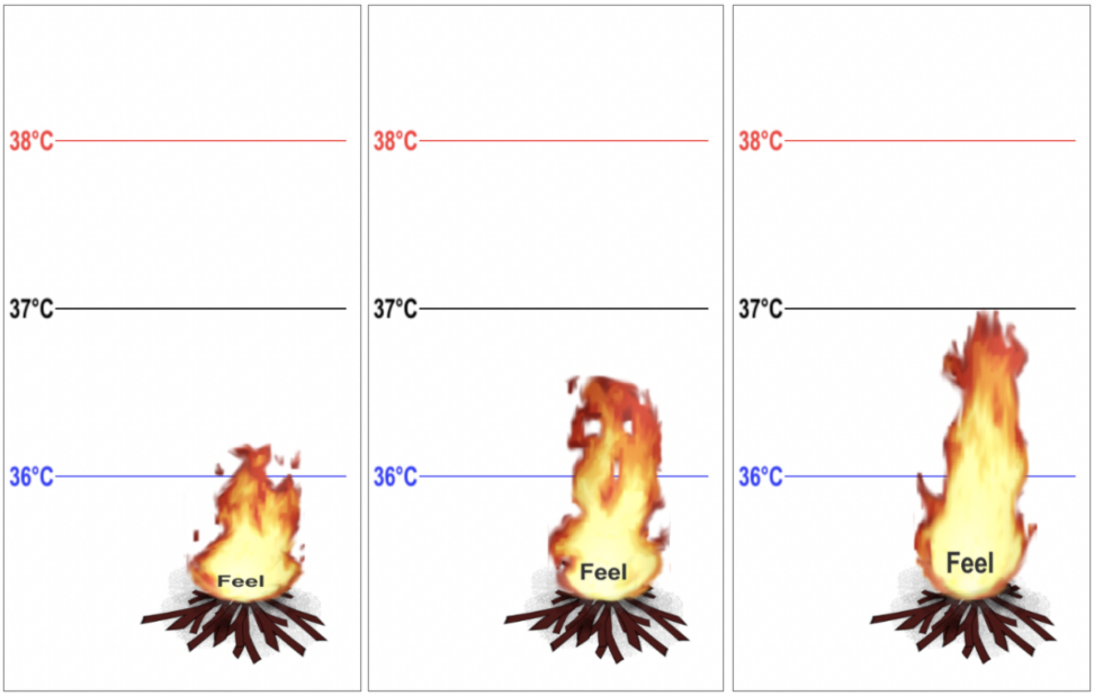



Figure 4.6: Three pictures show how the flame height increases as body temperature rises.

The Guts Game ends when one of the players excretes the sensor. After the game ends, players receive an in-game message asking them to come back to the 'doctors' to check if the parasite is still alive. At the early stage of the design process, I have considered ending the game when both of the players excreted the sensor; however, the player who first excreted the sensor would need to wait until the game's end.

In the pre-study, I also found that electrical currents and obstructions could influence the sensor's accuracy. Therefore, players might be confused when seeing temperature fluctuations caused by the interference. To prevent this confusion, in the Guts Game the raw temperature data measured by the sensor was filtered using a threshold and then downsampled every 6 points using a first-order derivative edge detector. Visually, I used an animated flame's height to represent the temperature data (see Figure 4.6). As the flame height was more ambiguous than the real number, players might be less confused when seeing the 'wrong' body temperature data. The approach of visualising the temperature via an animated flame is also in line with prior work that suggests to not always providing numbers when visualising body data [88].

During the game, the two players are encouraged to interact with each other by sharing pictures. This design was inspired by the results of the pre-study. In the pre-study,

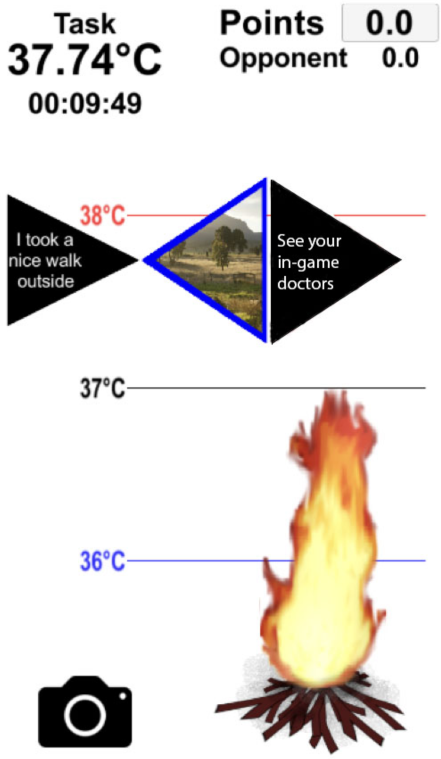



Figure 4.7: The interface of the Guts Game after receiving a general mode task. At the upper left, the task goal is displayed. Under the task goal, the interface shows the time until this task can be aborted. The messages and pictures sent by players are shown in the triangles.

the two researchers felt curious about the other person's experiences, and they even chose to undertake the same activities and compare their data when they were physically together. Prior works also confirm that social interaction can motivate players to engage in games, especially in pervasive games and bodily play [84, 163]. Therefore, the Guts Game was designed to support social interaction. Players can take and share pictures by tapping the camera icon in the game interface's bottom-left corner (see Figure 4.7). After players complete a task they are asked to enter what they did and how they feel via Twitter-sized text messaging. At the same time, the co-player receives an invitation to express their feeling on the progress using a picture. All the pictures and texts sent by the players can be seen by both players. With this social play game design, I aimed to facilitate an engaging and shared experience.

The Guts Game adopts task-based gameplay. The game asks players to complete a series of tasks to gain points. Players can choose the next task after completing or

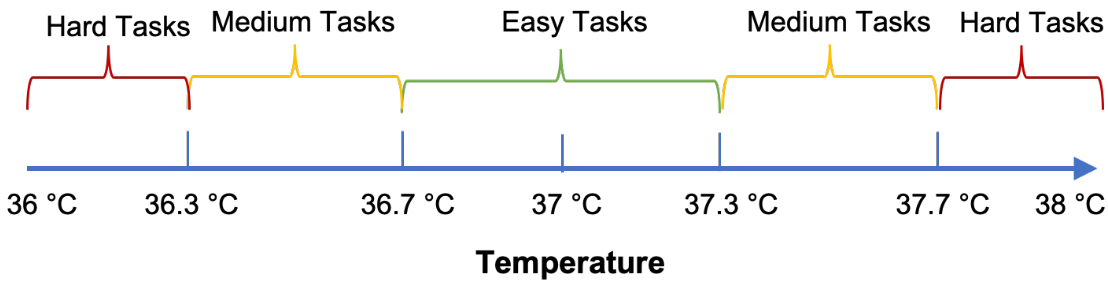



Figure 4.8: This figure shows how I defined a task's difficulty. As the normal human body temperature is around 37 °C, I saw 37 °C as the starting point.

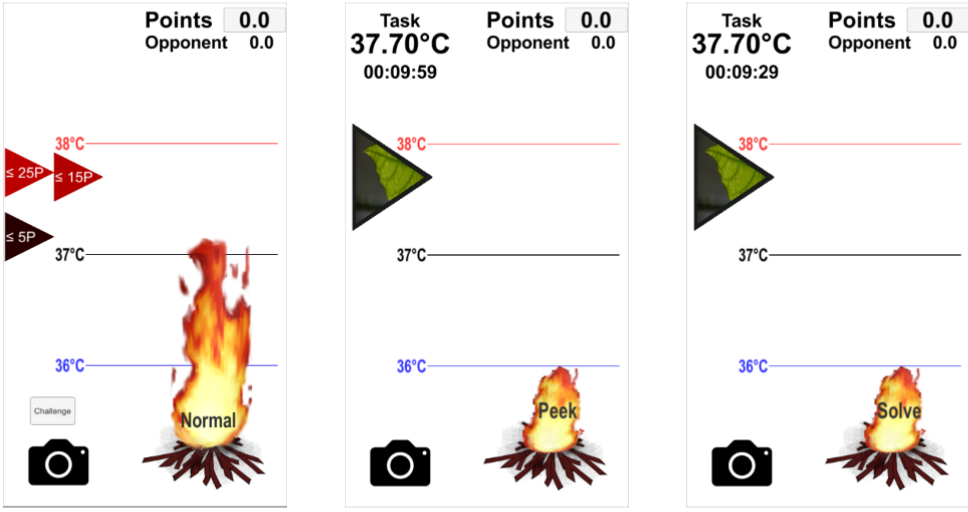
aborting a task. Figure 4.5 shows the game interface before the player chooses a task. Players receive a task by clicking one of the three triangles. The number shown in each triangle represents the points the player could get after completing the task. The line to which those triangles point represents the task's goal. After the player chooses a task (see Figure 4.7), the target temperature will also be shown at the screen's top-left corner. Both the player's and the opponent's points are displayed on the screen. The points can be used to block the opponent's flame: if the player taps the points button, their points will decrease by one, and the other player cannot see their flame changing within the next minute. To enrich the game experience, I designed three task modes.

### 4.3.1 General Mode – Visible Temperature

In the general mode, the player can choose from three tasks with different difficulties. Depending on the difficulty, the player will earn one, 3 or 5 points after completing the task. Figure 4.8 shows how the system evaluates a task's difficulty. All goals are meant to be achievable for most people as they are between 36 °C and 38 °C. The tasks can only be aborted 10 minutes after being received. With this, I aimed to encourage players to try their best to complete the tasks. There is no time limitation for completing each task.

### 4.3.2 Feeling Mode – Invisible Temperature

The player can tap the flame before choosing a task. After tapping, the number shown in each triangle displays the maximum points the player could get after completing the feeling mode task, which is five times the number in the general mode (see Figure 4.9). The player can then tap one of the three triangles to receive a feeling mode task. In this



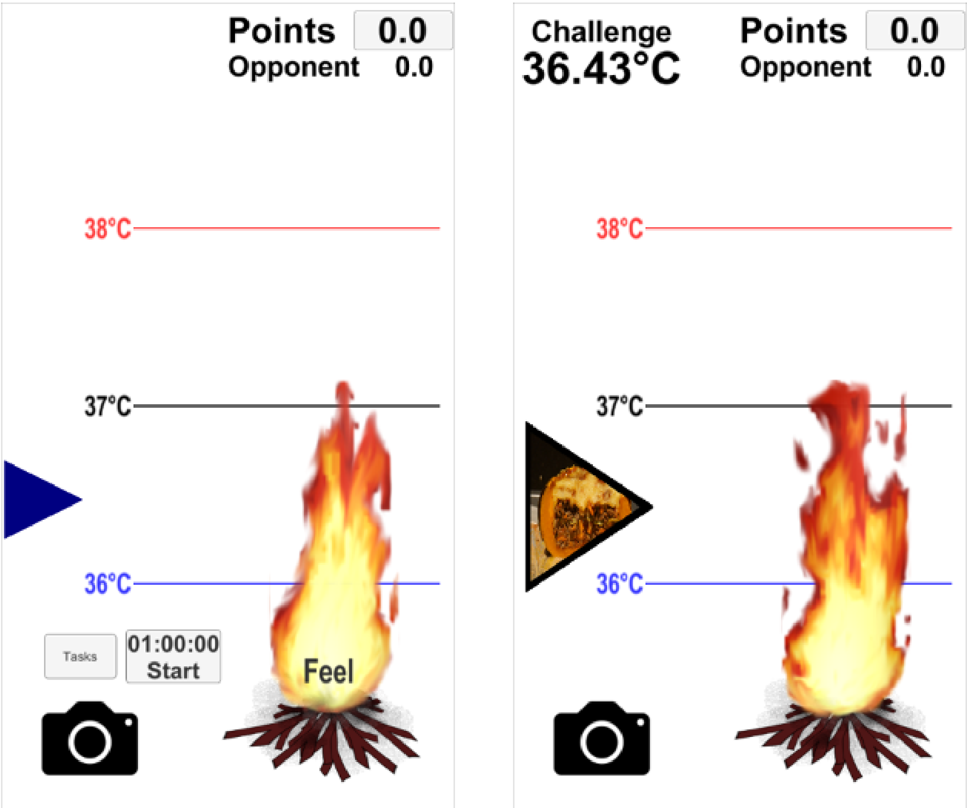

(a) (b) (c)

Figure 4.9: (a) The interface when a player is about to select a feeling mode task; (b) the interface when a player has selected a feeling mode task. The flame height is fixed. Clicking the flame that shows the 'peek' allows players to 'peek' on the flame for 20 seconds. During the peek time, the flame changes depending on the player's body temperature; (c) the interface after a player has 'peeked' the flame. Now the player can submit the task by pressing the solve button.

mode, the flame stays fixed, and the player can only tap the flame once to peek at the real-time body temperature for 20 seconds before the flame becomes fixed again. The player can tap the flame again when feeling the target temperature has been reached. Points are given to the player based on the task performance: the closer the player's temperature ($T_p$) is to the goal ($T_g$), the more points will be awarded. I defined $\Delta t = |T_p - T_g|$. If $\Delta t \leq 0.1$, players can get the full points. If $0.1 < \Delta t < 0.5$, the points the player can get are $0.001/\Delta t^3$ . If $\Delta t \geq 0.5$, no points will be given.

### 4.3.3 Challenge Mode – Social Play

Players can challenge each other by setting customised tasks. After tapping the challenge button, the player can choose a number between 36 and 38 as the task's goal ($T_c$). The player needs to complete the task before sending the task to their opponent. After sending a challenge mode task to their opponent, the opponent's normal gameplay will be locked for up to 1.5 hours. During the lock time, the player cannot be assigned any task and has to complete the challenge mode task to get the gameplay unlocked. The length of lock time depends on the task's difficulty: 30 minutes for an easy task ($36.7 < T_c \leq 37.3$);




(a) (b)

Figure 4.10: (a) The interface when setting a challenge mode task. The player can slide the triangle to choose the goal. The time for which the opponent player will be locked is shown on the start button (in this case 1 hour); (b) the interface after the player starts a challenge mode task. After completing the task, the challenge task will be sent to their opponent.

1 hour for a medium task ($36.3 < T_c \leq 36.7$ or $37.3 < T_c \leq 37.7$); and 1.5 hours for a difficult task ($36 \leq T_c \leq 36.3$ or $37.7 < T_c \leq 38$). With this mode, I hoped to encourage players to challenge their opponents in order to facilitate engaging social play experiences.

## 4.4 Study

I conducted a field study [190] to understand the UX of playing the Guts Game. I recruited 14 healthy participants (9 males and 5 females; mean age = 27.4 years, SD=1.2 years) and divided them into seven groups to play the game. There were four groups in which the two participants knew each other before the game. To minimise safety


Figure 4.11: The black waist bag is used to contain the data recorder. The yellow bag is a waterproof bag for players to put the smartphone into when showering or swimming.

risks, the players were asked to complete a risk factor assessment questionnaire before the study to determine their eligibility for participation. A paper document explaining the guidance for any potential first aid was also provided.

### 4.4.1 Players' Initial Briefing

Before the game, I provided a briefing and provided the following equipment to players: the ingestible sensor, the data recorder, an iPhone, a charging cable for the iPhone and a power bank. I also provided the users with a waist bag and a waterproof bag (see Figure 4.11). The waist bag allowed players to wear the recorder on their back, which is the best position for picking up the sensor signals (see Figure 4.12). The waterproof bag was there to protect the smartphone if players wanted to try aquatic activities such as showering and swimming. As it usually takes 24–36 hours for the sensor to pass through the body, I expected the game might run for one to two days. The power bank was provided to charge the iPhone in order to guarantee the game could operate continuously.

The CorTemp app and the Guts Game app were previously installed on the iPhones.

Figure 4.12: The player is wearing a waist bag that contains the data recorder.

Players could see their real-time body temperature data through the CorTemp app (see Figure 4.13). During the game, the CorTemp app transmitted the temperature data to Dropbox every minute, from which the Guts Game downloaded the data as the game input. Players were encouraged only to run the CorTemp app in the background and focus on the game app.

A printed game manual and an instruction sheet for solving technical issues were provided, both in the form of image and text. Players were advised to refer to these documents for troubleshooting any technical problems. For example, according to the pre-study, I found that the data recorder could occasionally lose connection with the ingestible sensor. This might happen when the recorder moved in the bag during everyday movements or if there was electromagnetic interference. The loss of connection might lead to the temperature data ceasing updating. I also suggested that players contact the researchers to seek help if they still found it hard to solve technology issues after reading

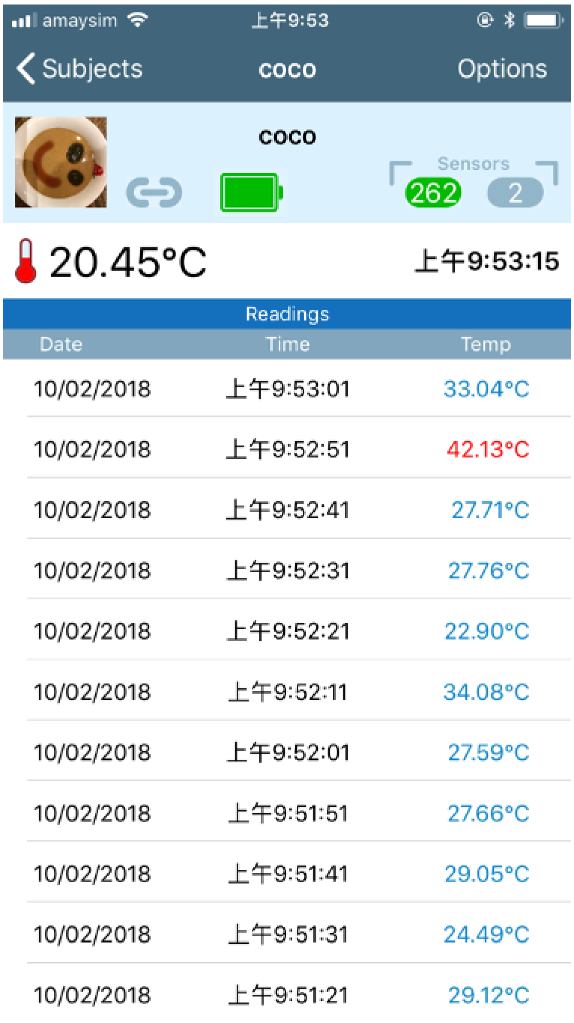



Figure 4.13: The CorTemp app interface.

the instructions.

### 4.4.2 Analysis

For each play session, a semi-structured interview was conducted with the two players together before the game, asking how they felt about ingesting the digital sensor and what they expected. This interview took approximately 15 minutes. During the game, data such as the body temperatures, points, texts and photos sent by players was logged. After the game ended, another semi-structured interview was conducted with the two players together, focusing on their play experience and lasting about 40 minutes. All interviews were audio-recorded. Thematic analysis [25] was conducted to analyse the

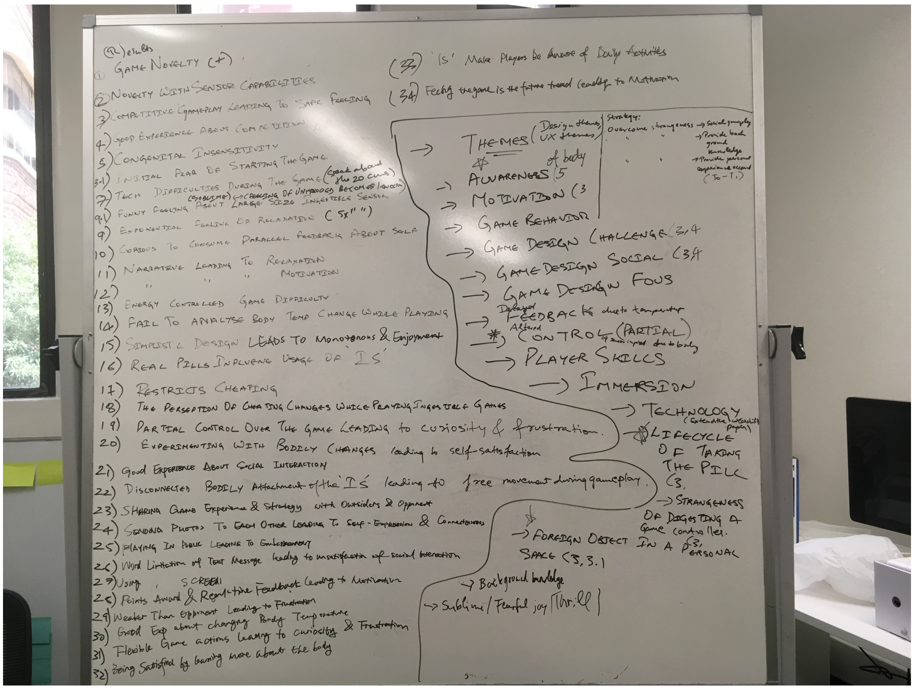



Figure 4.14: Two researchers wrote all the codes on a whiteboard and iterated them via discussion.

collected data (see Figure 4.14), which led to three themes and 12 findings that relate to the core player experience of the Guts Game.

## 4.5 Results

Overall, participants liked playing the Guts Game. They reported that: 'The experience was interesting. I have never played a game that places the sensor inside my body. I also felt excited because I had to put something physical inside my body to control the sensor. For example, I had to drink hot water to increase my body temperature.' I now unpack the players' experience as follows.

### 4.5.1 Theme 1: Human–Computer Fusion

In this work, I adopt the concept proposed by Mueller et al. [164]: using human-computer fusion as the extent to which the players perceived the sensor and the Guts Game as part of their body. The study of the Guts Game indicated that players might have perceived the ingestible sensor as part of their body during play.

### The Fusion between the Sensor and Body Evoked Emotional Responses

According to the interviews, ingesting a sensor could evoke the players' emotional responses. In this study, 6 participants mentioned that they felt nervous about swallowing the digital sensor before the game started. For example, Participant 1 (p1) said: 'At the beginning, I felt a little bit worried because I had to swallow something'. These participants mentioned that the game narrative about the parasite infection reduced their nervousness to some extent. For example, p3 said: 'I think the game's story motivated me to play and made me relax a little bit before I swallowed the pill'. The study results showed that the players' emotional response to the ingestible sensor might have been affected by the following three factors. The first factor is the player's professional background; for example, p12 said: 'I feel excited. I work in IT so I am interested in this game'. The second factor is whether they were an experienced gamer. p8 said: 'I have played games for 20 years. This game will be a new experience for me. I feel curious and excited'. The third factor is whether the players took pills regularly in their daily life; for example, p11 said: 'I often take pills so I am not afraid of swallowing the sensor'.

Table 4.1 shows the participants' demographics and their emotional responses to swallowing the sensor. All the information listed in the table was gathered during the interviews before starting the game. For the game experience, I asked players how they perceived their game level: beginners, intermediate level gamers, or game experts. For emotions before swallowing the sensor, I did not provide any pre-selected choice while only noting down how players described their emotions.

The six players who felt nervous before swallowing the sensor thought they were not frightened about the sensor after the game. For example, p10 said: 'We are all suspicious of new things initially and as we keep going we get used to it. I can safely say that I am less fearful than before'.

### Players Might Feel Uncomfortable Because of Violating Cultural Norms

Players suggested that they felt more comfortable when playing in a private place. For example, p6 said: 'It was a little bit embarrassing to play in public. If you're in public, you go and jog around to raise your temperature, but then you need to cool down. That's a little bit weird to watch. But we could work a little bit better at home and get competitive and silly'.

Table 4.1: Demographic information of the participants and their emotions before ingesting the sensor.

| Player | Profession | Game experience | Take pills daily? | Emotion |
|---|---|---|---|---|
| p1 | Civil engineering | Intermediate | No | Nervous |
| p2 | Design | Intermediate | No | Nervous |
| p3 | IT | Beginner | No | Nervous |
| p4 | Materialogy | Beginner | Yes | Curious |
| p5 | Design | Intermediate | No | Curious |
| p6 | Design | Intermediate | No | Curious |
| p7 | Electrical engineering | Intermediate | No | Nervous |
| p8 | Accounting | Expert | No | Excited |
| p9 | Games | Expert | No | Curious |
| p10 | Games | Expert | No | Nervous |
| p11 | IT | Beginner | No | Excited |
| p12 | IT | Beginner | Yes | Excited |
| p13 | Computer science | Intermediate | No | Nervous |
| p14 | Electrical engineering | Intermediate | Yes | Calm |

### The Limitations of Technology Led to Negative Game Experiences

As the sensor occasionally lost connection with the data recorder, players needed to troubleshoot the system, which they felt was a nuisance. For example, p4 said: 'There were some bugs with the recorder. I had to check the connection. It cost time and was boring'. Moreover, six players reported that they did not like carrying the recorder all the time. For example, p3 said: 'At first it was interesting, but later I felt the system was cumbersome as I needed to carry the recorder all the time, even when I was sleeping'.

### Players Appreciated They Could Not Feel the Sensor after Swallowing

After players swallowed the sensor, they usually tried to 'feel' the sensor. For example, p10 said: 'I am feeling it'. Players felt more relaxed after a while as they actually could not feel the sensor physically. p9 said: 'It's not an intrusive device because I'm not aware of it anymore. It's nothing attached to my skin causing me any irritation. So that's the beauty of it. It is weird at first to swallow but once it's there: perfect!'. Moreover, the game provided players with a sense of freedom to move as the sensor was inside their body. For example, p9 said: 'I liked the fact that I did not have anything attached to me.

It gave me a very natural way of consuming the sensor and measuring the temperature'.

#### Players Appreciated the Body Being the Interface

In the Guts Game, the ingestible sensor served as the game controller and turned the player's body into the game interface, which engaged the players. For example, p3 said: 'For a normal [mobile] game, we only need to tap [the screen]. But for this, you need to activate your body'. Similarly, p5 said: 'It was like the game wasn't under the phone. Most of it was actually here [in the body]. My body was the interface'.

#### The Novelty of Fusion Attracted Players

All the participants mentioned that the novelty of the Guts Game was the primary reason why they wanted to play. The novelty mainly came from utilising the ingestible sensors as part of the design. For example, p1 said: 'I think the sensor is quite innovative. It is inside my body. To me, it's very good'. Playing the Guts Game made players feel like they were involved in the next big thing. For example, p13 said: 'I haven't seen any other game with ingestible devices. This might lead [to] a new trend in the future'.

### 4.5.2 Theme 2: Bodily Awareness

According to Mehling et al. [150], bodily awareness involves 'an attentional focus on and awareness of internal body sensations'. In this study, I found that the Guts Game had the potential to increase players' bodily awareness.

#### Players Became More Aware of Their Bodies

All the participants mentioned that during the game, they were more aware of their bodies than usual. For example, p8 said: 'I just assumed my body stayed at 37 degrees all the time but it apparently doesn't. It's interesting to learn about what makes my body temperature changes. So I always looked at the phone and wanted to know how my interior temperature changes'. All the participants expressed that the increased body awareness let them learn more about their body and be more aware of their daily activities as the Guts Game did not limit their choice in terms of how to change their body temperature. For example, p11 said: 'I liked the fact that you were not limited to doing one particular task. I could do multiple things to play the game'. p4 also said: 'I wanted to explore the relationship between my body and my activities like eating, exercising, sleeping and so on. The pill made me pay attention to my drinks and food'.

### Social Play Contributed to Bodily Engagement

The social features were deemed to be important for players of the Guts Game by motivating the players to be more engaged with the system and hence their body. For example, p5 said: 'At the start, we shared the knowledge about how to change the body temperature. There was a kind of a collaborative effort at the start'. p14 also said: 'At the beginning, I just tried the general mode and the highest score I could get was five points. But I found my opponent always chose feeling mode tasks and they gave him higher scores. Then I tried the feeling mode'. Players also expressed that besides playing with their co-player, they also enjoyed social interaction with game outsiders to share their game experience. For example, p11 said: 'When I went back to the office, everyone was very interested in it and talking about it. It was fun to share and people found it interesting'. Furthermore, social interaction appeared to help participants become less nervous about having a sensor inside the body. For example, p10 said: 'It felt like both of us were taking this leap of faith into this unknown zone. It felt like we were holding hands before jumping into the unknown'. Players also reported that the game seemed to be more engaging when they were physically together. For example, p6 said: 'The game was interesting because we were both together'.

Players also mentioned that they enjoyed sending photos to each other. For example, p5 said: 'I think pictures are good as they give a quick snapshot to see what the other person is doing'. In this study, the photos sent by the players were mostly selfies, gestures and their surroundings. Figure 4.15 shows two of the pictures sent by players to each other.

Competition between players motivated participants to engage in the game as well. For example, p6 said: 'I was always trying to get more points than her'.

### Players Expected Explicit Feedback to Know More about Their Bodily Status

While participants liked the ambiguous feedback through the flame, they were also curious to see their exact temperature to know more about their bodily status. For example, p8 said: 'I can see the connection between the temperature and the flame. It's a good idea.

(a) (b)

Figure 4.15: Participants sent photos to each other: (a) a cup of ice water a player used to decrease their body temperature during the play; (b) sent by a player when the player could not complete a challenge mode task sent by their opponent.

But I want more details'. The feedback also seemed important to help players ensure that the system was working and hence to evaluate whether the game feedback showed a reliable representation of their bodily status. For example, p5 said: 'The real-time feedback is essential to make sure that it is working'.

### 4.5.3 Theme 3: Agency

Agency is the 'experience of controlling both one's body and the external environment' [132]. With the Guts Game, I found that the player's agency was usually lower than in traditional computer games considering the limited control we have over our interior body.

#### Players Experienced Four Phases During the Play due to the Sensor Mobility

The study suggests that the participants experienced the game differently as the sensor travelled through their body. Here, I divided the journey of the sensor travelling through


(a)

(b)

Figure 4.16: (a) The CorTemp sensor is packed in a plastic bag; (b) in the plastic bag, the CorTemp sensor is covered by a limited warranty with a magnet attached. The magnet can keep the sensor turned off.

four phases. Phase 0 started when the user unwrapped the sensor package (see Figure 4.16). Phase 1 began when user swallowed the sensor. Phase 2 began when the sensor left the user's stomach and entered the intestine. Phase 3 refers to the time after the sensor left the user's body. I refer to the starting points of the four phases as P0, P1, P2, and P3.

In this study, I could not determine the exact time when a sensor left a participant's stomach as the location of the ingestible sensor cannot be easily determined. Instead, I estimated the time point of P2 based on the variation in the logged temperature data. This was because the temperature data sensed by the ingestible sensor could easily be influenced by the temperature of sensor's environment. For example, when the sensor was in the user's empty stomach, the sensed data matched the user's body temperature. However, if the user drank some hot water, the sensor would sense the water's hot tem-

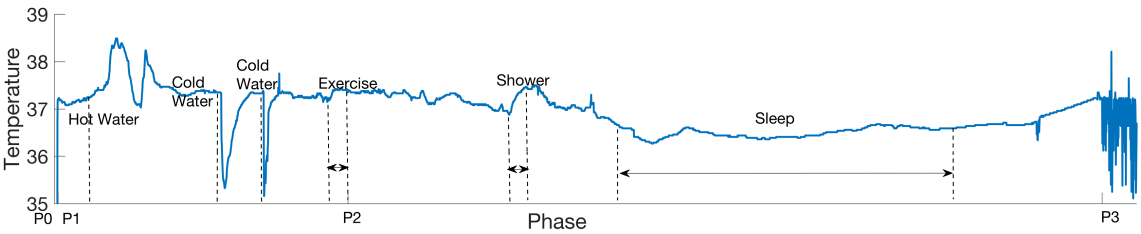



Figure 4.17: A player's temperature data during the play. The player's activities were identified based on the photos and texts that the player sent out and the interview data. This figure is only a rough illustration to give an impression, rather than a detailed representation.

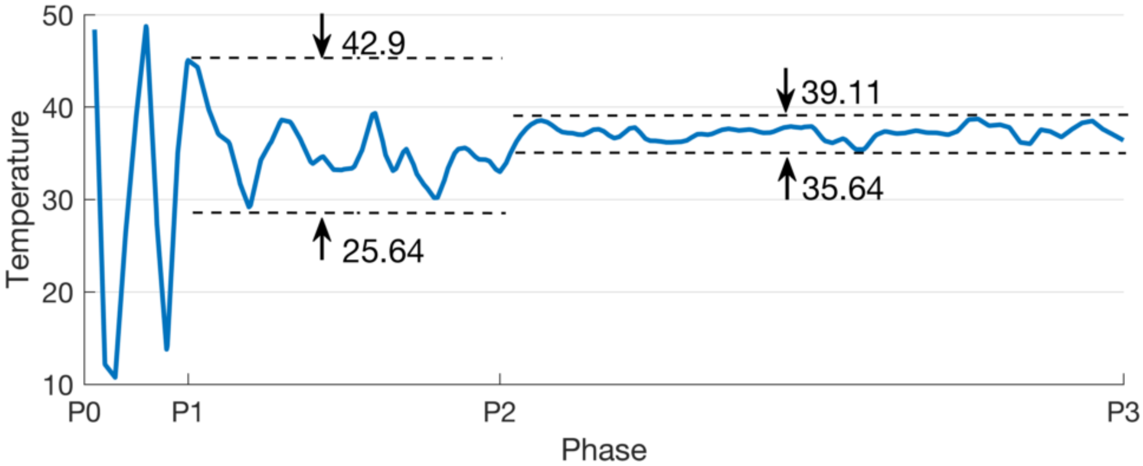



Figure 4.18: The possible temperature data range across the four different phases.

perature. Therefore, the sensed temperature data was higher than the user's body temperature and reflected the increased 'environment temperature' of the stomach where the digital sensor was located. For players of the Guts Game, influencing the sensor's environment temperature was relatively easy when the sensor was in their stomach. This was because food and drink can quickly enter one's stomach, while needing some digestion time to enter the intestines. Moreover, after a certain digestion period, the food and drink temperature is usually closer to one's actual body temperature when entering the intestines. Therefore, it can be envisioned that changing the temperature data sensed by the ingestible sensor to an extreme level (e.g., 40 °C) could be easier if the sensor was in one's stomach.

Figure 4.17 shows one of the player's temperatures during play. It is obvious that the fluctuation of the sensed data was more frequent and the fluctuation range was broader during the first couple of hours. According to the interviews, the players also identified such fluctuations among the four phases. Players mentioned that they found it more difficult to change the sensed temperature data during Phase 2 compared to Phase 1. For example, p7 said: 'You can discover which stage the pill might be in. If it is in my stomach, I can drink to change it. But when it goes down, I can only do exercise. It's a fun part of the game'.

I gathered the logged temperature data of all participants and found the maximum and minimum data during different phases. During Phase 0, the temperature data was equal to the room temperature when the player unpacked the sensor's package. The players could easily change the sensed temperature data at this stage, e.g., by blowing at the sensor or immersing the sensor in water at different temperatures. During Phase 1, the drink and food consumed by players might directly get in contact with the sensor, and therefore the temperature data was highly affected by what food and drink the player consumed. In this study, the range of the temperature data during Phase 1 was [25.64 °C, 42.9 °C]. During Phase 2, the temperature data was much closer to the player's real body temperature compared to Phase 1 and the range of the temperature data during Phase 2 was [35.64 °C, 39.11 °C]. Although some data during Phase 1, like 25.64 °C and 42.9 °C, seemed to be too low or high for body temperature, all the participants understood that they were healthy and the extreme data was affected by the food they ingested. I figuratively present the possible temperature data range across different phases in Figure 4.18.

With the Guts Game, the designed gameplay does not change across the four phases. This resulted in some players commenting that their engagement dropped after several hours. For example, p7 said: 'It was fun and I was quite conscious about the data, but it became monotonous after several hours'. However, participants reported that they were vigilant at the end of Phase 2, as they were thinking when they would excrete the sensor. For example, p5 said: 'I was quite conscious about [the excretion time]. It is definitely a game with a finite lifespan. I was more conscious of it on the second day and thinking:"Is it still there?".'

### Participants Experienced Limited Agency Over their Interior Body

Players reported that they experienced a low degree of agency during the game. First, the body temperature a player could reach was limited and hence participants sometimes felt frustrated when they could not achieve the game goal. For example, p8 said: 'Changing the temperature is a little bit difficult. The whole process is a little bit frustrating, but it is exciting because I get to know about it'. Some participants felt frustrated when the game became more difficult in Phase 2 compared to Phase 1. For example, p13 said:

'The game was very interesting during the first several hours as I know more about the body. But then I felt a little bit frustrated because it quickly became tough to change the temperature'. Second, it was hard for the players to control when they excreted the sensor. Players felt the game was unstoppable as the sensor was always inside their body. For example, p8 said: 'I could literally do nothing about it. I knew I could just put my phone aside; however, back in my head I still knew the sensor was there inside my body'. Players could slightly control when they excreted the sensor by consuming specific items such as bananas or coffee to speed up digestion. For example, p7 said: 'The ending of the game depends on the excretion of the sensor. It adds another layer of mechanics to the competitiveness of the game'.

#### Cheating in the Game Seemed to be Difficult Since the Sensor was Inside the Body

Participants expressed that cheating was challenging with the Guts Game. This was mainly because the sensor was inside the body. For example, p5 said: 'I think the ingestible sensor is better than other devices. It is hard to cheat. If it's on your skin [referring to wearables], there are opportunities to interfere with it'. Participants pointed out that they did not want to cheat even if they could. In the Guts Game, players could switch to the CorTemp app to see their temperature data. This data could help them achieve a good score in the feeling mode tasks where players were required to estimate their body temperature. However, none of the players said that they did this during the play. Also, participants said if the game had used a wearable device to measure their body temperature, putting the wearable device into hot water would have been considered cheating. However, when it comes to ingestible sensors, changing the temperature by drinking hot water was not perceived as cheating but, rather, a valid strategy: 'I don't consider drinking is cheating' (p7).

## 4.6 Discussion

This section presents design strategies based on the three themes and 12 findings listed in the prior section. These strategies provide insights into the future design of interior bodily play.

### Design Stable Interactions to Support Human–Sensor Fusion

The first theme speaks to the fact that players of the Guts Game might perceive the ingestible sensor as part of their body during play. This is in line with recent works suggesting that intracorporeal devices have the potential to support fusion between interactive systems and the user's body, letting users experience the interactive systems as part of their body [63]. However, in the Guts Game study, I found that the fusion between the users and the ingestible sensors could be interrupted when disconnections occurred with the data recorder. The technical problems might remind the participants that the sensor was not actually a real part of their body, leading to the breakdown of the fusion between the ingestible sensor and the player. This is similar to prior theory about the body–tool relationship, proposing that users may view a tool as an extension of their body, but this perception can be interrupted when the tool fails to function [91, 217]. Therefore, when designing ingestible play, I suggest designers try their best to design the system to be stable to make sure the human–technology fusion is not interrupted. If there is technology limitation, designers might consider dampening the negative experience or turning the technical challenges into design opportunities. In the Guts Game, I added a data filter to remove most of the erroneous temperature data. In a future design, I may consider how the erroneous data could be designed to be playful.

### Consider Facilitating Human–System Fusion Rather Than Mere Human-Sensor Fusion

Players can perceive the ingestible sensor as part of their body since the device is literally inside their body. However, I found that nearly all the participants did not mention that they perceived the whole game system as part of their body. I believe this is because the mobile phone where the Guts Game was running was 'distant' to the players compared to the ingestibles. Therefore, future design of ingestible play might consider making the whole system wearable or insertables (i.e., put into the user's body) in order to facilitate human–system fusion rather than merely a human–sensor fusion.

Appropriate feedback might also support the human–system fusion. With the Guts Game, the feedback is on the screen of the mobile phone and therefore is away from the player's body. According to Mueller et al. [159]:

> The difference between a perception of something outside of myself and the perception of my own body as Leib corresponds to differences in sensory in-

> put. Perceptions of something outside of myself are results from sensations that are not reflected within my body, whereas perceptions of my own body as Leib are results from 'localized sensations'. For example, when I perceive a red apple, I have particular color sensations that determine the fact that I attribute the quality 'red' to this apple, but this quality belongs to the apple outside of me and is not found somewhere within my perceiving body. The red is not localized in my eyes [207]. However, in the case of the sense of being touched, sensations are localized. I feel in my hand that it is touched.

If adapting Mueller et al.'s [159] argument to the player experience of the Guts Game, the visual feedback of the game only lets players experience the feedback as something outside of the players. Meanwhile, if the feedback produces any localised sensations such as cold, warm or haptic sensations on the player's body, the player might experience the feedback as part of their body. Therefore, in ingestible play designers might consider such feedback that can let players experience their body as theirs to support human–system fusion.

Another factor that dampens the human–system fusion in the Guts Game is the heavy demand for the player's attention when engaging with the game system. With the Guts Game, the players need to focus on the mobile phone screen in order to know the game progress and the real-time body temperature changes. However, for our own body, we do not need much attention to understand our bodily status. For example, we can directly know we are cold via sensations. We do not need to see the goosebumps on our skin in order to know we are cold. Therefore, I recommend that designers to consider designing alternative eye-free interactions [175] that do not require much of the player's attention to perceive and understand. Such a design might help players to improve their perception of the extent to which the digital play is part of their body.

#### Consider Designing a Narrative for Regulating Bodily Awareness

The second theme emphasises that the player's bodily awareness can be important in the UX of the ingestible play. Unlike traditional computer games that are not body-centric, digital play involving intracorporeal devices can lead the player's attention to their body, as players might feel nervous or even anxious about having a digital device inside the body. Although prior work suggests that promoting bodily awareness can bring about many benefits, e.g., promoting health and wellbeing [99], being too aware of the body might cause anxiety [68]. Therefore, I believe that it is important to regulate and balance the player's bodily awareness through certain design choices when it comes to ingestible play. In the Guts Game, ingestible sensors naturally increased the players' bodily awareness while the designed game narrative helped dampen their bodily awareness during Phase 0. Prior theory already suggests that well-designed game narratives can contribute to player engagement and improve the player experience [186,246]. In ingestible play, designers could consider designing a narrative to regulate bodily awareness and facilitate engaging play experiences.

### Consider How System Feedback Can Regulate Bodily Awareness

Although the players' bodily awareness increased because of ingesting a digital sensor at the beginning of the game, some players gradually lost interest in the game and hence their bodily awareness decreased. This might be because of the failure to pull the player's attention back to the ingestible play after the player was distracted by the physical world. The digital play around ingestible sensors can last for days since the sensor travels through the user's body for 24–36 hours. Prior work suggests that pervasive games should 'support the player in the process of switching concentration between in-game tasks and surrounding factors of importance' [107]. Therefore, designers might consider designing the system to support players shifting their attention back to the play and hence their body.

Moreover, different system feedback modalities afford different potentials in regulating one's bodily awareness [26]. The Guts Game is played on a mobile phone, and the visual feedback does not increase the player's bodily awareness much. Previous work suggests that certain sensory experiences can be perceived as inside the body and better for increasing bodily awareness than other sensory experiences [108]. For example, heat stimuli may increase bodily awareness since heat has the potential to permeate the skin and be perceived inside the body [108]. Designers may consider regulating the player's bodily awareness by considering different feedback modalities in future designs related to the interior body.

### Consider Different Interactions Across the Four Phases

With the Guts Game, the structure of the human body naturally made players experience the play differently across the four phases. This is usually different from traditional computer games where the experience of interacting with the keyboard and mouse often remains the same during play. Therefore, when designing with any intracorporeal device, designers are advised to consider how the UX of the device might change during usage. This can often be done via autobiographical studies [182].

Prior work suggests that players should feel a sense of agency over their game actions for positive play experiences [221]. Therefore, in ingestible play designers might create appropriate game designs to match the player's rather low level of agency over their interior body parts. In game design, a common strategy to deal with a low level of agency is to adjust the game difficulty to make sure the game tasks are achievable yet challenging [38,77]. Inspired by this, I expect that in future iterations of the Guts Game, the gameplay can be adapted depending on the game difficulty, i.e., different gameplay across the four phases. Therefore, I suggest designers consider adapting the gameplay if the extent of players' agency changes throughout the duration of ingestible play.

### Consider Dealing with the Low Extent of Agency Experienced by Players

The third theme highlights that players might experience a low level of agency in interior bodily play since one's agency over interior body parts is relatively low compared to agency over the exterior body parts, e.g., the limbs. With the Guts Game, players experience relatively low agency over their interior body temperature and also digestion speed. Prior work suggests the importance of a sense of agency in facilitating positive experience in digital play [221]. Therefore, when designing ingestible play, designers should consider how can they tackle the design challenge of the low agency. In the Guts Game, I designed the data visualisation of the temperature data to be ambiguous compared to a plain number, which could alleviate the frustration caused by the low level of agency experienced by players to some extent. I acknowledge that some participants still wanted to see the exact reading of their body temperature. Learning from prior works suggesting designers consider communicating the low level of agency over data to users in order to retain user trust [109,201], I speculate that in future designs I can communicate to players their low level of agency over their interior body via design.

Moreover, in many cases, design challenges can be turned into opportunities with careful design. In the Guts Game, although players expressed that they experienced a low level of agency over their digestion and therefore could not control the game end time, they mentioned that the unfixed game end time was playful. Moreover, players expressed that the unfixed end time added another layer to the gameplay. For example, with the Guts Game, when a player won more scores than their co-player, the player could ingest some food that helped speed up their digestion to end the game and win. In game design, uncertainty sometimes can be used as a design material to facilitate positive game experience [240]. Therefore, designers might consider turning the low extent of agency into a playful element to support engaging play experiences.

### Consider Uncomfortable Interactions

According to the three themes, players might feel uncomfortable during ingestible play, usually when they violated cultural norms. For example, swallowing a digital sensor might challenge the social norm of not ingesting 'inedible' devices. Playing the Guts Game led some players to behave abnormally in public spaces, which also challenged the cultural norm to some extent. Prior works suggest that uncomfortable interactions can become an important tool for designers, promoting entertainment, enlightenment and sociality when managed carefully and ethically [17]. Although discomfort is sometimes perceived as a negative factor in game experiences [243], uncomfortable experiences such as frustration exist widely in digital play [180]. For example, the playful system Musical Embrace has explored using discomfort as a design material to facilitate engaging interactive experiences [52, 103]. In ingestible play, the factors that lead to uncomfortable experiences can also be designed to be playful. For example, although swallowing the ingestible sensor might have been uncomfortable for some players, the sensor also made them more aware of their body during the play. Similarly, although some players complained that wearing the data recorder around their waist was uncomfortable, the visible recorder also served as a conversation starter and a social facilitator, which brought about engaging social experiences. Therefore, when designing ingestible play, rather than striving to ease the players' discomfort, designers can consider how the discomfort could be turned into engaging and playful uncomfortable interactions.

## 4.7 Summary of this Case Study

Designing playful experiences with a focus on the interior body via ingestible sensors is an unexplored area. This case study offers an initial understanding of this area through the Guts Game design and study.

I believe that the Guts Game serves as a compelling starting point for exploring the design of ingestible play. It demonstrates the potential of using ingestible sensors to engage players with their interior body and provides insights into future designs. From the Guts Game, I understand the importance of designing for the player's bodily awareness, the fusion between the interactive system and the player, the player's agency, and the importance of considering any uncomfortable interactions.

# Chapter 5

# Case Study 2: HeatCraft

Figure 5.1: HeatCraft.

Figure 5.2: HeatCraft used the same ingestible temperature sensor as the Guts Game.

## 5.1 Introduction

IN this chapter, I present the second case study, called HeatCraft, a playful wearable system with the same ingestible temperature sensor I used in the first case study (see Figure 5.2).

HeatCraft (Figure 5.1) is a wearable system that generates localised thermal stimuli where the intensity is based on the wearer's body temperature as measured by an ingestible sensor. To understand the UX, I conducted a field study [190] with 16 participants (8 pairs). Two participants in each pair experienced HeatCraft together. The results show that the overall experience of HeatCraft was intriguing and playful. The system increased the players' awareness of their body, their daily activities and the surroundings. Ultimately, HeatCraft moved towards an integration of play and life. Based on the UX and the design, I propose 8 strategies to help design playful experiences around ingestible sensors.

Similar to the Guts Game, HeatCraft also aimed to understand the design of playful experiences around interior bodily play via ingestible sensors. The Guts Game study has already shed some light on the future design of interior bodily play. However, I believe that the Guts Game did not utilise the full potential of ingestible sensors and the human body. Based on the themes I generated from the first case study, particularly regarding the

Figure 5.3: A player is putting on the HeatCraft system.

player's bodily awareness and the fusion between the interactive system and the player's body. This is mainly due to the fact the Guts Game was based on a smartphone. With the smartphone, system feedback was displayed on the screen, forcing players to stop any current tasks they were undertaking as part of their everyday life to play the game, which directed the players' experience away from their bodies. I, therefore, believe that it is limited in the smartphone's ability to engage players with their body compared to wearables and intracorporeal devices.

Prior works suggest that our bodies are not static entities and are continuously changing [207]. Intracorporeal devices have the potential to maximise the user's engagement with their always-changing body since intracorporeal devices such as ingestible sensors are pervasive to users as they are inside the users' body. Therefore, more design knowledge is needed to understand how the design of interior bodily play can further engage players with their body and facilitate a symbiotic relationship between the human and the interactive system to support body-centric interactions in a pervasive manner [129,143]. I chose to design the HeatCraft system to be wearable and use localised sensations as feedback to explore this. Localised sensations are sensations that 'mainly occur through touch, pain, proprioception, kinesthetic sensations and temperature perception' which have the potential to increase one's body awareness [207] (see Figure 5.3)). Moreover, perceiving the localised sensations does not need the user's full attention and hence

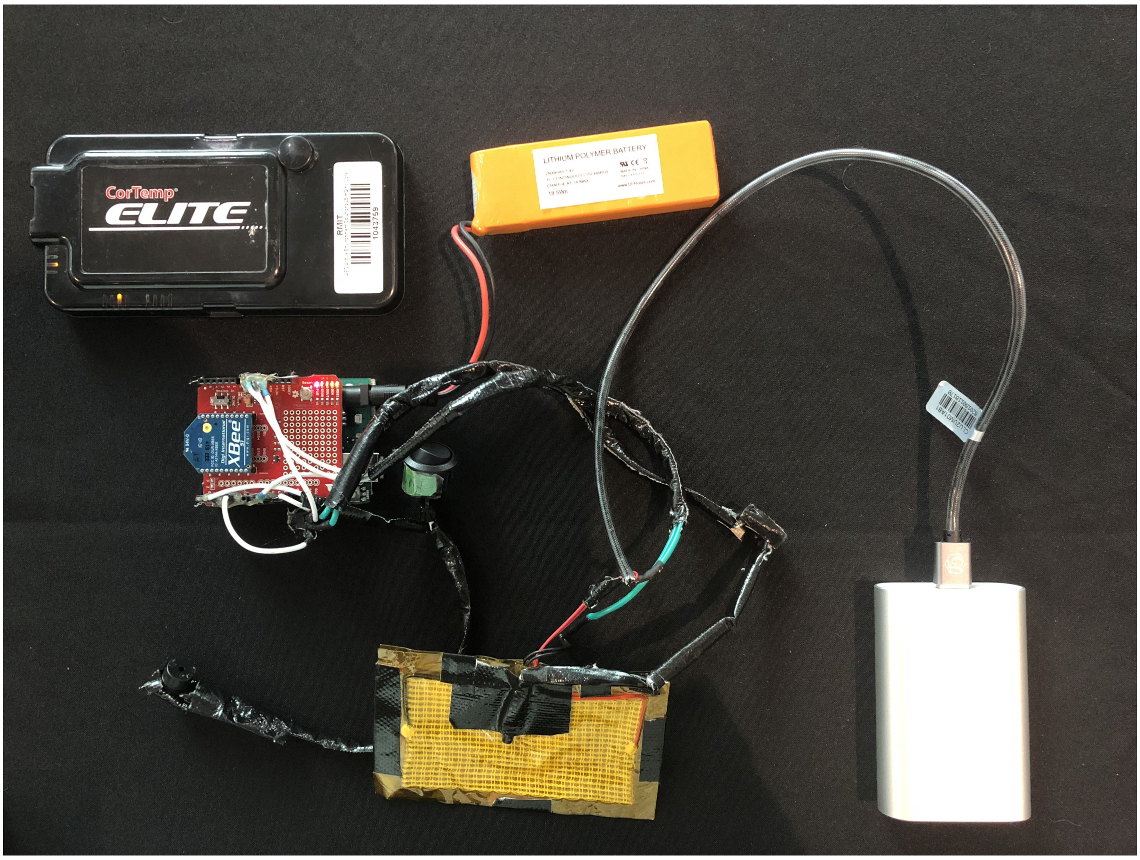



Figure 5.4: The HeatCraft system.

may support always-available play [185].

## 5.2 HeatCraft

HeatCraft comprises an ingestible temperature sensor and a waist belt containing a data recorder, an Arduino UNO, an XBee module, a MOSFET, a digital temperature sensor, two overlapping heating pads, a buzzer and a switch for the buzzer (see Figure 5.4). The ingestible sensor 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 data recorder receives temperature data from the ingestible sensor and sends it to the Arduino via XBee (see Fig 5.5). If $T_B$ is erroneous, the buzzer beeps. Otherwise, the Arduino calculates the temperature of the thermal stimuli $T_{HP}$. 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 are generated by the heating pads and adjusted by the Arduino and MOSFET via PID control. The digital


Figure 5.5: The ingestible temperature sensor sends data to the data recorder. The recorder then sends data to the Arduino wirelessly via XBee.

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 are encouraged to see HeatCraft as a toy and hence can freely explore the potential of HeatCraft to facilitate playfulness. With HeatCraft, players can freely explore how they can play with their body temperature. They can also design specific rules around the system.

## 5.3 Design Rationale

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

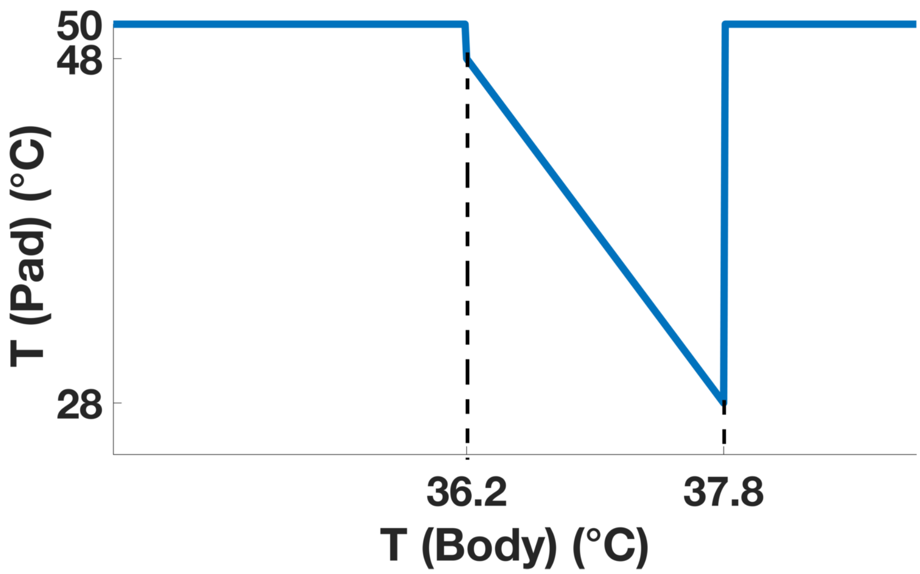



Figure 5.6: The relationship between the player's body temperature sensed by the ingestible sensor and the heating pads' temperature.

### 5.3.1 Using Heat Sensations as Feedback

HeatCraft uses thermal stimuli as feedback for five reasons. Firstly, I believe that 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 [108], contributing to always-available play. Thirdly, thermal stimuli can bring about pleasant experiences since they can evoke the users' emotional response [230]. Fourthly, localised thermal stimuli can increase one's bodily awareness [99,108], which may help users better manage their body [160] and increase body intelligence, leading to a more healthy and vibrant life [73]. Lastly, the subtle and cosy heat gives space for players to reflect on their bodily experiences and turn their attention inwards, which can positively influence their emotions and wellbeing [41]. I chose to locate the thermal stimuli on the player's waist because this allows unobtrusive and unhindered body movement [75]. Also, a thermal sensation on the waist can strongly influence overall body sensations [6].

### 5.3.2 Mapping Body Temperature to Thermal Stimuli

I designed the mapping between the player's body temperature ($T_B$) and the thermal stimuli temperature ($T_{HP}$) as shown in Figure 5.6 based on an autobiographical study [182] and prior works [57, 147, 157]. Two of the researchers experienced heat with different intensities. Both of the researchers were female (aged 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 show that the lowest heating pad temperature that can be sensed was 28 °C on average and there was an unpleasant sensation after the temperature reached 50 °C. Therefore, we designed the temperature of the heating pad to be between 28 °C and 50 °C. Designers need be aware that the lowest thermal stimuli temperature should be higher than the room temperature to ensure the players can sense the thermal stimuli. My work was conducted in winter, so the room temperature was usually lower than 28 °C. The two researchers also reported that they felt the heat stimuli to be pleasant when they were cold (when their skin temperature was about 23 °C. Similarly, previous work suggests that thermal stimuli are perceived as very pleasant in hypothermia [157]. Therefore, we designed the heating pad to be hotter when the player's body temperature was lower and the heating pad to be cooler when the body temperature was higher. In addition, previous work shows that the temperature data as measured by a rectal thermometer and by an ingestible sensor is very similar [57] and the normal rectal temperature is between 36.2 °C and 37.8 °C [147]. I, therefore, assume the normal temperature data range in this study is between 36.2 °C and 37.8 °C.

In light of the above, I designed the heating pad temperature as follows: if the body temperature data was lower than 36.2 °C or higher than 37.8 °C, the heating pad temperature was 50 °C to remind players of the extreme high/low body temperature; if the body temperature data was between 36.2 °C and 37.8 °C, the heating pad temperature gradually decreased from 50 °C to 28 °C. With this mapping, when $T_B$ changed by 0.1 °C, $T_{HP}$ was set to change by 1.25 °C. According to the autobiographical study, this temperature change can be sensed by the users. Moreover, it usually takes a minimum of 10 seconds to change $T_B$ by 0.1 °C according to my personal experiences with the ingestible sensors gained from case study 1, while it takes less than 2.3 seconds for the HeatCraft system to change $T_{HP}$ by 1.25 °C. Thus, there is sufficient time for the system to adjust $T_{HP}$ when there are body temperature changes.

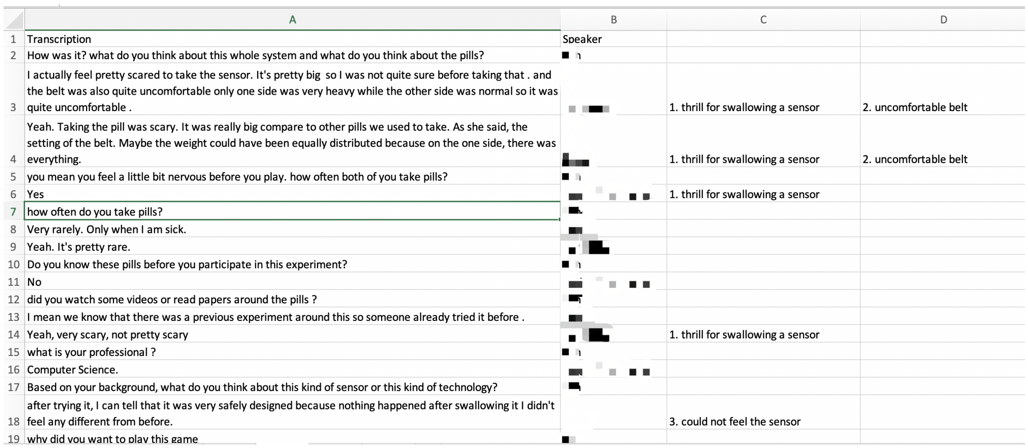
I do not see the designed mapping as a perfect way to represent the player's body temperature, since the mechanisms of how human body temperature changes and how one perceives thermal stimuli are complicated. For example, the study of the Guts Game with 14 participants suggests that the temperature data measured by the ingestible temperature 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 ingested might make contact with the sensor and significantly change the measured data (see Chapter 4). When the sensor entered the intestines, the data ranged between 35.64 °C and 39.11 °C. Therefore, this designed heat pattern in HeatCraft allows players to notice body temperature changes most times but they might miss some minor changes (e.g., from 39 °C to 40 °C).

### 5.3.3 Designing for Erroneous Data

I designed a buzzer to beep while keeping the heating pad temperature invariant when the system receives erroneous body temperature data ($\leq$ 22 °C or $\geq$ 45 °C). Such a design choice has three benefits. Firstly, this design allows players to be notified by the beep and not get confused when their 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 [30], the beep can also help players get to know more about their surrounding environment. Thirdly, the data recorder will send out random erroneous data when the ingestible sensor is excreted. Therefore, players will know they have excreted the sensor if the buzzer beeps once every 10 seconds, regardless of their location. I acknowledge that there might be erroneous data between 22 °C and 45 °C. However, according to my experience with the Guts Game's development and study, this rarely happens. Also, temperature data between 22 °C and 45 °C will not cause a dramatic change in the heating pad temperature as heat changes slowly, which will not confuse the players. Therefore, I designed the buzzer to only beep in response to erroneous temperature data that is below 22 °C or above 45 °C.

### 5.3.4 Designing Playful Experience

I believe HeatCraft is intrinsically playful. I analysed the potential UX of HeatCraft based on the PLEX model [140], which proposes 22 categories of playful experiences. HeatCraft can facilitate playful sensory experiences by providing localised thermal stimuli and bringing about the playful experience of thrill by letting players swallow a digital sensor. In addition, the open-ended gameplay might facilitate the playful experiences of exploration and discovery since players are given space to freely investigate how they can play with their body through HeatCraft, e.g., experiencing how their body temperature can be influenced by a variety of factors such as their diet, the surrounding environment and physical movement. Moreover, HeatCraft was designed as a two-player system and



| | A | B | C | D |
|---|---|---|---|---|
| 1 | Transcription | Speaker | | |
| 2 | How was it? what do you think about this whole system and what do you think about the pills? | [redacted] | | |
| 3 | I actually feel pretty scared to take the sensor. It's pretty big so I was not quite sure before taking that . and the belt was also quite uncomfortable only one side was very heavy while the other side was normal so it was quite uncomfortable . | [redacted] | 1. thrill for swallowing a sensor | 2. uncomfortable belt |
| 4 | Yeah. Taking the pill was scary. It was really big compare to other pills we used to take. As she said, the setting of the belt. Maybe the weight could have been equally distributed because on the one side, there was everything. | [redacted] | 1. thrill for swallowing a sensor | 2. uncomfortable belt |
| 5 | you mean you feel a little bit nervous before you play. how often both of you take pills? | [redacted] | | |
| 6 | Yes | [redacted] | 1. thrill for swallowing a sensor | |
| 7 | how often do you take pills? | [redacted] | | |
| 8 | Very rarely. Only when I am sick. | [redacted] | | |
| 9 | Yeah. It's pretty rare. | [redacted] | | |
| 10 | Do you know these pills before you participate in this experiment? | [redacted] | | |
| 11 | No | [redacted] | | |
| 12 | did you watch some videos or read papers around the pills ? | [redacted] | | |
| 13 | I mean we know that there was a previous experiment around this so someone already tried it before . | [redacted] | | |
| 14 | Yeah, very scary, not pretty scary | [redacted] | 1. thrill for swallowing a sensor | |
| 15 | what is your professional ? | [redacted] | | |
| 16 | Computer Science. | [redacted] | | |
| 17 | Based on your background, what do you think about this kind of sensor or this kind of technology? | [redacted] | | |
| 18 | after trying it, I can tell that it was very safely designed because nothing happened after swallowing it I didn't feel any different from before. | | 3. could not feel the sensor | |
| 19 | why did you want to play this game | [redacted] | | |

Figure 5.7: This screenshot shows the initial codes I labelled during thematic analysis. The speakers' names are covered with mosaics.

players were encouraged to be physically together to create the playful experience of fellowship [140]. According to prior works [160, 161, 163], social interaction can motivate players to actively engage with bodily play [160]. Also, the study with the Guts Game shows that social play can ease players' nervousness before swallowing the sensor. In light of the above, I believe HeatCraft has the potential to facilitate engaging and playful experiences.

## 5.4 Study

I conducted a field study [190] with 8 pairs of participants (7 males and 9 females; mean age = 27 years, SD = 4.7 years) to investigate the UX of HeatCraft. The two players in each pair were friends who could spend at least three hours physically together during the play.

After confirming the participants' eligibility for participation via a risk factor assessment questionnaire, I then invited eligible players to the lab. Since the players' perception of thermal stimuli might be affected by the thickness of their clothing [108], players were required to wear an ordinary T-shirt to minimise this influence. The two players were then provided with an information sheet explaining the ingestible sensor and offering guidance for potential first aid and the researchers' contact details for technical support. Then the two players swallowed the sensors, put on the belts, and released from the lab. I did not restrict the places where they could go and the activities they could do. After the players excreted the sensors, they went back to the lab and were interviewed together. Each semi-structured interview took about 45 minutes, and was audio-recorded. The players were asked about their perceptions in regards to the ingestible sensor, their motivations for taking part in the study and their experiences with HeatCraft. I utilised thematic analysis [25] to analyse the interview data (see Figure5.7). The analysis led to the three themes that will be presented in the following section.

## 5.5 Results

Overall, the findings suggest that HeatCraft facilitated ubiquitous playful experiences, augmented the players' bodily experiences and promoted the awareness of their environment. I have identified three themes: integration of the body and the technology; integration of the internal body and the outside world; and integration of the play and life.

### 5.5.1 Theme 1: Integration of the Body and the Technology

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

#### HeatCraft Extended Players' Capabilities

Participants reported that HeatCraft extended their sensing capabilities and might have influenced 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!' (see Figure5.8). The extended capabilities further influenced the ways 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 realised it was so weird to heat my body up with ice water. But at that moment, it was intuitive for me'.

Figure 5.8: The two players felt like secret agents when wearing HeatCraft systems.

### Players Appreciated HeatCraft being Fused with the Body

Ten participants mentioned that they liked the fact that 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 fused 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 Scanning

Body scanning is a common method in mindfulness meditation practices, letting one bring attention back to the body and feel the bodily sensations from head to toe. With HeatCraft, participants reported that HeatCraft made them think about their internal body, which is similar to the body-scanning exercise. For example, p13 said: 'It made me think about my body from the inside and think about my organs as a separate thing rather than the body as a whole. It made me think about my inner body structure and how things [are] travelling through my body'. p8 said: 'It let me think about the size of my organs. I was imagining this sensor going through my stomach and entering 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'. 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 us. When I was alone, I was more likely to think about my internal body'. This indicates that social play might bring the player's attention to the thermal feedback outside the body, rather than to the body itself.

#### Ingesting the Digital Sensor Increased Players' Bodily Awareness

Fourteen players reported that HeatCraft increased their bodily awareness by providing information on 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 Embodied Feedback Deepened the Fusion between the System and the Body

Participants reported that they liked the thermal feedback as it was embodied. For example, p2 said: 'Heat is better than the number. It might not be precise but it makes

Figure 5.9: A player experiencing the heat while reading.

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 (see Figure 5.9). 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'.

### 5.5.2 Theme 2: Integration of the Internal Body and the Outside World

This theme includes how the system helped players gain bodily knowledge and become aware of the interplay of their internal body, body surface, bodily actions and the en-

(a) (b) (c)

Figure 5.10: Players tried different activities when experiencing HeatCraft: (a) a player ate noodles to see how their body temperature changed; (b) a player drank ice water; (c) the player feels the heat being increasing after drinking the water.

vironment. Players reported that HeatCraft made them aware of how their actions and environment influenced their internal body through heat sensations. For example, p2 said: 'It's interesting to expose everything to the sensor these days and know more about my body and environment'. p5 also explained: 'The whole experience is like a loop. The environment and actions I take make my body change. I feel this change via my skin and this sensation affects my mind. Ultimately, this influences my behaviours again. It's amazing'.

#### HeatCraft Made Players Aware of Their Daily Activities

Players reported that HeatCraft made them more aware of their daily activities (see Figure 5.10). For example, p4 explained: 'It's fun to think that 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 behaviours 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 realise the exercise I didn't do because I knew the pads would change if I had done physical exercise. It made me think I should do more exercise'. Moreover, the player's awareness of their activities further contributed to their 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 behaviours even after the play and therefore they were interested in the long-term effects 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 still be in my body although the beep sound told me that I had 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 relationship 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 have motivated their 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 behaviours'.

#### HeatCraft Increased Players' Awareness of the Outside World

Twelve participants mentioned that HeatCraft made them more aware of their surroundings (see Figure 5.11). For example, p14 reported that: 'I enjoyed knowing more about the environment. When I heard the beep, I thought there was a wave travelling beside me and connecting to someone's mobile phone. Also, it made me observe the number

Figure 5.11: A player heard fewer beeping sounds in the park, where there was less electromagnetic interference.

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 bushwalk. I felt so good to feel the nature'. Similarly, p2 reported: 'The system indicated the environment temperature. One time when the heating pad temperature increased, I realised I was in a cold space'. Their awareness of the outside world might have affected the players' perceptions of a certain place. For example, p3 said: 'When I played the game, I went to an electronics 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 Helped Players Treat Their Bodies Better**

Their 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 information about 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 attuned to nature. This system definitely helped me towards this. For example, it made me aware that I should adjust my clothes based on the environment temperature'.

### 5.5.3 Theme 3: Integration of the Play and Life

This theme illustrates how HeatCraft facilitated ubiquitous playful experiences. For example, p15 said: 'The system turns daily activities into potential game actions and turns all the objects around me into 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 touched each other's belt to see who could 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 their co-player's temperature. p11 and p12 said they raced against each other to see who excreted the sensor first. p1 and p2 reported that they compared the heat feedback of different activities. p13 and p14 said they exchanged their belts and tried to influence the heat felt by their 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: '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 [140]. 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 risk and danger [140]. Participants reported that they experienced thrill during the play, especially before swallowing the sensor. 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 liked it'. Four players reported that they had thrill experiences when they periodically thought about the fact of having a sensor in their body. For example, p1 said: 'Before I went to bed, I thought about the sensor. It was scary but still interesting'. Players regarded the experience as a safe adventure for several reasons. Firstly, the device would not be inside their body permanently. For example, p8 said: 'I think this could 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 was interesting and it would just stay in my body for three days. It's better than implantable devices'. Secondly, the study procedures such as the screening protocol and guidance 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 commercialised for 10 years'.

**Players Appreciated the Playful Experience of Subversion**

Subversive play refers to playful experiences facilitated by breaking social norms [140]. Participants reported that they enjoyed experiencing 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 realise 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 had 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. I did not ask how long players were together but, from their activities they did, I inferred that they spent about 3–22 hours (mean = 9 hours) together. For example, p11 laughed: ‘Now we are very open. I never thought about updating information to her whenever I went to the toilet’. Similarly, p13 said: ‘Exchanging our belts and feeling the other one’s body temperature created a 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 localised 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’.

### 5.5.4 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 was because I didn’t trust the device at this stage since it is a prototype. It would be great to have some feedback that is easy to learn to indicate the system is working, like an LED’.

#### Players Expected a Combination of Numbers and Sensations as Feedback

Five participants said they would like a combination of localised heat and digital numbers 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'.

## 5.6 Discussion

Based on the findings from the study of HeatCraft, I present a set of design strategies in this section. Similar to the strategies I presented in Chapter 4, this section's strategies do not represent a complete list guiding the design of ingestible play. Instead, they represent design knowledge I gained from this single prototype, i.e., HeatCraft.

### 5.6.1 Design Always-available Interactive Systems to Facilitate Player–System Fusion

Theme 1 shows that players regarded HeatCraft as fused with their body. With HeatCraft, the ingestible sensor was inside the human body, while the remaining parts of the system were always available and let players experience that their bodily capabilities were extended, i.e., they could easily know their body temperature changes at any time and any place. Theme 3 shows that the fusion between the system and the players' body further facilitated ubiquitous play by integrating play into the user's everyday life. Prior work suggests that augmented human (AH) technology is always-available and fused with the human body [129]. These technologies could improve human abilities and have the potential to change the way users perceive themselves and their bodily functionalities, and players might perceive these technologies as extensions of themselves [129]. Therefore, designing the interactive system to fuse with the player's body may bring about novel experiences, augment the player's bodily perceptions and provide ubiquitous playful experiences.

To facilitate the player–system fusion, Themes 1 and 2 highlight the importance of designing ingestible systems to be always available. Prior work suggests that always-available health technology can turn any place where the user is in into a therapeutic landscape [142]. Inspired by this, I argue that designing playful experiences with always-available technology such as ingestible sensors can turn any place where the player is in into a playground and therefore facilitate ubiquitous play (just like prior work suggests [102]). Moreover, such always-available body-centric technologies can make users aware of their bodily state at any time and therefore support self-discovery and self-development [173]. HeatCraft supported always-available interactions by designing a wearable belt with always-on thermal feedback, making the whole system more pervasive than portable technologies such as smartphones. Therefore, when designing ingestible play, I recommend an always-available design. For example, wearables that generate sustained localised sensory stimulus as system feedback can be considered. More broadly, for designers who aim at creating ubiquitous play experiences, always-available systems such as AH technology that directly changes the body's morphology (e.g., exoskeleton) or sensing capabilities (e.g., biosensing tattoo) [129] could be considered a design resource.

### 5.6.2 Embrace the Functional and Affective Perspectives to Facilitate Bodily Extensions

Theme 1 highlights how players appreciated HeatCraft being fused with their body and being perceived as their bodily extensions. Hence, the design of interior body play systems might learn from prior work around bodily extension. Slatman [207] argued that whether one perceives a transplanted organ as part of the body is influenced by the functional limits and affective limits. Functional limits refer to the transplanted organ's useability, while affective limits refer to whether the transplanted organ can be accepted psychologically. For example, the transplanted organ may be regarded as a stranger rather than an extension if it is not accepted [207].

The interactive systems design to support interior bodily play might also be considered from the functional and affective perspectives. From the functional perspective, HeatCraft facilitated bodily extension by providing always-available body temperature data. Although the ingestible sensor sometimes sent out errorneous data when interfered with by electromagnetic fields, I used a beeping sound to indicate the erroneous data to keep the players' trust in the system and at the same time to indicate the intensity of the players' surrounding electromagnetic interference. Therefore, the errorneous data did not seem to affect the players' experience but added another layer of playfulness. This is similar to Nunez-Pacheco and Loke [173]'s argument that the user's trust in biodata can help create a sense of ownership towards the system feedback, which motivates self-exploration in biofeedback projects. Thus, I suggest designers could consider turning unreliable aspects of the system into features that players can play with via careful design when designing ingestible systems for digital play.

From the affective perspective, players might not regard interactive systems as their bodily extension due to issues such as safety, cultural effects, and data security [86].

Theme 3 shows that HeatCraft supported players to accept the system psychologically by embedding ethical design choices. For example, players reported that they felt more comfortable and safe after being evaluated for their participation eligibility and being provided with first-aid guidance. Therefore, it might be important for designers to let players feel safe with the system and trust the technology. The implementation of this strategy can learn from prior works in ethics research. For example, a prior work [118] that explored the ethics of ingestible sensors mentioned that ingestible sensor providers need to be transparent with clinicians and patients about all technology aspects. Learning from this, in HeatCraft players were provided with detailed information about the ingestible sensors and were welcome to ask any questions before and during the study to address their concerns.

### 5.6.3 Consider Ambiguity to Facilitate Playful Experiences

Theme 2 suggests that ambiguous aspects of HeatCraft could motivate players to reflect on their daily activities and environment. Prior work [72] suggests that pointing out things without explaining the reasons can encourage people to consider the personal significance of things, behaviours and events in their environment. With HeatCraft, players were only aware of their body temperature change, but did not know the exact causes. This ambiguity encouraged players to reflect on the reasons for their body temperature changes and facilitated playful experiences of exploration and discovery according to the PLEX model [140]. Prior work also suggests that ambiguity is an important factor in creating playful systems integrated with users' lives to facilitate ubiquitous play [179]. Therefore, designers might want to consider ambiguity a design resource to create future interior bodily play in order to facilitate playful experience and let players reflect on their interior body changes at the same time.

### 5.6.4 Consider Players' Surrounding Environment in Ingestible Play

I suggest designers consider engaging players with their environment when designing interactive systems for ingestible play. The environment might influence one's interior body status. For example, with HeatCraft players found out how the room temperature could influence their interior body temperature. Moreover, the buzzer functioned as an environment sensor to indicate surrounding electromagnetic interference. This contributed to a ubiquitous play experience since the player periodically entered new places during the play. Once the player entered a new place, they could explore the environment via the HeatCraft system. Similarly, prior work [61] indicats that a key attribute of pervasive games is that they can influence the player's experience of their environment, evoking emotions that affect the player's perceptions of the real world. Therefore, designers might want to consider additional environment sensors such as temperature sensors and humidity sensors when designing ingestible play to let players become more aware of their surroundings and support them to explore how their body might interact with the outside environment.

### 5.6.5 Consider Body Boundaries to Facilitate Playful Experiences

Although one might consider the skin as the body boundary, the body boundaries are actually not fixed. The pores of the skin, the mouth and the anus are continuously absorbing and excreting things in and out of the body [207]. In HeatCraft, the ingestible 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 and guessing when the sensor would come out. When the sensor was inside the body, players could not know its exact status as they could not directly see the sensor because of their body boundaries. This might bring about fantasy experience [140] when a foreign object entered their body boundaries since players regarded the ingestible sensor as a reference point to imagine their interior body structure, leading to body-scanning activity, which might facilitate mindfulness [174]. Therefore, to engage players with their interior body, designers might consider this crossing of the body boundaries a design resource to facilitate a playful experience.

### 5.6.6 Embrace the *Körper* and *Leib* Perspectives to Facilitate Lived Experiences

*Körper* and *Leib* are two German words, both referring to the body. *Körper* refers to the objective body, while *Leib* highlights the lived body. The findings with HeatCraft confirmed the theory proposed by Mueller et al. [159] that players can 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 localised 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, I suggest designers embrace the *Körper* and *Leib* perspective and learn from the related design knowledge [159] to let players experience their interior body as digital play. For example, designers may want to consider shifting between *Körper* and *Leib* by allowing intracorporeal devices to measure what the *Körper* does and turning this data into a localised sensation to support the *Leib*.

### 5.6.7 Design Social Play for Ingestible Play

Theme 3 shows that players enjoyed social interaction during the play. With the first case study, I learned that designing social interactions in interior bodily play could enrich game experiences and help players relax before swallowing ingestible sensors (see Chapter 4). Similar to the findings from the Guts Game, HeatCraft shows that social interaction is a key element to facilitate positive game experiences, which is also similar to other types of digital games [221]. Moreover, similar to the Guts Game findings, HeatCraft also provided a topic for players to start a conversation with their co-player and outsiders. Considering that I designed the gameplay of HeatCraft to be open-ended, HeatCraft facilitated spontaneous social play more often compared to the Guts Game. For example, HeatCraft promoted the connection between the two players when they exchanged their belts and let their co-player feel their temperature. Prior works also suggest that ubiquitous play usually encourages spontaneous interaction with outsiders, which enriches the game experience [84]. Therefore, designers might want to consider social play when designing playful experiences for ingestible play. Designers should keep in mind that social interactions might distract players from feeling themselves from the inside (Theme 1).

## 5.7 Summary of this Case Study

HeatCraft has provided a conceptual understanding of designing always-available playful experiences with the interior body via localised sensations. The associated user study shows that HeatCraft can increase the player's awareness of their body, daily activities and surrounding environment. This awareness contributed to the integration of the system and the user's body, and the integration of the internal body and the outside world, and ultimately facilitated the integration of the play and life.

Combined with the results of the Guts Game, HeatCraft helps move towards a more complete understanding of interior bodily play. However, both the Guts Game and HeatCraft are based on the CorTemp sensor, which measures the player's interior body's one-dimensional data. In the next case study, I will explore multidimensional data: the player's real-time endoscopic video.

# Chapter 6
# Case Study 3: InsideOut

Figure 6.1: InsideOut.

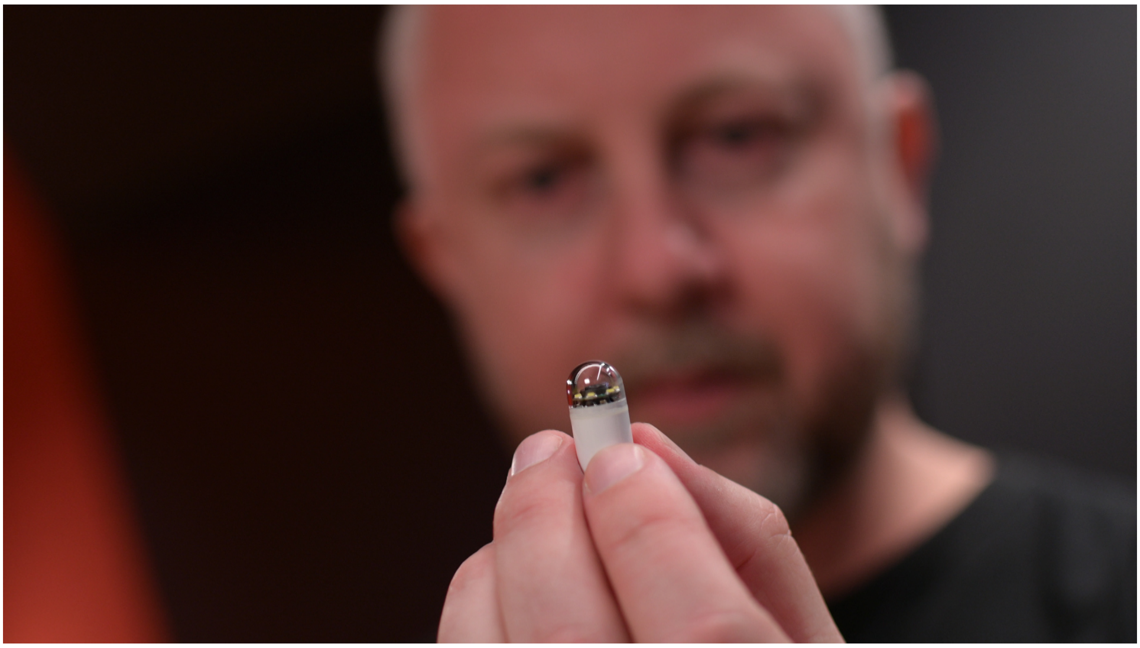


Figure 6.2: The imaging capsule.

## 6.1 Introduction

THIS chapter presents the third and last, case study, InsideOut, a playful system designed around an imaging capsule.

Imaging capsules (see Figure 6.2) are similar in shape to standard pharmaceutical capsules and contain a small video camera, LED light (see Figure 6.3), and video transmitter powered by a battery. Once swallowed, the capsule moves naturally along the user's GIT, taking continuous pictures to form a video for medical analysis [105].

Recent research suggests that in addition to their medical utility, imaging capsules have the potential to facilitate intriguing bodily experiences [207]. However, current research related to imaging capsules mainly focuses on their technical development and usability in medical diagnosis [36, 40, 105, 111, 130, 131], while the technology's potential to support experiential qualities is mostly overlooked.

In this case study, I present a playful system called InsideOut that supports interior bodily play around an imaging capsule (see Figure 6.4). With InsideOut, the player swallows an imaging capsule and wears a garment containing a display showing the real-time video captured by the capsule. The system supports players to freely explore how they can influence their GIT, motivated by software that maps the player's body movements to various video image manipulations such as scaling and rotation. Moreover, to pro-

Figure 6.3: The imaging capsule includes an LED light flashing as it moves along the GIT.

long and enrich the player's engagement with the system, I designed six additional play modes. I invited seven participants to experience InsideOut in the real-world setting (i.e., using the system in their homes and workplaces), followed by semi-structured interviews afterwards to understand the player experience with InsideOut. Through a thematic analysis [25], I articulate four themes explaining the player experience, i.e., Experiencing the Enchanted Body as Subversive Play, Experiencing the Lived Body as Exploratory Play, Experiencing the Absent Body as Relaxed Play and Experiencing the Cultivated Body as Serious Play. Finally, I propose design implications for designing ingestible play around imaging capsules by combining the themes with my design craft knowledge. These implications might also inspire the future design of digital play around interior body images.

## 6.2 Design Background

Unlike the prior two case studies that engage players with their body temperature, InsideOut engages players with their interior body video. I envisioned that seeing one's unfamiliar interior body would be very different from knowing the interior body temperature. In this section, I present prior works that can provide insights into the potential

Figure 6.4: A player wearing the InsideOut system.

experience of engaging with interior body images.

In most cases, people only see their interior body images when undergoing medical imaging procedures such as X-rays and ultrasound scans. These procedures produce one's medical images for doctors to diagnose. Medical images can also bring about intriguing experiences for observers. Considering the experiential affordances of medical images, these images have already been used outside a clinical context. As early as 1896, Natale [171] analysed the visual power of X-rays for public entertainment and called it 'making the invisible visible', even before the technology became popular in medical practice.

Prior works suggest that seeing the images of one's interior body might facilitate intriguing bodily experiences and engage the individual with their own body [187,203,205, 227]. Helman [92] suggested that despite being confronting at first, interior body images can bring about a strange pleasure to the viewer [46,187] due to the images' novelty and the low level of bloodiness and messiness [228]. This indicates that in this work, the video filmed by the imaging capsule might facilitate uncomfortable interactions that can be used as a design resource to inform bodily play design [32,165]. Moreover, prior works indicate that the social context can influence one's experience with medical images. A patient might feel embarrassed when their 'unclean' intestines were seen by others [187]. This motivated the work to explore the player experience when the GIT video is shown to others.

Besides facilitating engaging bodily experiences, observing interior body images might bring practical benefits. Di Stefano [53] argued that seeing interior body images can make viewers more aware of their bodies and reach a deeper body consciousness. Slatman [203] also argued that images of the interior body can change the viewers' imagination of their interior body and their bodily perceptions, which may further influence their self-identity. Van Dijck [227] proposed that watching their endoscopic video can make viewers experience more power over their bodies and influence their understanding of body and health. Moreover, prior works indicate that showing interior body images on public media such as magazines and TV can make viewers become more accepting of surgical procedures [228]. Giraud et al. [78] summarised that the interior body images could benefit therapy planning, support predictive simulations and enhance diagnosis, education, and patient–doctor communication. Therefore, to obtain these benefits, in this work I have designed most game experiences depicting realistic video of their GIT to engage players with their own bodies.

Medical images have also been used as a design material in the field of HCI. For example, Hoang et al. [94] developed an augmented reality system that projects anatomical structures and annotations over the user's body for educational purposes. Huerga et al. [102] let hospitalised children use their X-ray sheets to create play characters in order to make young patients more active participants in their hospital experience. Giraud et al. [78] proposed an installation that explores how medical images and self-images interfere with each other. These works provide a background for designing playful interactions around medical images. However, none of these works explored the design around interactions with one's real-time interior body images. In this work, I investigate the design around real-time video filmed by the imaging capsule as it travels through the user's GIT.

Overall, these prior works provide insight into the interior body images' experiential affordance, indicating how these images might engage people with their interior body. In this work with InsideOut, I explore how the experiential perspective on the interior body images can inform the design of ingestible play.

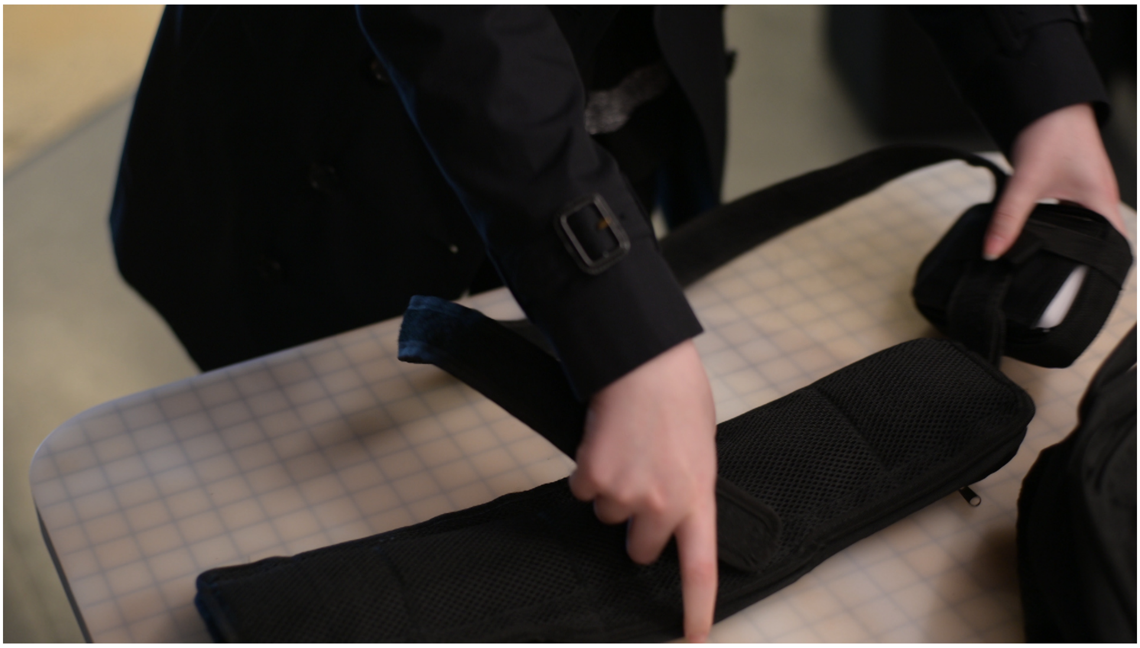


Figure 6.5: The waist belt and the data recorder in the black pouch.

## 6.3 InsideOut

To explore design around imaging capsules, I designed InsideOut. InsideOut is based on the OMOM® SmartCapsule Endoscopy System[1], which is TGA- and CE-approved [131]. The system consists of an imaging capsule, a waist belt containing an antenna array for receiving signals from the capsule wirelessly, a data recorder receiving data from the antenna array and a software called ImageStation that supports seeing the video captured by the imaging capsule in real time when connecting the data recorder to a PC. During usage, the data recorder is put into a pouch and worn by the user over their shoulder (see Figure 6.5). The size of the OMOM imaging capsule is 11.0*25.4mm and it is less than 4.5g in weight. The capsule's visual angle (in the air) is 157°. Its depth of focus (in the air) is 0 35mm and the resolution (in the air) is 8 lp/mm. The image format of the capsule supports 320 by 240 pixel resolution and the image data is 24-bit true colour. The frame rate of the imaging capsule is 2fps.

In addition to the OMOM® SmartCapsule Endoscopy System, InsideOut comprises a display (iPad), a laptop (MacBook) and a power bank to provide additional power for the laptop, as the play can last about 8 hours (see Figure 6.6 and Figure 6.7). The specifica-

[1]OMOM SmartCapsule Endoscopy System is a production of Jinshan Science & Technology (Group) Co. http://english.jinshangroup.com/capsuleendoscopy.html

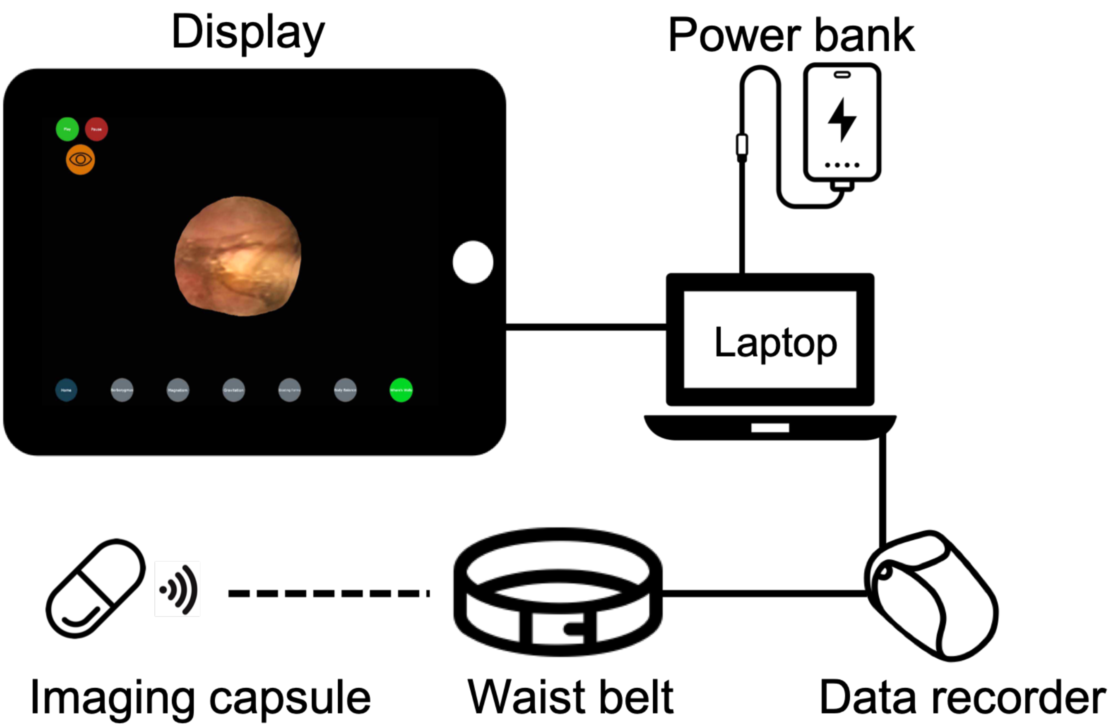



Figure 6.6: The system diagram of InsideOut.

tions of the iPad display is 9.7 inches (250 mm) 2048 × 1536 px (264 ppi) and of the display of the MacBook is 12 inches 2304 × 1440 px (225 ppi). The laptop uses Open Broadcaster Software (OBS)[2] to collect the video shown on the ImageStation software and stream it to the TouchDesigner software[3] for composing and interactivity. The transformation of the capsule video is based on the player's body movements and surrounding environment, which are sensed by the iPad and sent to TouchDesigner via GyrOSC[4] (see Figure 6.8). The output video from the TouchDesigner is shown on the display (iPad) via Duet Display[5]. Both TouchDesigner and Duet Display support a 60 fps frame rate.

I acknowledge that the resolution of the capsule's image data is relatively low. However, none of the participants reported any difficulty in seeing their GIT. This resolution

[2]Open Broadcaster Software (OBS) is an open-source program that can be used for recording and streaming and recording. https://obsproject.com/

[3]TouchDesigner is a software that supports node-based visual programming for real-time interactive multimedia content. www.derivative.ca/

[4]GyrOSC is an application that sends the data sensed by sensors embedded in an iPhone, iPod Touch or iPad to any OSC-capable host application over a local wireless network. www.bitshapesoftware.com/instruments/gyrosc/

[5]Duet Display is an app that supports users to turn an iPad into a second monitor. www.duetdisplay.com/


Figure 6.7: The InsideOut system.

is sufficient for the purpose of entertainment and for players who do not have a medical education background to engage with their interior body. If such play is designed for health professionals, for example, in designing the gamification of the diagnosis process, designers might need to carefully design the system to keep the resolution high. Moreover, I believe that with the advancement of technology, the resolution of imaging capsules' image data will become higher.

## 6.4 Design Rationale

In the following subsections, I elaborate on the design rationale for InsideOut.

### 6.4.1 Wearability Design

The findings from HeatCraft emphasised the importance of supporting always-available interactions in ingestible play (see Chapter 5). Therefore, in this work I designed InsideOut to be wearable for providing always-available interactions. The maximum play duration of InsideOut is about 8 hours due to the imaging capsule's battery life. Currently available AR head-mounted displays are usually not suitable to be used continuously

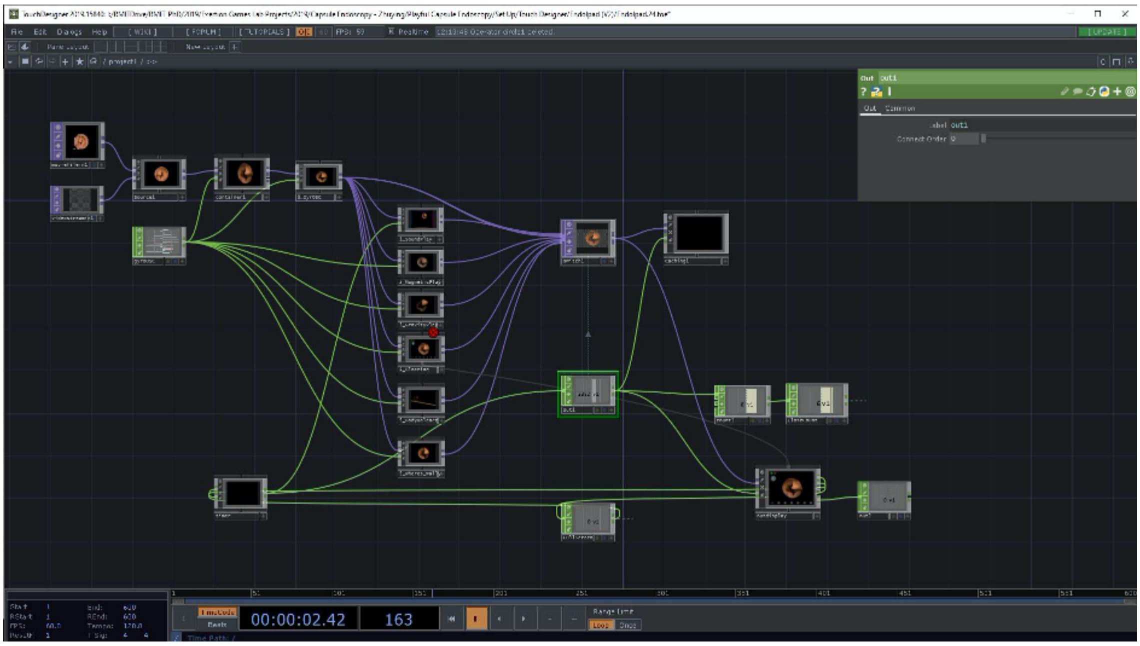
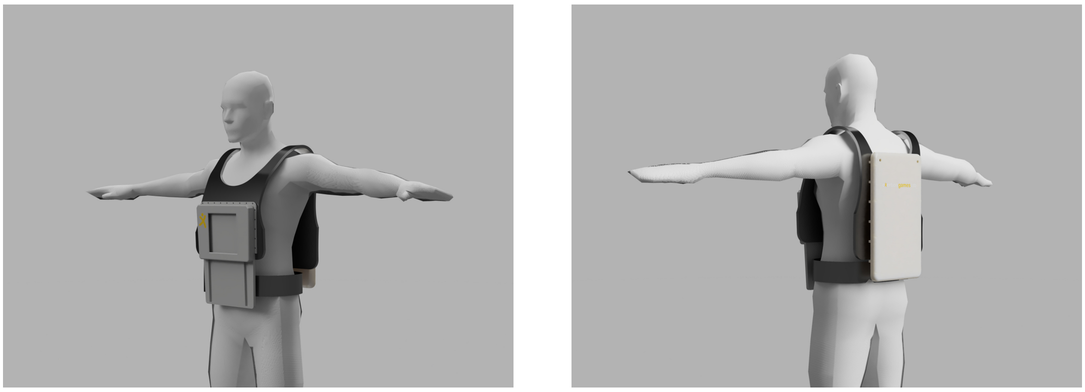



Figure 6.8: The TouchDesigner program that motivated InsideOut.

for 8 hours due to their weight and battery limits. Hence, I decided to design InsideOut as a system that is worn like fashion clothing, where the display is worn on the user's body. Wearing the display in front of the body may not hinder the player's movements. The player can lower the head to view the screen at any time, moving towards always-available play.

During the design process, I considered using a smartwatch as the display; however, smartwatches are too unobtrusive, making it hard to facilitate social interaction and also hard to pull the player's attention back to the play without explicit notification. Inspired by one of the design strategies I presented with HeatCraft (see Chapter 5) that suggests designers consider body boundaries to facilitate playful experiences, I chose to place the display in front of the user's stomach. An imaging capsule already challenges one's body boundary by literally entering the body. I envisioned that placing a display in front of the user's body would further highlight the crossing of body boundaries by creating the feeling that the skin has become transparent and the body boundary is blurred. Also, this position allows other people to see and interact with the capsule video, which might facilitate engaging social play experiences (see Figure 6.10). Moreover, according to the Guts Game findings, being observed by others when behaving strangely might facilitate uncomfortable interactions (see Chapter 4). Inspired by this, I believe that letting others see the player's interior body image might bring about uncomfortable interaction expe-



(a) (b)

Figure 6.9: In early design, I designed the display to move from the chest to the abdomen as the capsule moved along the player's GIT.

riences, which might facilitate playful experiences and at the same time, promote critical reflections on the interior body and associated technologies [17, 120]. To balance the uncomfortable interaction, I also designed a button that looks like an eye to hide the video for privacy.

After confirming the position of the display, I have considered designing the display to move from the chest to the abdomen (see Figure 6.9). The reason was that the move of the display can be seen as a literal metaphor of the moving capsule as the capsule moves from the player's mouth to the large intestine. I communicated the idea to other designers, members of my lab, and my friends. Most of them found the moving display to be confusing as they did not connect the moving display to the moving capsules. Therefore, I gave up the idea and designed the display to be fixed.

### 6.4.2 Gameplay Design

In the case study of HeatCraft, I suggested designers embrace the *Körper* and *Leib* perspectives to support engaging lived body experiences. According to Mueller et al. [159], supporting players in exploring the interplay between *Körper* and *Leib* can increase the players' understanding of the human body, e.g., by supporting players to use their *Körper* to influence their *Leib* experiences. With InsideOut, players' *Leib* experiences can be evoked by seeing their interior body images [207] according to the experiential affordances of interior body images as presented in Section 6.2. Therefore, I designed InsideOut's principal interactions as letting players activate their bodies (*Körper*) to experience their interior body changes (*Leib*). To be more specific, I designed InsideOut to be open-ended,

Figure 6.10: Others can touch the display and interact with the player's GIT video.

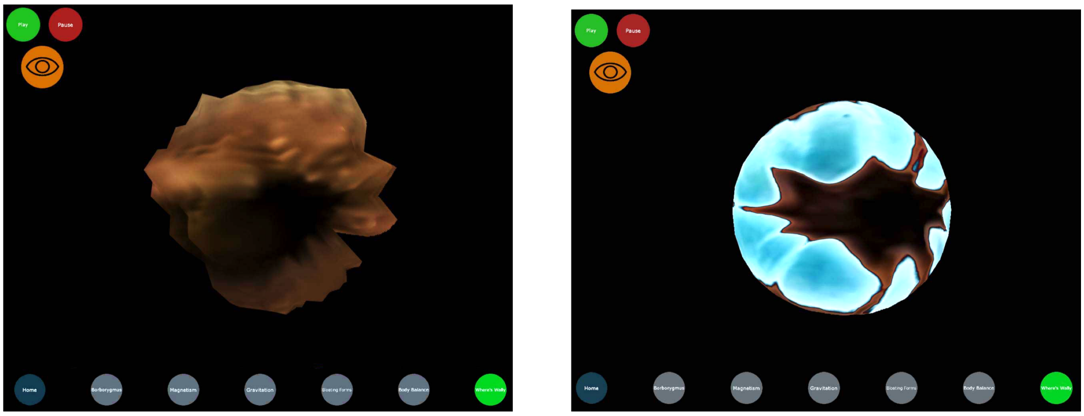
encouraging players to freely explore how they can interact with their interior bodies.

### 6.4.3 Enhancing and Enriching Playful Experiences

I adopted the experience prototyping design method, enabling designers and users to gain first-hand experience by engaging with prototypes [28]. The three researchers involved in this project each wore an iPad playing a video of the human GIT as captured by an imaging capsule for one day. During the experience, the authors also used this prototype to communicate the idea with their friends to collect informal feedback on InsideOut's design. Most people who interacted with the researchers loved the idea of InsideOut. Based on this initial experience with the prototype, I identified the following problems that might make the design challenging:

1. Users may experience fascination with the interior body video at first while feeling uncomfortable after looking at the video for a long time, which might lead to disengagement with the video.

2. Users may feel uncomfortable to show the video within certain social contexts, e.g., in public spaces.



(a) (b)

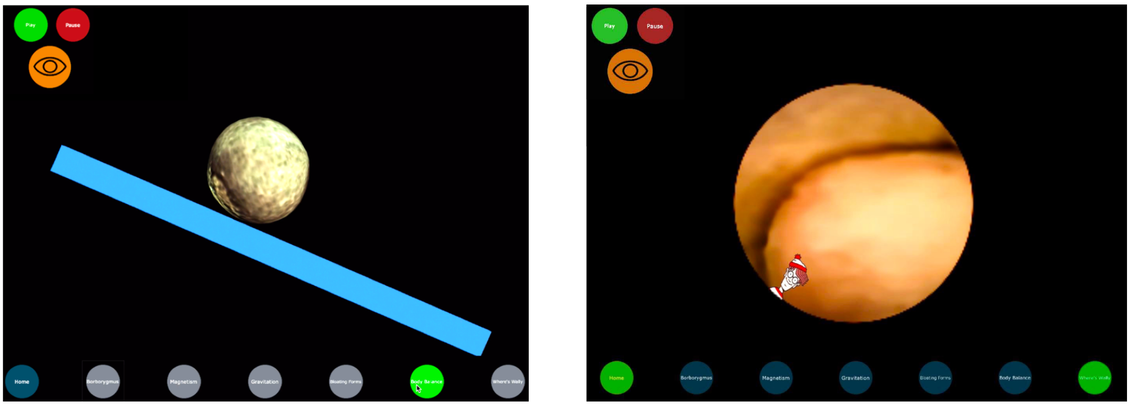
Figure 6.11: (a) Gravitation and (b) Magnetism transform the player's GIT video based on the surrounding magnetic field's strength and gravitational acceleration respectively.

3. Many people like to see how food is digested, while few people think of how moving can influence their interior bodies. This might prevent players from exploring how they can influence their interior bodies through movement.

4. Most people expect high agency towards their interior body; hence they might feel frustrated if they experience a low level of control over the video.

Considering the above design problems, I decided to use body movement to influence the video images' scaling and rotation to further enrich the play experience and encourage player actions. By doing so, players can still freely explore their interior body since the video feed is still provided; however, I hoped they would experience higher agency towards the video, tackling the fourth design problem. As a result, players may enjoy better play experiences [221] and experience more control over their bodies, which could increase their wellbeing [141]. Moreover, mapping the players' movements to influence the video transformation can tackle the third design problem by encouraging players to perform more bodily movements, which might further influence the shape of their GIT and thus their video. As such, players might be inspired to try more bodily movements to interact with their interior bodies.

The first design problem I found is in line with the Guts Game findings, suggesting that players might feel disengaged with the play after several hours. To enrich the gameplay and prolong the players' engagement, I designed six additional play modes. The six play modes were designed based on the 'four keys' for creating emotions in play [125]. Gravitation and Magnetism (see Figure 6.11) were added to the design to facilitate the



(a) (b)

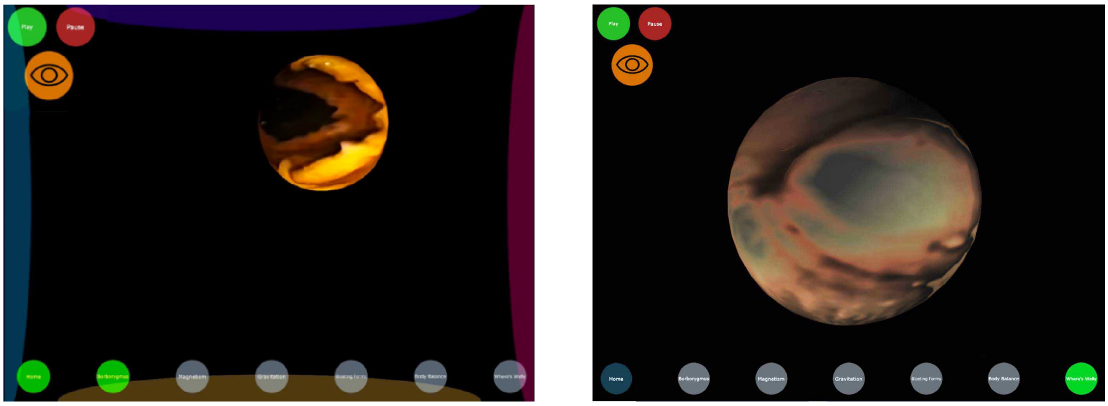
Figure 6.12: (a) Body Balance turns the GIT video into a rolling ball and requires the player to move the body to balance the ball on a seesaw; (b) Finding Wally requires the player to search for hidden gems – identifying them results in a visual effect and a rumbling sound.

key 'Easy Fun' by embracing ambiguity and environmental data to evoke players' curiosity and facilitate interaction, exploration and imagination [125,140], which also helps tackle the second design problem, as players can make the video ambiguous in public space. I designed Body Balance and Finding Wally (see Figure 6.12) to facilitate the key 'Hard Fun' by proposing game challenges and directing players' attention to the associated goals. Finding Wally facilitates the key 'People Fun' because it supports other people interacting with the video on the display. Borborygmus and Bloating Moves (see Figure 6.13) were designed to facilitate the key 'Serious Fun' since they might motivate players to reflect on how imaging capsules might change their interior bodies by simulating the intestines' rumbling sound and shape-changing in an exaggerated way.

## 6.5 Study

I conducted a field study [190] with seven participants (4 males and 3 females; mean age = 29 years, SD = 3.7 years) to investigate the UX of InsideOut.

To participate in the study, each player visited the lab in the morning, swallowed an imaging capsule and put on the wearable system. The participant then left the lab and experienced InsideOut in everyday life.As each capsule's battery lasted for approximately 8 hours, the participant returned to the lab after that time to return the devices (belt and data recorder) and for a semi-structured interview. Each interview lasted about 45 min-




(a) (b)

Figure 6.13: (a) Borborygmus moves the GIT video on the display based on the player's body movements – when the image touches any of the four arcs, a rumbling sound is played; (b) Bloating Moves maps the video onto the surface of a flexible 3D ball, with its shape changed through the player's body movements.

utes and was audio-recorded. Within the 8-hour study, all participants witnessed the capsule's journey from their mouth to their intestine (see Figure 6.14). None of the participants had excreted the capsule before returning to the lab. Later, I conducted thematic analysis [25] to understand the interview data (see Figure 6.15).

## 6.6 Results

Overall, the findings suggest that players engaged with their interior body via InsideOut. I identified four themes that are presented below.

### 6.6.1 Theme 1: Experiencing the Enchanted Body as Subversive Play

InsideOut facilitated subversive play [140], as swallowing a digital sensor and watching and showing the interior body video break social norms, at least to some extent. Following McCarthy et al.'s definition [149], I use 'enchanted' to describe the interior body since players experienced the video as attractive, novel, and unexpected during the play.

#### Seeing the Interior Body was a Strange Pleasure

All of the players reported that they enjoyed seeing their own interior body (see Figure 6.16). They described the video as 'fascinating', 'novel', 'intriguing', 'pleasant' and 'play-

Figure 6.14: A player saw their oral cavity after putting the imaging capsule into their mouth.

ful'. p1 said: 'It was quite confronting at first, but later I found it very interesting. I have never seen my intestines before'. Similarly, p2 said: 'Actually I was hesitant before the study because I was a bit afraid to see something wrong with my body. I thought it was weird to see my interior body but it was actually a pleasant experience, much more fun than I thought!'. p4 also said: 'At first the video was a bit shocking. But later I was absorbed in the images and felt like travelling inside my body. After the capsule left my stomach, it entered my intestine, and the pictures were messy and a bit disgusting. But it was still fun. I kept checking the video during the whole procedure'. All the players reported that they engaged with the video although they did not have the professional medical knowledge to interpret the video. p3 said: 'I knew it was not a medical imaging examination and I could not tell whether I am healthy based on the video. But I still felt the experience was immersive. Just seeing the video was already very interesting'.

#### Watching the Changing Body Facilitated Ongoing Playful Engagement

The moving imaging capsule enabled InsideOut to show players different parts of their GIT. The fact that the video was changing evoked players' curiosity and facilitated ongoing engagement. For example, p4 said: 'It was amazing to see how the different parts of my digestive system look. At first, I saw my stomach wall, which is quite smooth.

| Transcript | Speaker | Code 1 | Code 2 | Code 3 | Code 4 |
|---|---|---|---|---|---|
| How was it? | [redacted] | | | | |
| Um, quite confronting! Like...seeing my insides. It was quite kind of shocking at the start especially. Because it changed so much throughout the day. I wasn't expecting it to look so different in different places. [laugh] Um, but pretty fun. | [redacted] | Seeing the interior body is confronting | Learning the differences among different parts of GIT | Seeing the interior body is fun | |
| So it was shocking at first, but... | [redacted] | | | | |
| Yeah! I found like...I sort of...checking throughout the day...like, what's happening there. And I start watching it and then I would just...sort of... keep on watching it [laugh] I'm like, there is my lettuce that I ate earlier! And like..then sometimes it's just like this blurry messy and then...other time you can really see your pink flesh and um...I said to my partner like...reminds me of...like white water rafting [laugh]. You know it's like a boat, like a boat going through somewhere and it was really cool! | [redacted] | Engaging with the system throughout the day | Seeing the consumed food is fun | | |
| So you enjoy seeing the food inside your body? Or flesh body? | [redacted] | | | | |
| Um, I probably found the food more...oh no both aspects. Because I feel like once you've eaten food you kind of forget about it. It's like...it sort of ceases to exist once you have eaten it. But when that camera in there, it's like, oh, not that's the lettuce that I ate..like it's in my body! I also saw...I don't know whether I saw...I definitely saw some bubbles [chuckle] and then I feel like I also saw like fat? like seperate from...like oil that has been separated or something. I don't know what...I was just like making it up is my mind [chuckle]. Um, but that also made me a lot more...sort of conscious of like..consuming food, like the idea of consuming something. So, yeah... Um, the flesh bit was cool. I really liked seeing. So she's like the bit where it like...opens, and then goes, and it's like goes through to the next bit. Um, and then I'm guessing because then I started researching my intestines, [chuckle] all the different parts. So I think it's in the lower intestine at the moment, which looks super different to when it was in like higher up. Yeah, I had fun trying to work out where it was in my body as well. | [redacted] | Seeing the consumed food is fun | InsideOut prolonged the engagement with food (after eating) | Seeing unfamiliar interior body motivated self-learning | Self-learning on GIT structures to figure out the capsule's location |

Figure 6.15: This screenshot shows the initial codes I labelled during thematic analysis of the interview data. The speakers' names are covered with mosaics.

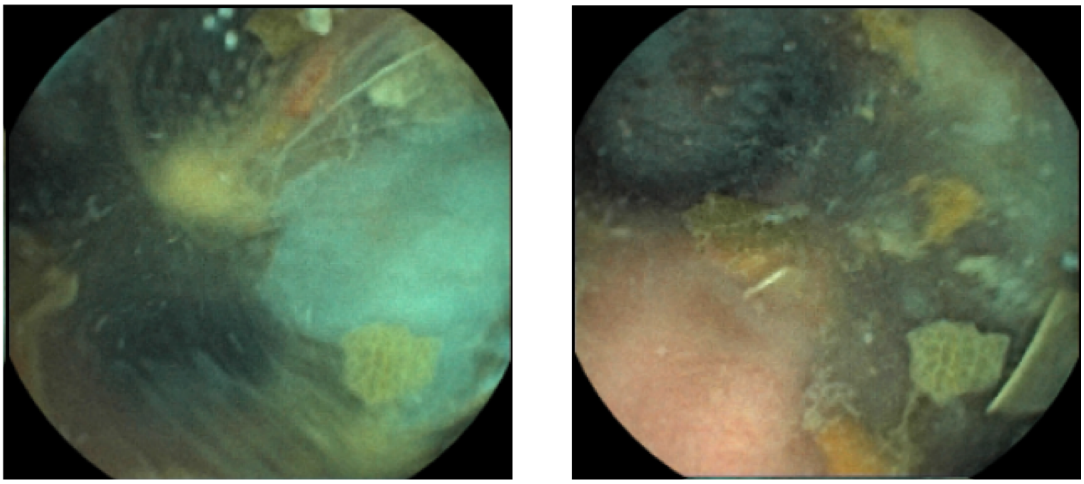
After several hours, I saw my fluffy intestine wall'. Moreover, players reported that they were curious about how food would change after being ingested. For example, p5 said: 'I tried some bubble tea and then I clearly saw the black bubble inside my stomach. After some time, I could still see the bubble's shape, which made me feel a bit disgusted. But I should say that it was fascinating to see how the food changed inside my body'.

### 6.6.2 Theme 2: Experiencing the Lived Body as Exploratory Play

People can experience exploratory play when investigating an object or situation [140]. This theme articulates how InsideOut motivated the players to explore their bodily capacities in influencing their interior bodies, resulting in exploratory play. Here I use the definition of 'lived body' from Gadow [70] as one capable of affecting the world.

#### Building a Connection Between the Video and the Player's Body was the Basis of Exploratory Play

The interviews suggested that once the players established a connection between the displayed video and their bodies, they performed more activities to explore how they could influence their interior body. This finding confirmed the prior theory that suggests a strong correlation between self-identification with personal data and the will to influence it [173]. The study suggests several ways that allowed players to experience the video as their own body. First, the extensive screening procedure strengthened the connection



(a) (b)

Figure 6.16: The screenshots of a participant's GIT video.

between the video and the player's body. For example, p1 said: 'The screening procedure made me feel better, because I believed it could minimise the risks. At the same time, it made me realise that it was my body to be examined'. Second, the video showing the process of swallowing the capsule helped facilitate the connection. For example, p2 said: 'After picking the capsule out of the [packing] box, I saw the video showing the room view. When I swallowed it, I saw my teeth, my tongue, and I saw it entering my stomach. This was very different from seeing some internal body images online. It made me realise: "Ah, it is my body!".' Third, the experience of swallowing a digital capsule helped connect the video to the players' bodies. For example, p4 said: 'Swallowing the capsule was exciting, but a bit scary. This motivated me to keep checking the video, since I wanted to confirm my body condition'. Fourth, the players connected the video to their bodies if their body condition corresponded to their actions before swallowing the capsule. For example, p3 said: 'Before I came here, I had some protein shake for breakfast. Thus, after I swallowed the capsule, I could hardly see how my stomach looked like'. Similarly, p6 said: 'I did not have any food after yesterday's lunch. Then I saw a very clear view of my stomach. I was thinking, "Yeah, it works".' Fifth, the players experienced the video as their body when they saw they could influence the video. For example, p2 said: 'After I swallowed the capsule, I had some beef for lunch and I saw it through the video. I think it motivated me to try more activities afterward because it let me know this is my body and I can influence it'.

Figure 6.17: A player eats to see the food inside the GIT.

**Players Explored Their Lived Body via Eating and Moving**

All the players reported that they were curious about their capacity to influence their interior body, and therefore, they tried different activities to achieve this. Players mentioned that the most intuitive strategies were eating and drinking (see Figure 6.17). For example, p6 said: 'After I ate something, I always fixed my eyes on the video trying to find the food. It was interesting to find the food I had in my stomach'. Similarly, p3 said: 'I saw the lettuce I had for lunch! It was fascinating and encouraged me to try more things to see how it would look like'. Some players also spontaneously tried to perform bodily movements in order to influence their interior bodies. For example, p1 said: 'I twitched my abdominal muscles and it was amazing to see the fluid in my intestines sloshing immediately!' Similarly, p4 said: 'When I sat down, my intestines looked folded, but when I stood up, they looked smooth. I was surprised that I can easily influence my body interior'. Four participants mentioned that the play modes motivated them to move their bodies. When they found to their surprise that movement influenced the interior body, they were motivated to explore further the relationships between different activities and the interior body. For example, p3 reported: 'I knew little about my interior body before the study and I had no idea how to influence the video. At first, I just moved my body because I was playing with some play modes like Body Balance and Borborygmus. Then

I was surprised to see my intestines' shape changed! So, I began to try different activities, not because of the play mode rules, but just for exploring my own body'. Similarly, p5 said: 'The other play modes made me realise the relationship between my moves and the shape of my intestines. When I was at home, I tried to bend my body to squeeze the capsule [laugh]'. During the interviews, I asked the participants what they did to influence their interior body. This included the following activities: eating, drinking, changing their standing, sitting and lying down, moving and shaking their bodies, as well as performing abdominal twitches.

### 6.6.3 Theme 3: Experiencing the Absent Body as Relaxed Play

The playful experience of relaxation refers to relief from bodily or mental work [140]. I have borrowed the term 'absent body' from Leder, who expressed that our bodies are sometimes phenomenologically absent from our awareness [127]. This theme suggests that after being intensely conscious about their interior bodies by watching the video, players played with certain play modes that did not show a very realistic interior body and as a result experienced relaxed play.

#### Additional Play Modes Let Players Relax after Prolonged Watching

Four players reported that although seeing and interacting with their realistic interior body was playful, they felt a bit uncomfortable after watching the unmodified video at times. These players mentioned that InsideOut's other play modes let them 'take a breath' and engage in bodily play. For example, p3 said: 'The images of my large bowel were messy and I felt a bit disgusted to see them for a long time. Then I tried other modes where I could hardly see the images, like the magnetic one and the balancing game'. Similarly, p7 said: 'When the images were transformed, it was hard to know how my real intestines looked like [. . .] I like the idea of using the invisible environmental factors to visualise the images in an artistic way after watching the realistic video for a long time'. Players also enjoyed the play modes when they felt they had less influence over their interior body. For example, p2 said: 'After several hours, it was hard to see the food I ingested. The food could not catch up with the capsule. So I turned to other play modes which made me feel more in control'.

Figure 6.18: Some players chose the game modes that showed abstract GIT videos when with others.

#### Different Play Modes Let Players Experience Their Bodies from Different Perspectives

Players reported that InsideOut's different play modes let them experience their bodies from different perspectives, which facilitated ongoing engagement. For example, p3 said: 'The original video was quite 'realistic', letting me experience my interior body directly. The video in the Gravity and Magnetism modes was very artistic and ambiguous. It made me feel very relaxed after seeing the original video. With other modes such as the Wally and Balancing modes, I could still see the original video while my attention was more directed to my movements such as the touch and the body swing. I can say that these modes also engaged me with my body, but very differently from the engagement with my interior body in the default mode'. Players expressed that they appreciated that InsideOut supported different play modes. For example, p2 said: 'I played with the visualisation a lot, but I still wanted to see the real images, especially at the beginning when I swallowed the capsule'.

#### Players Chose When to Experience Relaxed Play Depending on Social Context

All participants reported that they regarded the video of their interior body as 'intimate' data, so they would not display the video in public even if the study allowed them to do so. For example, p5 said: ‘I would not share the video with people I am not familiar with. I am a “private person”.’ Similarly, p6 said: ‘I don’t want to share the data in public. I know it is not a clinical examination, but I still feel the data is my medical data, which is private. I should own the data, rather than sharing it with strangers’. Hence, players mentioned that they changed to the play modes Magnetism and Gravitation when they were with unfamiliar others (see Figure 6.18). For example, p5 said: ‘These two modes looked artistic. I think it was good to show such visualisations to people I am not that familiar with. By doing so, I can share my story without showing my realistic private images’. Players said that they decided whether to show the video to their friends depending on the video’s ‘appearance’ since the video formed part of their self-identity. For example, p2 said: ‘I enjoyed showing my friends the video during the first several hours because then my intestines looked clean. But later the video became messy when the capsule was in the large bowel and I did not want to show it to others [...] It is very like sharing your photos on social media. You only want to share others your good pictures’. When it came to intimate relationships, all the players reported that they enjoyed sharing the video and play experiences with partners, close friends or parents, but this was dependent on the other person’s personality. For example, p4 said: ‘When my boyfriend returned home, I was very excited and asked him to see my intestines. I think this was fun and was part of my body. I wanted to share this with him’. Similarly, p3 said: ‘I shared the video with my colleagues because I knew they would love to see this. But I did not show it to my mum. I thought she would not feel comfortable’.

### 6.6.4 Theme 4: Experiencing the Cultivated Body as Serious Play

According to Gadow’s theory [70], the cultivated body is experienced when harmony between the lived body and the object body is reached. I found that InsideOut has the potential to deepen players’ understanding of their body and ultimately move towards a cultivated body, which corresponds to an understanding of serious play, i.e., digital play that can motivate real-world benefits to help players change how they think, feel and behave or to accomplish serious work [125].

#### Players Became More Aware of Their Bodies

All players mentioned that InsideOut made them more aware of their bodies, especially the interior parts. Players reported that before doing the study, they were not aware of their interior bodies. For example, p1 said: 'I rarely thought about my interior body, maybe because the interior parts are invisible and I nearly have no sensory experiences with these parts. But when playing InsideOut, I was fully aware of the existence of my interior body because it was constantly showing me how my intestines looked like!' Similarly, p7 said: 'It definitely increased my body awareness. One reason is that I swallowed a digital sensor and this made me more conscious of my body. Also, seeing the video of my internal body made me more aware of my body than usual, especially of my digestive system. I consciously linked my feelings like being hungry and full to the images I saw'.

**InsideOut Increased Players' Bodily Knowledge**

All players said that InsideOut increased their bodily knowledge. For example, p2 reported: 'It helped me know more about the digestive system, like the digestion speed. It was amazing that the food I had two hours later caught up with the capsule!'. p6 also said: 'I knew little about my interior body before the study and I had no idea how to influence the interior parts. But after the procedure, I think I recognised the digestive system as part of my own body'. The play with InsideOut also motivated self-learning about the human body. p4 reported that: 'It taught me a lot about my body. After several hours, I saw my intestine wall being fluffy and then I searched online. Now I know that it was my small bowel. The texture of different parts of the digestive system is different.' p1 said: 'This experience motivated me to learn more about my body. I searched the related body knowledge online and I was particularly interested in the digestion rate'. Some players reported that they knew more about how their food was digested through the play. For example, p5 said: 'The food's digestion process is amazing. When [the food was] in the stomach, I could still recognise the food. But later, it was smashed up'.

**InsideOut Let Players Feel More Intimate with Their Bodies**

InsideOut deepened the players' understanding of their body and increased their intimacy with their bodies. By doing so, the body and self became more harmonised. By harmonisation between the body and the self, I mean participants appeared to experience less conflict between their lived body and their object body [70] as they became more aware of and knew more about their interior body. For example, one might initially experience conflict between the lived body and the object body when finding it hard to control the GIT motility, while one might feel less conflict after learning more about the GIT, for example, their agency over their GIT and their average GIT motility. For example, p4 said: 'It made me [think] about my body. I can feel the pain, touch, and lots of sensations on the skin, but I usually could not feel them with my digestive system. The body is weird, isn't it?'. Similarly, p7 reported that: 'It was interesting to know that I actually have some control over my digestion. But I could not fully control it. I remembered once I saw something big on the screen, but it passed very quickly. I really wanted to control the capsule to catch up with it, but I couldn't. I knew this is my own body, but it can never be fully controlled'.

**InsideOut Facilitated Self-Reflections**

InsideOut motivated players to reflect on their behaviours, especially in relation to their movement and diet. For example, p3 said: 'It made me think about my diet. When I saw something which was hard to recognise, I thought about what I had in my last meal'. p7 also said: 'After I found that different postures might influence my intestines' shapes, I began to think about what postures might be good for my digestion'. The reflections modified the players' behaviour even outside the game. For example, p3 said: 'My digestion rate is slower than I thought. I could see the food I had several hours ago in my stomach. This made me eat more slowly and mindfully'. Interestingly, InsideOut might be able to influence the players' long-term behaviour as well. p3 contacted me a week after the study, telling us she still consciously ate more slowly and chewed more often (as recommended in mindful eating [55]). Moreover, the Gravitation and Magnetism play modes encouraged players to reflect on the relationship between their bodies and the environment. For example, p6 said: 'I like the modes combining the environment data and the video. It made me think of how my environment might influence my body. The gravity and the magnetic field are invisible for me; however, they act on my body'.

## 6.7 Discussion

Based on the craft knowledge and the study results, in this section I discuss design implications to improve the design of future playful experiences with imaging capsules. These implications might also inspire future design of ingestible play with other sensors and design of digital play with interior body images.

### 6.7.1 Design Always-Available Changing Video to Support the Enchanted Body

Theme 1 suggests that the players enjoyed seeing their interior body video and the changing content showing a dynamic body, facilitating ongoing engagement. InsideOut moved towards a lasting engagement with the imaging capsule's video by engaging with the following strategies. First, InsideOut did not decrease the frame rate of the video captured by the imaging capsule (2fps), hence providing real-time images of the player's interior body. That is, players could get immediate feedback on certain activities they did to influence their GIT. Second, InsideOut was designed to be wearable and hence supported ubiquitous play experiences, facilitating ongoing always-available play. Third, since the parts of one's GIT might look different, InsideOut provoked players' curiosity by presenting the 8-hour video captured by the travelling capsule to show the differences, promoting players' ongoing engagement.

The findings with InsideOut align with prior play theories. For example, the elements 'Concentration' and 'Feedback' in the Pervasive Gameflow Model [107] suggest that pervasive play should let players concentrate on the play, support switching concentration between the play and physical surroundings, and provide immediate feedback to the players. InsideOut showed the entire body voyage to facilitate play concentration, used always-available interaction to support switching concentration and used high-frame-rate video to support immediate feedback. Therefore, designers might consider supporting player concentration and designing immediate feedback, which can be facilitated by the always-available high-frame-rate video showing the entire GIT.

### 6.7.2 Guide Players to Play with the Interior Body to Support the Lived Body

Theme 2 suggests that with InsideOut, players played with their lived body by exploring their capacity to influence their interior body. Based on the players' strategies before swallowing the capsule, I divided them into two groups. I called these 'the dieters" and 'the eaters'. Dieters restricted their diet one day before the play and hence could see a clear view of their GIT. During the play, dieters tended not to eat anything several hours after swallowing the capsule in order to keep a clear view. Eaters did not diet before the play and hence they usually could see food residue in their GIT. During the play, eaters usually enjoyed trying different foods to see the digestion and identifying the residue based on the food they had before and during the play. Therefore, dieters might gain more bodily knowledge, while eaters might know more about the body–food relationship. Moreover, dieters spent more time watching the unmodified realistic video, while eaters usually switched between the unmodified video and other play modes. Dieters and eaters also had different social play experiences. Dieters were usually willing to share the video with their family and friends, while eaters might only want to show the 'messy' GIT to people with whom they had close relationships.

Cognisant of these differences between dieters and eaters, I suggest designers guide players to be a dieter or an eater based on the design goals. As dieters, players can see a clear view of their GIT and hence the experience can be more bodily-centred. Designers might encourage players to be dieters if aiming to increase the players' bodily awareness and educate the players with body knowledge. As eaters, players can see the food they have eaten. This might open up a design space in the field of playful human–food interaction (HFI) [4]. Bertran et al. [4] defined playful HFI as 'interventions that use game- or play-inspired mechanisms to add value to food-related experiences'. The current playful HFI project mainly focuses on enriching the sensory experience before or during eating [114, 236] as it would be challenging to design an experience after food was swallowed due to the qualitative reduction of the interior body [127]. For example, with an apple in our hand (exterior body), we use our five main senses to experience the apple. However, after we eat the apple our experience becomes limited. We cannot see or touch the apple anymore, although we might occasionally hear, smell or taste the apple via esophageal reflux. Imaging capsules provide an opportunity to enrich our experience with ingested food. Therefore, I believe InsideOut can serve as a starting point for designers to explore future design that allows players to interact with their food after the food has been eaten.

To guide the players to choose being a dieter or an eater, I propose two strategies. First, I suggest designers engage with body preparations (i.e., one day before swallowing the imaging capsule). Designers could design a strict diet during the preparation phase to guide players to be dieters or allow players to freely decide what to eat during the preparation to guide them to be eaters. Designers could even encourage players to ingest certain kinds of food to facilitate specific food-related experiences. This strategy is similar to a prior theory that suggests the preparation for medical imaging procedures transforms a patient's body into an object of medical visualisation, which influences the patient's sensory perceptions, emotions, reflections, agency and experiences [187]. Second, I suggest designers consider the input of play. To guide players to become dieters, a playful design might encourage body movements to influence their interior bodies. Designers should note that the GIT is lined with smooth muscles that cannot be directly controlled by the player [60]; however, the shape of the GIT can be influenced by skeletal muscles, which are muscles that produce the movements of body parts in relation to each other [59]. Therefore, I suggest designers consider the design of skeletal muscle movements, e.g., by designing exterior body movements that can influence the player's GIT shape if aiming to guide the players to be dieters. For designers interested in facilitating playful imaging-capsule experiences with food digestion, eating can be designed as an interactive way to manipulate the video images to encourage various eating actions. Examples of using eating as play input can be seen in Arnold et al.'s work [7], where eating is used to influence the player's vision in a VR game. Therefore, future designs with imaging capsules could use eating as input, for example, to influence the scale of the capsule's video, in order to motivate food-related experiences.

### 6.7.3 Manipulate the Interior Body Video to Support the Absent Body

Theme 3 suggests that InsideOut supports absent body experiences by providing play modes without a very realistic interior body video. I divide the manipulations I designed into two types: *video as a playful expression* and *video as a play resource*. These two types of manipulations attracted players' attention differently.

#### Video as a Playful Expression

Magnetism and Gravitation's artistic and ambiguous visualisations aroused the players' curiosity, facilitated playful expressions and also encouraged social sharing by dampening the 'messiness' of the GIT. With this manipulation, the players' attention was directed towards the body as well as the video, going back and forth. This finding corresponds with prior works suggesting that ambiguity as a design resource can evoke non-goal-oriented interactions [47,229] and facilitate exploratory play [35,37,58,72,93,140]. Therefore, designers might consider manipulating the video to be ambiguous and even artistic to support self-expression and facilitate social sharing. In InsideOut, I designed an ambiguous transformation related to the environmental data, which facilitated players' reflections on their bodies and surroundings. Hence, designers could consider designing the transformation based on specific data which they hope the players will reflect on.

**Video as a Play Resource**

Borborygmus, Bloating Moves, Body Balance and Finding Wally manipulated the interior body video to be a play resource that players could interact with through movements or gestures. With this type of manipulation, the players' attention can be directed outwards to the play (the device), rather than the body. I found that players particularly engaged with this type of play mode when they wanted to escape from the 'messy' interior body video or felt frustrated because of experiencing low agency over their interior bodies. Therefore, when designing playful experiences with imaging capsules, I suggest designers consider transforming the capsule video into a play resource. This strategy can help players relax from the intense experiences with the realistic interior body video and the frustration caused by their low agency over their interior body parts. Moreover, Borborygmus and Bloating Moves facilitated engaging bodily play experiences by amplifying the influences of one's body movements on the interior body, facilitating playful experiences and increasing bodily knowledge. Therefore, I suggest designers consider letting players interact with the play resource, i.e., the interior body video, and playfully amplify how such an interactive way might influence their interior body.

## 6.8 Summary of this case study

This study has explored the design of ingestible play with imaging capsules via designing InsideOut, a playful wearable system that motivated participants to engage with their interior bodies as part of a field study. The study shows that InsideOut players can experience their interior body as subversive play, exploratory play, relaxed play and serious play. This case study led me towards a more comprehensive understanding of the design of ingestible play.

In the next chapter, I will present the design framework for ingestible play based on the three case studies.

# Chapter 7

# The Design Framework

## 7.1 Introduction

IN this chapter, I present the design framework for ingestible play. The framework has been generated based on the design and practical knowledge I gained through the design, implementation and analysis of the three case studies I have presented in previous chapters.

## 7.2 Revisiting Ingestible Play: Extending the Magic Circle to the Interior Body

In the Introduction (see Chapter 1), I defined ingestible play as interior bodily play that involves ingestible sensors as play technology. Although this definition highlights the utility of ingestible sensors as a design material when creating ingestible play, it does not reveal how the player experience of ingestible play may differ from experience of other types of bodily play. In this section, based on the understanding gained from the three case studies and Huizinga's theory of the magic circle [104], I elaborate on how ingestible play extends the current bodily play genre.

Huizinga proposed the term 'magic circle' to explain play; to play a game is to step inside a magic circle with specified rules [104]. The concept of the magic circle has been widely used to explain play. Play takes place in a separate time and space which are governed by certain game rules. However, the concept needs to be expanded when it comes to pervasive games. Montola [155] proposed that a pervasive game is 'a game that has one or more salient features that expand the contractual magic circle of play socially, spatially or temporally'. Unlike traditional play, where certain players play in certain spaces and at certain times, pervasive gameplay can occur at any time, in any place and

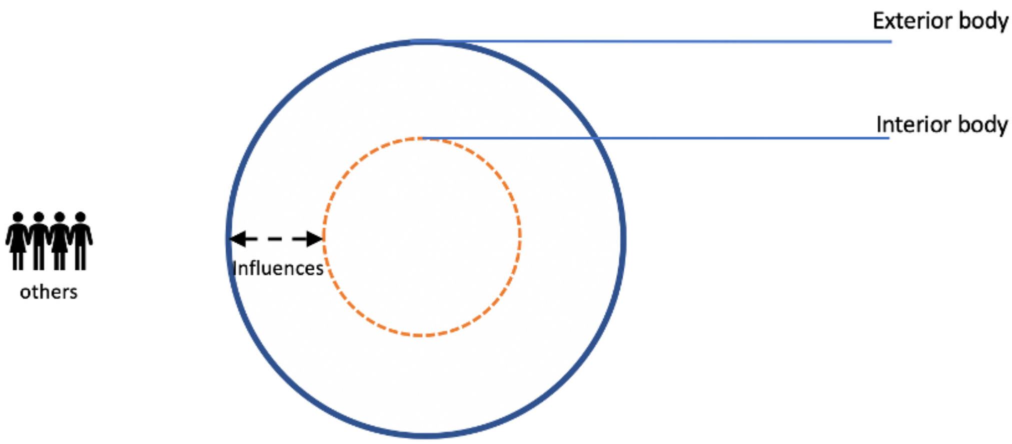



Figure 7.1: In daily life, the interior body is usually absent from consciousness, depicted with a dotted line. Also, the influence between the exterior body and interior body is under the level of one's body consciousness. The exterior body can be seen by others, while the interior body remains private.

anybody can become a player.

To better understand how pervasive games expand the magic circle, I elaborate on Montola's definition of pervasive games [155]. By spatial expansion, Montola means that the pervasive game's location is unclear or unrestricted. For example, some location-based games turn the entire city into a playground [177]. By temporal expansion, Montola means that the play sessions and the players' daily lives might overlap. Social expansion suggests that bystanders might affect the gameplay, blurring the boundaries between players and outsiders.

According to Montola's definition of pervasive games [155], I believe ingestible play can be considered pervasive play for the following three reasons. First, the three prototypes I have presented in the case studies expand the digital play spatially. Due to the pervasive nature of the ingestible sensor, i.e., the sensor is always inside the user's body during the play, the three projects can turn any place the player inhabits into a playground. Second, the three prototypes expand the digital play temporally. Considering the ingestible sensor might be inside the player's body for days, the play session can be integrated into the player's ordinary life. Third, the three prototypes expand the digital play socially since the players might interact with bystanders during the play and these interactions might affect the players' play actions and bodily experiences. For example, in the user studies some players followed the bystanders' suggestions on how they might influence their interior body data.

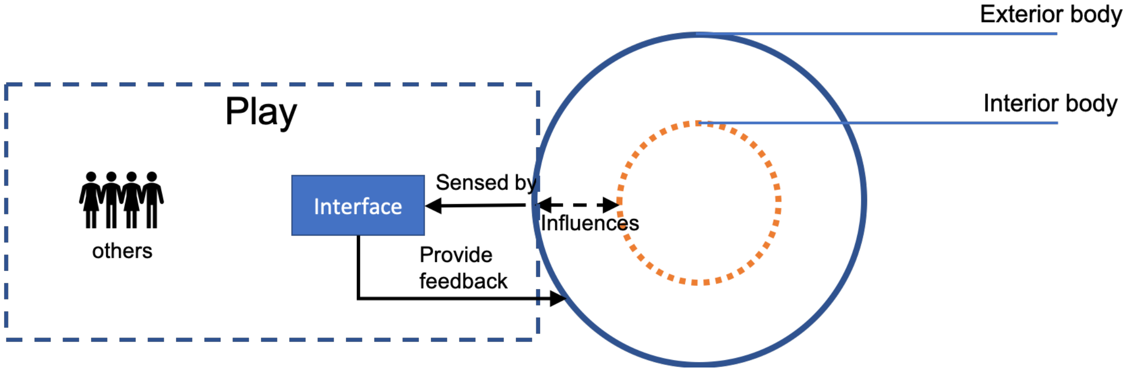



Figure 7.2: In a conventional movement-based game, the player uses their exterior body to play. The exterior body's movements are sensed by extracorporeal sensors, which are part of the interface, and mapped to the feedback, usually on a screen. There might be spectators watching the players play or other players playing. Although the player's exterior body movements influence their interior body, the player is not conscious of the their exterior body's influence on their movement or the state of their interior body itself. Therefore, a dotted line is used to depict the interior body.

Compared to pervasive play, the three prototypes go further and expand the magic circle corporeally. Salen and Zimmerman [194] emphasised that the players create the circle when discussing the magic circle concept. The game will not exist if the players do not adopt a playful attitude, which suggests the magic circle's corporeal dimension. If play happens, there must be someone entering the circle and performing play actions. In other words, without the corporeal dimension, the magic circle would be meaningless.

While the current magic circle model does not appear to include a corporeal dimension, I propose that it is already included in the model. Commonly, the exterior body is seen as the boundary of the corporeal dimension in the magic circle. Figure 7.1 shows that in the real world, outside the magic circle, one's interior body and the influence between the exterior body and interior body usually remain unknown, although they clearly exist. Figure 7.2 shows the role of the interior body in conventional movement-based games. For example, in a Nintendo Switch movement game, the game controller's sensors track the player's bodily movements, which in turn influences the game feedback shown on the screen. As such, the player can adjust their body movements based on the feedback to increase game performance. In this case of the Nintendo Switch movement games, the player's interior body can be affected by bodily movements, for example, the player's body movements can influence the player's GIT shape. However, the interior body is not sensed by the game console in order to influence the game.

The three case studies extend the boundary of the magic circle's corporeal dimension

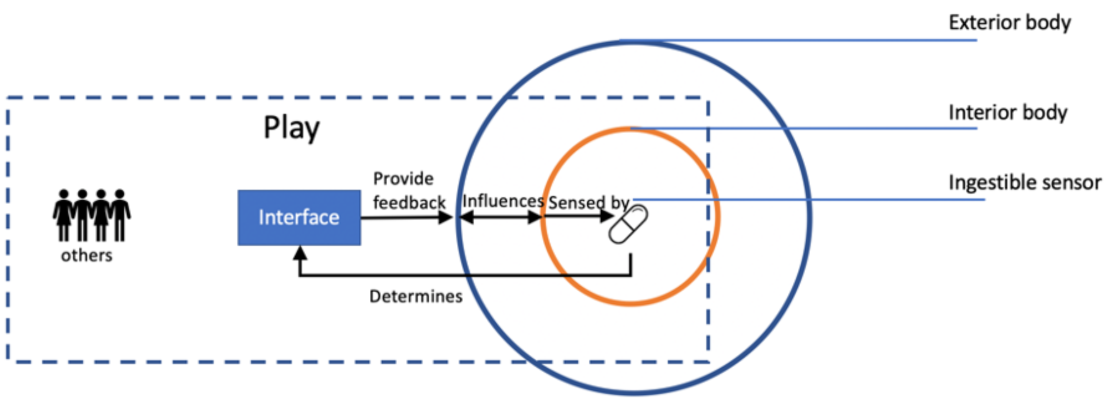



Figure 7.3: With interior bodily play, the interior body is usually surfaced and depicted with a solid line. In my studies, the interior body is sensed by the ingestible sensor, and the sensed data determines the feedback shown by the interface. Others can also influence the player experience in interior bodily play.

to the interior body. Once the player enters the magic circle, the play surfaces the player's interior body (see Figure 7.3). To engage in ingestible play, the player activates their exterior body to influence their interior body. Any change in the interior body data sensed by the ingestible sensor influences the system's feedback. Receiving the feedback can then motivate the player to explore their interior body further. With different play systems, the modality and the location of the feedback that acts on the player's exterior body can be different. For example, the Guts Game and InsideOut provide visual feedback, while HeatCraft provides thermal feedback sensed by the skin. Hence, the feedback module of HeatCraft is physically closer to the player's body compared to the Guts Game and InsideOut. I can envision that in the future, ingestible sensors might embed feedback modules such as vibrators, allowing players to directly experience the feedback through their interior sensory receptors.

The analysis of ingestible play based on the magic circle better situates ingestible play in the field of digital play. I argue that the design of ingestible play might learn from pervasive interaction design. However, the design of ingestible play needs to go a step further and focus on designing for the player's engagement with their interior body.

## 7.3 Three Key Characteristics of Ingestible Sensors

To understand the design of ingestible play, I have investigated the experiential affordances of ingestible sensors from a technology perspective. I gathered the 41 findings from the three case studies. I coded each finding based on what characteristics of ingestible sensors facilitated the player experience identified in this finding. Then I iteratively clustered these codes into higher level groupings, and finally generated three key characteristics of ingestible sensors: sensing, fusing and moving. Table 7.1 shows each finding's related ingestible sensors' characteristics.

The characteristic of sensing refers to the sensing ability of ingestible sensors. After being swallowed, ingestible sensors can measure certain kinds of bodily data of the player. The fusing characteristic highlights that ingestible sensors are inside the human body after being swallowed. Before excreting the sensor, ingestible sensors are always fused with the player's body. The characteristic of moving refers to the fact that ingestible sensors move along the user's GIT after being swallowed. The moving speed depends on the player's digestion rate which might be slightly influenced by ingesting food.

Table 7.1: This table depicts the 41 findings of the three case studies and their relationships with the ingestible sensors' characteristics.

| Case study | Findings | Characteristics |
|---|---|---|
| The Guts Game | - The Fusion between the Sensor and Body Facilitated an Emotional Response | Fusing |
| | - Players Might Feel Uncomfortable Because of Violating Cultural Norms | Fusing |
| | - The Limitations of Technology Led to Negative Game Experiences | Sensing, Fusing |
| | - Players Appreciated They Could Not Feel the Sensor after Swallowing | Fusing |
| | - Players Appreciated the Body Being the Interface | Sensing, Fusing |
| | - The Novelty of Fusion Attracted Players | Fusing |
| | - Players Became More Aware of Their Bodies | Sensing, Fusing, Moving |
| | - Social Play Contributed to Bodily Engagement | Sensing, Moving |
| | - Players Expected Explicit Feedback to Know Their Body | Sensing |

| | | |
|---|---|---|
| | - Participants Experienced Limited Agency Over their Interior Body | Fusing, Moving |
| | - Players Experienced Four Phases During the Play due to Sensor Mobility | Fusing, Moving |
| | - Cheating the Game Seemed to be Difficult Since the Sensor was Inside the Body | Fusing |
| HeatCraft | - HeatCraft Extended Players' Capabilities | Sensing, Fusing |
| | - Players Appreciated HeatCraft being Fused with the Body | Fusing |
| | -The Intimacy between HeatCraft and the Body Facilitated Body Scanning | Fusing, Moving |
| | - Ingesting the Digital Sensor Increased Players' Bodily Awareness | Fusing, Moving |
| | - Heat as Embodied Feedback Deepened Fusion between the System and Body | Sensing, Fusing |
| | - The Subtle Thermal Stimuli did not Interrupt Players' Daily Lives | Sensing, Fusing |
| | - HeatCraft Made Players Aware of Their Daily Activities | Sensing, Fusing |
| | - The Ambiguity of the System Offered Space for Reflection | Sensing, Fusing |
| | - HeatCraft Increased Players' Awareness of the Outside World | Sensing, Fusing |
| | - Increased Awareness of the Outside World Helped Players Treating Their Bodies Better | Sensing, Fusing, Moving |
| | - HeatCraft Motivated Spontaneous Play | Sensing, Fusing, Moving |
| | - Players Appreciated the Playful Experience of Exploration and Discovery | Sensing, Fusing, Moving |
| | - Players Appreciated the Playful Experience of Thrill | Fusing |
| | - Players Appreciated the Playful Experience of Subversion | Fusing |
| | - Players Appreciated the Playful Experience of Fellowship | Sensing, Fusing, Moving |

| | | |
|---|---|---|
| | - Players Appreciated the Playful Experience of Sensory Stimulation | Sensing |
| | - Players Expected to be Able to Check if HeatCraft was Running | Sensing, Fusing |
| | - Players Expected the Combination of Numbers and Sensations as Feedback | Sensing, Fusing |
| InsideOut | - Seeing the Interior Body was a Strange Pleasure | Sensing, Fusing |
| | - Watching the Changing Body Facilitated Ongoing Playful Engagement | Sensing, Fusing, Moving |
| | - Building a Connection Between the Video and the Player's Body was the Basis of Exploratory Play | Sensing, Fusing |
| | - Players Explored Their Lived Body via Eating and Moving | Sensing, Fusing |
| | - Additional Play Modes Let Players Relax after Prolonged Watching | Sensing, Fusing, Moving |
| | - Different Play Modes Let Players Experience Their Bodies from Different Perspectives | Sensing, Fusing |
| | - Players Chose When to Experience Relaxed Play Depending on Social Context | Sensing, Fusing, Moving |
| | - Players Became More Aware of Their Bodies | Sensing, Fusing, Moving |
| | - InsideOut Increased Players' Bodily Knowledge | Sensing, Fusing, Moving |
| | - InsideOut Let Players Feel More Intimate with Their Bodies | Sensing, Fusing, Moving |
| | - InsideOut Facilitated SelfReflections | Sensing, Fusing, Moving |

## 7.4 Understanding the Bodily Experience in Ingestible Play

After exploring the ingestible sensors' affordances in interaction design, I provide more detail on the player experience of ingestible play in this section.

This dissertation explores the design of ingestible play, aiming to move towards a more complete understanding of interior bodily play design, i.e., bodily play in which the main source of enjoyment comes from players' engagement with their interior body (see Chapter 1). My definition of interior bodily play indicates the central role of the player's bodily experience with their interior body. To more deeply engage with the player's bodily experience, I turn to Grīnfelde's phenomenological work, which presents four bodily experience dimensions [81].

The approach of seeking theories from phenomenology to understand the UX in body-centred design is not new, since phenomenology works usually put the human body at the centre of one's lived experience. For example, Mueller et al. [160] learned from van Manen's phenomenological work on analysing one's lived experience [231] and proposed four lenses to understand exertion interactions. Similarly, inspired by Merleau-Ponty's phenomenological theories about the lived body [152], Svanæs [218] explored how designers can use the first-person perspective on their body as a resource in design.

In this work, I take a similar approach. Based on Grīnfelde's phenomenological work [81], I argue that the player's bodily experience can be approached through the four dimensions presented by the author: the material dimension, the functional dimension, the affective dimension and the social dimension. Although I explain the four perspectives separately, I acknowledge that these four dimensions are not separable and are intertwined tightly with each other [81]. For example, the material dimension of one's bodily experience might influence the functional dimension. In a biofeedback loop, if users can hardly build a connection between the system's feedback and their own body, they might not engage with the material dimension of bodily experience, further hindering the players' bodily exploration (the functional dimension) [173]. The aim of presenting these four dimensions of bodily experience is not to suggest designers split one's bodily experience into four parts when designing and evaluating bodily play, but to take the four dimensions into account in viewing and unpacking the player's bodily experience, which might lead to a more complete understanding of the design of interior body play. These four dimensions of bodily experience form the foundation of the design framework for ingestible play.

### 7.4.1 The Material Interior Body

The first dimension of one's bodily experience is the material dimension. According to Grīnfelde [81], the human body can be conceived of as a material object. However, according to phenomenological works [81,127], the material dimension is rarely manifested in our everyday lives. We usually perceive this dimension when we experience the disruption of bodily functions or in other extreme situations. Slatman [207] used an example from the novel *Slow Man* in which a man calls his amputated legs 'the ham', indicating that he experiences his legs as a purely material thing, an object other than him and not a part of himself.

In general, we can barely engage with the interior body's material dimension because of the interior body's invisibility and inaccessibility. We know little about our material interior body as it is underneath the skin and cannot be directly seen and touched. However, with the support of ingestible sensors, one might engage with the interior body's material dimension, as the sensor can provide the interior bodily information. In other words, ingestible play has the potential to augment the player's bodily experience with their material interior body.

### 7.4.2 The Functional Interior Body

The second dimension of one's bodily experience is the functional dimension. According to Grīnfelde [81], the human body can be viewed as a 'set of free movements' which shows the body's possibilities for action in the world. This dimension of function is in line with phenomenological theory's conceptualisation of the body as an embodied consciousness of 'I can' [70]. The functional dimension emphasises the interplay between the body and the world, namely, what I can do to influence the world and how it can influence me. The functional dimension of bodily experience rarely comes to the fore. This is because one usually does not experience the body itself, but things which one's actions deliberately direct one towards. For example, suppose a person plans to grab a cup from a table. In that case, they usually focus on the cup rather than their arm, as long as the body functions properly.

With ingestible sensors, one might not be familiar with the full functions of the interior body, and one might only experience functional interior body limitations; for example, it is hard to control digestion speed. However, ingestible play might influence the player's experience with their functional interior body, for example, by letting the player know more about their interior body's functions.

### 7.4.3 The Affective Interior Body

The third dimension of one's bodily experience is the affective dimension. According to Grīnfelde [81], the human body can be viewed as a 'bearer of sensations'. Localised sensations include touch, pain, proprioception, kinaesthetic sensations and temperature perception; these let us experience our bodies as ours [207]. In addition to localised sensations, the affective dimension also includes inner feelings that are inseparable from our body. For example, we might feel joyful in the sunshine, and nobody else would experiences this feeling in the same way. The affective dimension of embodiment might direct us to focus on our bodies or parts of the body.

One might barely experience the affective interior body because of the limited sensory receptors in the interior parts. However, ingestible play might engage players with the affective dimension of their body since the sensor inside the player's body naturally leads the player's attention inwards to their interior body and evokes various emotions and feelings.

### 7.4.4 The Social Interior Body

The fourth and also last dimension of one's bodily experience proposed by Grīnfelde is the social dimension. According to Grīnfelde [81], other people's gaze can influence our bodily experience. Grīnfelde focused on how the other's gaze might influence one's bodily experience, especially the body's material dimension. According to Sartre [196], the gaze of others can lead to bodily objectification and alienation. Slatman [206] proposed that the social dimension of the bodily experience can be influenced by cultural and social contexts. For example, Ahmed [2] argued that the colour of one's skin influences how one orientates oneself in the world even though the skin colour has no impact on one's bodily capacities.

In general, one can barely experience the interior body's social dimension since others cannot see nor have access to one's interior body. However, ingestible play has the potential to support the social dimension of the interior bodily experience. In the field of bodily play, research has extensively explored how the design of social play might engage players with their body [146, 161, 163]. In most bodily play, one activates the exterior body that can be seen by other players, allowing for social interplay such as mimicking and

Table 7.2: The structure of the ingestible play design's framework.

| | Sensing | Fusing | Moving |
|---|---|---|---|
| The material interior body | | | |
| The functional interior body | | | |
| The affective interior body | | | |
| The social interior body | | | |

fighting [161]. Similarly, ingestible play can support social play, for example, by letting players explore how they might influence their interior bodies together or by supporting players to compare their interior body information. Therefore, ingestible play has the potential to influence the social dimension of the player's bodily experience.

## 7.5 Design Framework for Ingestible Play

In the last two sections, I have presented the key characteristics of ingestible sensors that mostly contribute to the player experience in ingestible play and the four dimensions of players' bodily experience with their interior body in ingestible play. These led to the structure of the design framework for the ingestible play (see Table 7.2).

The Table 7.2 could serve as a starting point for designers to consider the ingestible play design. The first column of the table shows the four dimensions of the player's bodily experience with the interior body. This can help designers consider which dimension(s) of the players' bodily experience they might want to highlight through the design. The first row of the table shows the three key characteristics of ingestible sensors that might influence players' bodily experience. This provides insights into how designers might engage with an ingestible sensor during the initial stage of the design process. With an unfamiliar sensor, the designers can first examine how the sensor can sense, fuse with and move in the player's body.

By combining the first column and row, the table can serve as a design tool for designers to ideate ingestible play systems. With Table 7.2, designers can choose one or more dimensions of the interior bodily experience they want to highlight and choose one or more ingestible sensor characteristics as design resources, and then consider how design can utilise the chosen sensors' characteristics to facilitate the interior body experience. In the following subsections, I will present a design theme and a set of implementation suggestions for each combination of the bodily experience and the sensor's characteristics.

### 7.5.1 Design Theme 1: Confrontation (Sensing Ingestibles – the Material Interior Body)

The first design theme is confrontation. I use 'confrontation' to refer to the player experience when engaging with their material interior body, i.e., when knowing their interior body information as sensed by the ingestible sensor. The idea of using the word 'confrontation' was inspired by the users' quotes in the case studies. In InsideOut, players described the experience of seeing their GIT as 'confronting'.

According to the studies, confrontation in ingestible play is not a negative game experience. This is derived from both the players' expressions and also their game behaviours. In InsideOut, players mentioned that they appreciated the opportunity to see their GIT and felt thankful to know more about their interior body via the play. Also, although InsideOut provided other play modes that made the video more ambiguous, making the play experience less 'confronting', all the players mentioned that they engaged with the original video for most of the play time. Therefore, in ingestible play confrontation is a key design theme to facilitate intriguing bodily experience and engage players with their material interior body.

However, designers should be aware that the confronting experience sometimes leads to negative play experiences. For example, in InsideOut some players mentioned that watching the original video for a long duration could result in anxiety and stress. Players mentioned that they switched to other play modes to take a break from the 'confronting interior body,' especially when they saw 'awful' parts, such as the 'messy' large intestine containing waste matter remaining after food had been digested. Therefore, it is advisable to consider balancing the extent of confrontation the player might experience when facing the sensor's raw data in designing ingestible play.

#### Implementation Suggestions

**1) Consider the Fidelity of Interior Body Representations**

The confronting experience in ingestible play can be designed via changing the fidelity of the interior body representations.

With ingestible systems, the player does not directly see or touch their interior body but engages with their interior body via the system feedback, i.e., the representation of their interior body data sensed by the ingestible sensor. Here, I use 'fidelity' to refer to the degree of exactness with which the player's interior body is 'reproduced' by the ingestible play system. The fidelity determines to what extent the players get to know the material dimension of their interior body. For example, InsideOut players can see the video of their GIT when engaging with the original play mode. However, in the play modes Magnetism and Gravitation, players are less likely to recognise their GIT due to a low-fidelity representation, resulting in a highly abstracted visualisation. Therefore, designers might consider adjusting the degree of fidelity of interior body representations to balance the confronting experience.

Although players might prefer a low-fidelity representation to dampen a confronting experience in many contexts, high fidelity of the interior body representation might be necessary for ingestible play design. It is easy to anticipate that, to show the players their material body, ingestible play might need to provide a higher level of fidelity compared to traditional bodily play, which mainly engages players with their exterior body. This need arises because the interior body is unfamiliar. For example, in certain body-centric interactions the users' body movements might be represented ambiguously and artistically [184], but these representations do not hinder their understanding of the representation as they can easily associate the representation with their own bodies. It might be that audiences retain this perception of fidelity because humans are quite familiar with the exterior body, how it looks and how they activate it. Nevertheless, without technological intervention, most people have only a very rudimentary understanding of their interior body. As such, in ingestible play, if the fidelity of the interior body representation is too low, the player may struggle to associate the representation with their own interior body. In InsideOut, the level of fidelity of the manipulated GIT video was different across different play modes. Players reported that especially at the beginning of the play they preferred the high-fidelity version, as it let them know the materiality of their GIT, which they did not know before. Similarly, in HeatCraft, although players appreciated the heat as system feedback, some players still expected to know the exact temperature number.

#### 2) Add Playful Elements to the Interior Body Representations

Adding playful elements might also balance the confronting experience in ingestible play with the interior body's high-fidelity representation. For example, in the 'Where's Wally?'

play mode of InsideOut, I designed the animated character as moving quickly in the player's GIT and asked players to tap it to 'capture' it. With this mode, although the GIT video was represented with a high level of fidelity, the design engaged players with the gameplay and hence players were less irritated by the video. This implementation strategy is similar to the findings in prior intimate data design studies that suggest designing humour into bodily interactions can help overcome taboos and awkwardness [3]. However, designers should note that adding playful elements might also lead the player's attention towards the gameplay, rather than the interior body representations. For example, with 'Where's Wally?', players might have a less confronting experience as they are more focused on the animated character than their GIT.

### 7.5.2 Design Theme 2: Exploration (Sensing Ingestibles – the Functional Interior Body)

'Exploration' highlights that exploring the interior body can let players engage with the sensed interior body data with their functional interior body in ingestible play.

Participant players usually did not understand how to influence their interior body and the extent to which they could control their interior body before the play started. While they might have anticipated that certain activities could influence their interior body, they more commonly did not have a full understanding. Therefore, during the play, players activated their exterior body to explore how they could control their interior body. Such exploratory play satisfied the players' eagerness to know more about their interior body's functional dimension.

However, unlike the exterior body that players can easily activate, the interior body's operation is almost automatic and they could only control it in indirect ways, which might have hindered the players' exploration of their interior body. Moreover, how the players explored their interior body was usually based on their prior knowledge and expectations. For example, if a player considered that the sensed interior body information could be influenced by eating, the player would mainly explore how eating behaviour could change the data. If the player did not envision that their interior body data could be affected by physical exercises, the player might not have tried any physical activity during the play. Therefore, to maximise the players' exploration, designers might consider how to further motivate players to explore their interior bodies and orient the them towards this.

**Implementation Suggestions**

**1) Provide Extrinsic Motivations for Exploration**

According to the self-determination theory, motivations can be divided into two types: intrinsic motivation and extrinsic motivation [48]. Intrinsic motivation refers to 'doing something because it is inherently interesting or enjoyable', while extrinsic motivation refers to 'doing something because it leads to a separable outcome' [193]. In ingestible play, eagerness to know more about the interior body could be regarded as intrinsic motivation for players to explore their interior body. To further motivate the exploration, designers could consider designing extrinsic motivations. For example, in the case studies the Guts Game provided extrinsic motivations by setting game goals and supporting competitions with the co-player. Although HeatCraft did not set game goals, the system motivated exploration by supporting social play. The interactions with their co-player motivated players to explore their interior body.

**2) Provide Guidance to Players for Exploring their Interior Body**

Players may not fully engage with exploration because of their limited knowledge of their interior body. For example, some InsideOut players mentioned that they had not expected to influence their GIT by physical movement. Therefore, designers might embed guidance in the gameplay to support explorations. For example, designers could design activities that influence the sensed interior body data as game actions. In InsideOut, the players' physical movements could influence the GIT video display, which naturally motivated the players to activate their body. This encouragement to perform body movements let players find out that the movements could influence their GIT shape.

### 7.5.3 Design Theme 3: Ownership (Sensing Ingestibles – the Lived Experience of the Interior Body)

'Ownership' refers to supporting players to build a connection between the system feedback and their interior body.

To facilitate players' lived experience with their interior body, they need to experience a sense of ownership towards the system feedback. This is similar to prior work suggesting that with body-centred self-tracking technology, the users need to recognise and accept that the system feedback shows their body's data. Only if the users experience a sense of ownership towards the feedback will there be a strong motivation for the user to further influence the feedback via bodily activities [173].

In ingestible play, the sense of ownership towards the system feedback might be even more important than in other types of bodily play. The reason is that one has very limited interior bodily sensations. Hence, it would be hard for players to confirm whether the ingestible system's feedback revealed their interior body status accurately. The case studies confirm this. For example, in HeatCraft, players mentioned that they expected additional explicit feedback and they hoped to have an LED to show whether the system was operating reliably (see Chapter 5). Therefore, designers might need to consider how to facilitate a sense of ownership towards the sensed interior body data to support the player's lived experience of their interior body.

#### Implementation Suggestions

#### 1) Minimise the Time Interval between Actions and Feedback Changes

One way of helping players connect the feedback to their interior body is to provide real-time (or near real-time within the human perception loop) feedback. This real-time feedback minimises the time interval between the actions and feedback changes, and increase players' awareness that their bodily actions influence their interior body. The connection between the data and the interior body can be established when players recognise that their actions influence the feedback.

In ingestible play, immediate feedback changes might be hard to achieve due to technology limitations and physiological reasons. For example, the CorTemp temperature sensor senses the temperature every 10 seconds; hence there might be some delay between the actual body temperature changes and the data reading. Moreover, unlike the exterior body that players can immediately influence (e.g., moving the limbs), the interior body changes might have delays. For example, according to my findings in the Guts Game study, the interior temperature might start to change several seconds after players drink hot or ice water. Despite these challenges, in all the case studies, I designed the feedback to be as close to real-time as possible to help players recognise the feedback as a representation of their interior body. None of the players reported that they could not connect the feedback with their body.

**2) Build a Conceptual Link between the Feedback and the Interior Body**

Another way to facilitate a sense of ownership towards the data is to build a conceptual link between the feedback and the interior body. For example, designers can consider the location of the feedback to support a conceptual link between the feedback's location and the sensed interior part's location. In InsideOut, I placed the display that shows the feedback on the player's body around the stomach area, similar to the location of the GIT. This let players easily build a conceptual link between the feedback and their GIT, letting them feel that their body became 'transparent'.

The conceptual link between the feedback and the interior body is created by designing the feedback as an analogy to the unsensed interior body data. For example, in HeatCraft, I designed thermal stimuli acting on the players' exterior body as an analogy to the players' interior body temperature. Players could not feel the warmth or coldness of their interior body the same way as with their exterior body. However, with the embodied feedback that simulated the interior body sensations, players could easily connect the thermal feedback and their interior body temperature changes. Although one can barely experience the interior body sensations, designers can design the system feedback to simulate the interior body sensations. The choice of feedback modalities for the simulation can be based on the system's interior body data to build a conceptual link between the feedback and the interior body.

### 7.5.4 Design Theme 4: Resonation (Sensing Ingestibles – the Social Interior Body)

I use'Resonation' referring to the resonating experiences when the players know their own and also their co-player's interior body status. The word 'resonation' was inspired by the resonance theory proposed by Rosa [192], suggesting that people are seeking resonance in the modern world, for example, via practising yoga and other mindfulness activities. Aslan et al. [9] designed a tangible artificial heart to display one's partner's heartbeat to facilitate resonating experiences.

Without technology intervention, one could not know much information about others' interior body status. In ingestible play, players appreciate the resonating experience of knowing their own interior body information and their co-players' information. For example, in the studies, players mentioned that they felt closer to their co-players. They shared their interior body information with others including the sensed data, the digestion information and even the time of going to the toilet. Therefore, designers could consider how social interaction in ingestible play can be designed to facilitate resonating bodily experiences.

**Implementation Suggestions**

**1) Consider Data Sharing to Support Resonating Experiences**

Data sharing might facilitate resonating experiences. Although the players could not directly see their co-player's temperature data with the Guts Game, a player could receive system messages when their co-player finished a game task, informing the player about their co-player's body temperature. In HeatCraft, both co-players and game outsiders could touch the player's belt to feel the temperature, which indicated the player's body temperature. In InsideOut, the player could show their GIT video on the screen so that anyone around them could see their interior body video. According to the studies, data sharing can facilitate resonating experiences. For example, players of HeatCraft mentioned that they exchanged their belts with each other to experience the others' body temperature.

**2) Support Communication among Players and with Outsiders**

Supporting communication among players and also with outsiders might facilitate resonating experience. In HeatCraft, players were encouraged to be physically together and players mentioned that they mimicked the other player's bodily actions to change their body temperature. Supporting communication with game outsiders might also facilitate a resonating experience. For example, in HeatCraft, a player mentioned that when communicating with friends who were not players, those friends gave him suggestions on what to do and he then reported to the friends how these activities changed his body temperature.

### 7.5.5 Design Theme 5: Compatibility (Fusing Ingestibles – the Material Interior Body)

To engage the material body with the fusing sensor, designers could consider the compatibility of the ingestible play system that includes ingestible sensors and other parts (e.g., the feedback module and data-recording module).

Ingestible systems are integrated into the human body and hence biocompatibility is important to ensure their safety and comfort [164]. For example, ingestible sensor developers need to consider using biocompatible materials to seal the sensor and consider the safety of ingesting the electronics inside the sensor if the capsule shell breaks. Also, the sensor's weight and size needs to be carefully chosen. Except for the sensors, ingestible systems usually involve wearable or portable data-recording modules. These modules also need to be compatible with the user's body.

Designers could add more modules to the ingestible play system and augment the existing parts based on the design goals. For example, with the Guts Game I added a sports waist bag to include the data recorder so that players could wear the recorder. I also added a smartphone to support the gameplay. Similarly, with HeatCraft I added more electronics modules to support players experiencing their body temperature via thermal stimuli and attached all these modules and the data recorder onto a waist belt. With InsideOut, I added an iPad to support players watching and interacting with the video. All such added or augmented modules need to be comfortable to wear and robust enough to be used in a real-world setting, considering that the sensor might be inside the player's body for days.

**Implementation Suggestions**

**1) Consider the Wearability of Ingestible Systems**

Designers need to consider the influence of the whole ingestible system's wearability on the player's experience with their material body. For example, designers could consider appropriately placing the system to ensure it does not hinder the player's movements and hence their exploration of their interior body. In both HeatCraft and InsideOut, the systems were designed to be wearable, and players could easily perform bodily actions while wearing the systems. Also, the system's weight and material might determine whether it is comfortable to wear. Designers could learn from prior works in wearable design in order to consider the various factors that can influence the system's wearability [134] in ingestible play.

### 7.5.6 Design Theme 6: Augmentation (Fusing Ingestibles – the Functional Interior Body)

Human augmentation refers to enhancing human abilities through medicine or technology [188]. Here, the design theme 'augmentation' encourages designers to consider how the fusing sensor can extend the player's functional interior body.

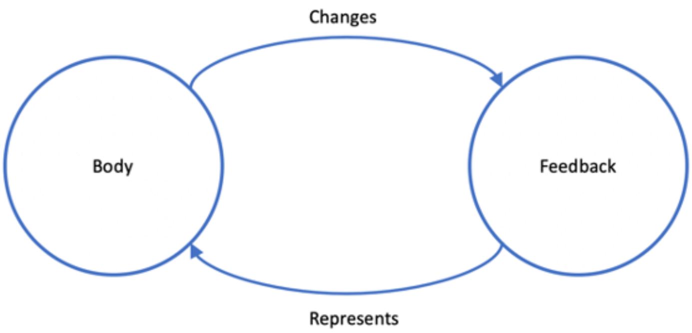
Ingestible play has the potential to let players experience their bodily capabilities being extended. For example, with the Guts Game, the players mentioned that the system let them know something that they would never have known before. In HeatCraft, players even reported that the system let them feel they had superpowers. In the three case studies, players experienced this augmentation mainly because the system provided 'mysterious' interior body information that cannot be collected without technological intervention. Designers of ingestible play could consider how to design the augmentation to engage players with their functional interior body. This finding may also inspire future research on how ingestible sensors can be designed to support various types of human augmentation [129]. For example, designers and developers could consider whether a motor can be included in the sensor to provide haptic feedback.

#### Implementation Suggestions

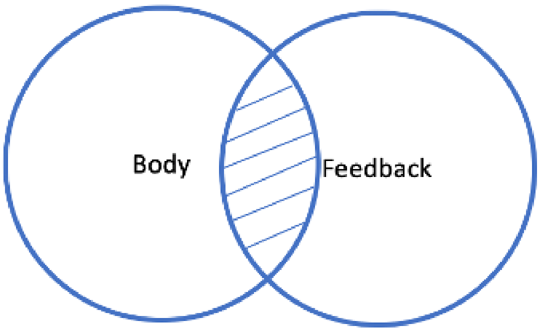
**1) Integrate the System Feedback into the Human Cognition Loop**

I believe integrating the system feedback into the player's cognition loop can support the experience of augmentation. In HeatCraft, a player shared her story about how she felt the system extended her body. The player told that she once felt cold during the play, so she drank some ice water to decrease her interior body temperature and thus increase the heating pad temperature to receive the heat. Then she felt weird because one would not normally drink ice water to get warm. The player thought the system augmented how she perceived and used her body. Also, compared to the Guts Game more players of HeatCraft mentioned that they experienced the system augmenting their body as the system supported them to directly know their interior body information.

I believe HeatCraft better supports body augmentation than the Guts Game because HeatCraft's feedback was integrated into the player's cognition loop. I present Figure 7.4 to better illustrate what I mean by integrating the feedback into the cognition loop. Figure 7.4a shows how traditional body games map the player's body movements to the feedback that is shown to the player. Players receive the feedback and then adjust their




(a)




(b)

Figure 7.4: (a) This relationship between body and system feedback in traditional body games; (b) how the system feedback might be integrated into the player's cognition loop.

bodily movements to achieve 'better' feedback for achieving the game goal. However, the players may not experience their body as augmented. Figure 7.4b illustrates how the feedback can be integrated into the cognition loop. In this case, players might experience their body as augmented as they feel that they are the ones who are capable of experiencing their interior body, rather than being informed by external technology. Therefore, to support augmentation designers could consider integrating the feedback into the players' cognition loop, for example, via physical or spatial closeness (like in InsideOut) or psychological closeness (like the localised sensations in HeatCraft) between the body and feedback.

### 7.5.7 Design Theme 7: Cultivation (Fusing Ingestibles – the Affective Interior Body)

'Cultivation' refers to tuned bodily experience where harmony between one's lived body and object body is reached [70].

In ingestible play, I see conflicts between the player's lived body and object body in ingestible play mainly coming from three aspects. First, ingesting a foreign digital sensor might cause players to experience the body as an object, letting players experience their body as a container for the sensor. With this experience, the player might focus on the sensor rather than their own body. Second, players might only focus on the system feedback outside their body and overlook their affective body. Although some players reported that the existence of the sensor fused with their body naturally directed their attention towards their interior, the level of engagement with the affective interior body can be further increased by careful design. For example, with the same ingestible temperature sensor, HeatCraft players mentioned more about their bodily experiences while the Guts Game players reported more about their temperature data changes and their game behaviours during the interviews. I believe this is because the thermal feedback engaged players more with their affective body. Third, players can experience bodily cultivation when they know more about their interior body, including their capabilities and limitations. Players might initially fail to experience cultivation when their interior body capabilities do not meet their expectations. For example, the Guts Game players reported a frustrating game experience when they could not finish the game goals. However, after becoming familiar with their interior body, players gradually reached the cultivation and knew better how to take care of their interior body. For example, InsideOut players mentioned that the play helped them learn more about their digestion and nudged them to modify their behaviour to better look after their GIT.

#### Implementation Suggestions

#### 1) Increase Player Acceptance of Ingestible Systems

User acceptance is users' willingness to use a particular information technology for the tasks it is designed to support [54]. I believe that increasing player acceptance of the ingestible sensors in ingestible play can better support cultivation through players experiencing the sensor as part of their body rather than an alien object. Prior works have identified various factors that influence the user acceptance of information technology

[128, 156, 244]. The design of the three case studies confirms some factors presented in the Technology Acceptance Model (TAM) [128]. For example, the TAM suggests that computer playfulness can increase user acceptance, which is in line with the designed playful experiences in ingestible play. Similarly, end-user support can increase user acceptance, which is similar to providing players with the system instructions and also the researchers' contact details for any technical issues, as in the three case studies. In short, increasing the players' acceptance of the ingestible systems in ingestible play might contribute to the players' cultivation experience and designers could learn from prior works related to user acceptance.

**2) Give Space for Reflection**

Reflection can be defined as 'reviewing a series of previous experiences, events, stories, etc., and putting them together in such a way as to come to a better understanding or to gain some sort of insight' [13]. Supporting reflection can contribute to cultivation as reflection helps players gain a deeper understanding of their interior body. In all three case studies, players reported their reflection experiences. Table 7.3 shows how ingestible play might support the five levels of reflection presented by Fleck et al. [66].

Table 7.3: How ingestible play can support players' reflections. The first two columns are the five levels of reflections [66], and the last column shows the players' behaviours that I relate to the levels of reflections based on the user studies.

| Reflection level | Meaning | Ingestible play behaviours |
|---|---|---|
| R0 Description | Description about events without explanation. | Players know their interior body data via the system. |
| R1 Reflective Description | Description including justification or reasons for action or interpretation, but in a descriptive way. | Players try to understand why their interior body data changes. |

| | | |
|---|---|---|
| R2 Dialogic Reflection | Looking for relationships between pieces of experience or knowledge, evidence of cycles of interpreting and questioning, consideration of different explanations, hypotheses and other points of view. | Players explore various factors that influence their interior body data. |
| R3 Transformative Reflection | Revisiting an event with intent to re-organise or do something differently. | Players modify their actions to further explore their interior body. |
| R4 Critical Reflection | Where social and ethical issues are taken into consideration. | Players consider the ethical issues related to ingestible play. |

Designers could consider how ingestible systems can be designed to better support reflection. For example, supporting social interactions might facilitate dialogic reflection as others might ask players about their game strategies and their findings regarding their interior body. Critical reflection can be facilitated via provoking design, for example, showing the realistic GIT video in public.

### 7.5.8 Design Theme 8: Intimacy (Fusing Ingestibles – the Social Interior Body)

'Intimacy' highlights that designers could consider the player experience of sharing intimate information with others when supporting the social interior body with the fusing sensor.

We usually regard the interior body as something private and intimate. This can be revealed via the studies: some participants mentioned that they only shared their interior body information with people they were close to. Moreover, as ingesting a digital sensor is against social norms to some extent, players mentioned that they shared their play stories with others carefully. Sharing an intimate experience with others can facilitate positive social experiences, making people feel more connected. Designers should also be aware that players might not want to share intimate experiences with certain people.

#### Implementation Suggestions

#### 1) Consider the Public Aspects of Ingestible Systems

Designers could consider adjusting the public aspects of ingestible systems in order to balance the intimate experience. Designing the interior body data to be more public might blur the boundary between the 'public' exterior body and the 'private' interior body, providing an opportunity for engaging with the social dimension of the interior body by utilising the fusing sensor. For example, InsideOut made the interior body public by showing the player's interior body video on the screen located on the front of the player's body. However, to balance the experience of intimacy InsideOut gave players control over the display by having play modes that supported ambiguous visualisation and adding a button to hide the display. Despite the public nature of the interior body representation, designers also need to consider the ingestible system's public aspects. For example, some players of HeatCraft mentioned that they felt a bit embarrassed or anxious in public spaces because they thought the belt containing electrical wires made them look suspicious.

#### 2) Support Others to Interact with Players' Interior Body

Another way to facilitate intimate social experience with the interior body is to support others, including co-players and game outsiders, to interact with the player's interior body. For example, in HeatCraft I designed sensory feedback that others could also experience through putting their hands on the player's stomach. Inspired by this, future ingestible play could facilitate intimate social experiences by designing localised sensory feedback. Localised sensory feedback is not as public as the visual display of data. With localised sensory feedback, others can only experience the player's intimate interior body when allowed. Intimate social experience can also be facilitated by designing the interior body information as a game element. In the play mode called Finding Wally of InsideOut, the player's GIT video was turned into a game element (i.e., the game background) and others could touch the animated characters quickly moving in the background. Some players mentioned that they only wanted close friends and family members to play this because they 'feel' others were touching their interior body when tapping their GIT video displayed on the front of their body.

### 7.5.9 Design Theme 9: Ubiquity (Moving Ingestibles – the Material Interior Body)

'Ubiquity' highlights that designers could consider the ubiquity of the system to support players to engage with their material interior body via the moving ingestible sensor.

The human body is not a static entity. It is continuously absorbing and excreting [207]. Therefore, the material interior body is dynamic. For example, medical studies suggest that the amplitude of gastric contractions decreases during night-time sleep [85]. Moreover, the interior body information is also related to spatiality, i.e., the different parts of the interior body might be different. For example, one's stomach wall is smoother, while the small intestine wall is 'fluffier' because of the intestinal villi. Ingestible sensors usually move along the player's GIT for days and hence have the potential to show players their material body in different times and spaces. To support this, designers need to consider the ubiquity of the ingestible system. The more ubiquitous the system is, the more players might be engaged with their dynamic interior body.

#### Implementation Suggestions

**1) Consider the Play Time based on the Sensor's Specifications**

The play duration influences to what extent the players might engage with their material interior body. For example, the InsideOut play experience was designed for 8 hours due to the imaging capsule's limited battery life. Most of the players had seen their large intestines before the game ended and therefore they learned the difference between the various parts of their GIT. However, if the playtime had been designed to be short, e.g., one hour, the players might only have seen their stomach and missed the opportunity of engaging with their material intestines. Similarly, with the Guts Game and HeatCraft the play did not end until players excreted the sensor, providing players with the opportunity to learn how their interior body temperature changed across the day. Therefore, designers could consider the play duration to be the maximum duration of the technology affordances in order to fully engage players with their material body.

**2) Make the Ingestible System Always Available**

To support ubiquity, designers could design the ingestible system to be always available to facilitate a continuous experience. For example, in HeatCraft the system was wearable, and the thermal feedback was always there and non-obtrusive. Players reported that they appreciated the heat acting on their body at any time, letting them feel their temperature even when they were not paying attention. Compared to HeatCraft, the Guts Game did not fully engage players with their material interior body. The Guts Game was based on a smartphone, so players could not engage with the play when they were not interacting with the smartphone. Therefore, players might have been unaware of their interior body changes when they were not actively playing the game. Therefore, designers should consider designing always-available systems for ingestible play.

### 7.5.10 Design Theme 10: Agency (Moving Ingestibles – the Functional Interior Body)

'Agency' highlights that designers could consider the players' agency over their sensed interior body data as agency might influence the players' willingness to explore their interior body. The extent of agency might vary as the sensor moves inside the players's body.

The experienced level of agency influences the extent to which players can engage with the functional interior body. Here, I regard agency as the level of interior bodily control a player perceives they have. A degree of agency is an essential factor in engaging and enjoyable gameplay [221]. Without agency, the game output is completely out of the player's control, hindering the player's interactions (turning it into a 'story').

One's agency over one's interior body data as sensed by the ingestible sensor is usually low compared to many other interactive systems. For example, in a screen-based one-button game, the game immediately responds to the player's touch, while in the Guts Game the players might see their body temperature changes with a delay of 20–40 seconds after drinking water (see Chapter 4). Even compared to other intracorporeal devices, the user's agency might be lower with ingestible sensors. For example, with implantables a press sensor can be embedded under the user's skin that supports a high level of agency. However, with the ingestible sensor moving inside the player's body, players might only experience a limited level of agency over the sensed data. Moreover, one has limited agency over sensor mobility. For example, in the case studies, players could barely control the ingestible sensor's speed and, hence, the excretion time. In some cases, the low level of agency was even caused by technology limitations. For example, with the CorTemp temperature sensor, the sensor and recorder's connection could break when the sensor moved to somewhere in the player's GIT that was hard for the recorder to pick up the signal from. A low sense of agency might decrease the player's will to engage with the play [221].

One's agency over the data sensed by ingestible sensors might change as the sensor moves along the GIT. I take the ingestible temperature sensor I used in the Guts Game and HeatCraft as an example. Before swallowing the sensor, the player's agency over the data is high. For example, the player can immerse the capsule into water of differing temperatures to see how the data changes. When the capsule enters the player's stomach, their agency over the data decreases. However, the player has some agency as they can influence the data by drinking water of different temperatures; however, the feedback is much delayed in comparison. After the sensor leaves the stomach and enters the intestine, the player's agency over the data decreases further. At this stage, players can hardly influence the data through eating and drinking. Players can only influence the data by exercising or through significant environment temperature changes, such as by going into a sauna.

Therefore, agency is a key design theme that designers need to consider when engaging players with their functional interior body. When dealing with low agency, designers should note the changes in level of agency across the play.

#### Implementation Suggestions

#### 1) Design Open-ended Play to Dampen Frustration Caused by Low Agency

Designing the play to be open-ended might dampen the frustration caused by low agency. The Guts Game's gameplay was more structured, setting clear game goals for players to complete while HeatCraft was more open-ended, allowing players to freely explore. As a result, players experienced a greater extent of frustration in the Guts Game compared to HeatCraft, especially when their agency became very low as the sensor entered the intestines. In the Guts Game, players reported that after the sensor entered the intestines, their agency decreased and completing the game tasks became more difficult, which caused frustrating game experiences and disengaged players, letting them feel less motivated to pursue the game goals. With HeatCraft, the players mostly reported that they found it interesting to notice the change in agency across the play without mentioning a frustrating play experience. Therefore, designers could consider more open-ended play compared to structured gameplay when the player's agency is low.

**2) Design Sensed Data to Influence Peripheral Factors in Games**

To dampen the frustration caused by low agency, designers could consider using the sensed data to only influence peripheral game factors rather than core elements. The Guts Game players might have experienced frustration as the core game mechanics required players to change their body temperature as sensed by the sensor. However, InsideOut players did not feel frustrated with their low agency when playing Finding Wally and Body Balance. In these two modes, the players' interior body information only influenced peripheral factors. In Finding Wally the GIT changes only influenced the game background and in Body Balance the GIT influenced how the ball looked. This strategy is similar to those of prior works in biofeedback game design. According to Nacke et al. [169], physiological data that is hard for players to directly control can be used for altering peripheral environmental variables that do not directly influence game mechanics.

### 7.5.11 Design Theme 11: Imagination (Moving Ingestibles – the Affective Interior Body)

'Imagination' suggests that players might engage with their affective interior body via imaging how the ingestible sensor moves inside their invisible interior body.

In ingestible play, the ingestible sensor can serve as a reference point to lead the players' attention back to their body. In all three cases, participants suggested that having the ingestible sensor – a foreign object – inside their body encouraged them to periodically think about this sensor and hence their interior body. When players thought about the sensor, they tended to imagine how the sensor was moving inside their body. For example, a player of HeatCraft mentioned that when getting small random pains in the body, he was wondering what the sensor was doing and imagining how the sensor was tumbling over and pushing the intestines' wall. Moreover, since the location of the sensor is ambiguous, players might try to 'feel' the sensor and their interior body, which is similar to the body-scanning exercises that can engage players with their affective body.

**Implementation Suggestions**

**1) Lead Players' Attention Inwards**

Leading players' attention inwards might naturally evoke players' imagination of the sensor and their interior body. This is similar to interoceptive practices that encourage us to 'feel' our interior body. In HeatCraft, players reported that the thermal stimuli could direct their attention back to their body, facilitating looking inward to let them experience their affective body. This is similar to prior works in somaesthetic design, which aims to direct the attention inwards in order to increase self-awareness [99]. Jonsson et al. [108] suggested that subtle heat acting on the body can be a good modality for somatic design by leading the attention inwards. Therefore, future design of ingestible play could consider how players' attention can be directed inwards and back to the players' own body to support their imagination, for example, by adding subtle localised sensory feedback.

**2) Add Playful Fantasy Elements to Support Imagination**

Designers could consider adding fantasy elements to support imagination. In both the Guts Game and HeatCraft, the sensor's location was unknown. This gave space for players to imagine how the senor was moving. InsideOut gave less space for imagination as it provided visual information on the GIT filmed by the sensor. Designers could support imagination by adding playful fantasy elements. For example, in the play mode Borborygmus I designed rumbling sounds to stimulate the imagination that the GIT was cramped and generated sound when the capsule hit the GIT wall. This might have helped players to imagine the interior body information that they could not sense.

### 7.5.12 Design Theme 12: Uncertainty (Moving Ingestibles – the Social Interior Body)

'Uncertainty' suggests that the moving sensor brings uncertainty to the interactions, which can be used as a design resource when designing social play with ingestible sensors to engage players with their social interior body. This uncertainty is based on the features of the ingestible sensor (as it moves along the user's GIT) and also the uncertainty of the human body (e.g., one's digestion speed).

In ingestible play, the moving sensor adds uncertainty to the play as its speed is hard for players to control. Therefore, the time when players would excrete the sensor was uncertain. Also, it would be unclear when the sensor left the players' stomach and entered the intestines, so when the agency might change was also unclear. Uncertainty is often used as a design resource in game design to spark interest [42]. This can be confirmed, as almost all the players in the case studies expressed their interest in knowing the sensor excretion time before the play. This interest facilitated related spontaneous play. For example, in HeatCraft, players voluntarily bet with their co-players on who would excrete the sensor earlier. Also, players mentioned that they regarded the excretion as intimate information, while sharing this information with others made them feel closer to others. Therefore, designers could consider using uncertainty as a design resource in ingestible play to engage players with their social interior body.

#### Implementation Suggestions

#### 1) Consider Uncertainty in Social Play Design

Designers should consider embedding the uncertainty in ingestible play design, in particular social play design. For example, designers could facilitate the players to compete in who can excrete the sensor sooner. The uncertainty of the sensor mobility could also be combined with game competitions to enrich the experience. For example, the Guts Game required players to play against each other, and players reported that the uncertain excretion time, which determined the game duration, made the competition more playful. For example, when a player got advantages, the player might want to end the game sooner by eating food that might speed up their digestion. In contrast, players who fell behind may have wanted to prolong the game in order to have more time to surpass their co-players. Therefore, designers could consider how the uncertainty caused by the moving sensor can enrich social play experiences when it comes to ingestible play design.

## 7.6 Summary

The design themes I have presented above led to the design framework for ingestible play (see Table 7.4). This framework can be used as a tool to design the UX of ingestible play.

I see this design framework as intermediate-level design knowledge between a design practice and a general theory [100, 139]. In this work, I do not give a set of prescriptive design tactics. Rather, I present key design themes of ingestible play to support future

Table 7.4: The design framework of ingestible play.

| | Sensing | Fusing | Moving |
|---|---|---|---|
| The material interior body | Confrontation | Compatibility | Ubiquity |
| The functional interior body | Exploration | Augmentation | Agency |
| The affective interior body | Ownership | Cultivation | Imagination |
| The social interior body | Resonation | Intimacy | Uncertainty |

'creative design', instead of 'useable design' that solves a certain practical problem, for example, motivating patients to swallow a sensor [191]. In summary, the framework I propose in this work may not serve as an instruction for designers to follow step by step, but it can serve as 'sensitizing devices' [208] for designers to consider when desiging future ingestible play.

I acknowledge that the framework can be further updated with the growing understanding of ingestible play design and also the advancement of ingestible technologies. For example, future ingestibles might have more characteristics that support intriguing bodily play. Also, the implementation suggestions I have presented are not a complete list, but have been generated based on the design of the three case studies and also prior works.

In the next chapter, I will conclude the dissertation and discuss the limitations and future work.

# Chapter 8
# Conclusion

THIS chapter summarises the dissertation, presents limitations of the work, and proposes future work that relates to interior bodily play.

## 8.1 Thesis Summary

This thesis study has adopted the RtD approach [247] to explore the design space of interior bodily play which I define as bodily play where the main enjoyment comes from playing with the interior body. To carry out the exploration, I designed and developed three case studies about interior bodily play. For each case study, I conducted a user study in real-world settings [190] and semi-structured interviews for understanding the UX. The interview data was analysed through thematic analysis [25]. By combining the results of the analysis and my reflections on the design process, I have developed a better understanding of the design of interior bodily play and presented a design framework for interior bodily play.

All three case studies have contributed to the final framework. The first case study, the Guts Game (see Chapter 4), is a two-player mobile game based on temperature data from a sensor that measures the user's core body temperature every 10 seconds as it travels through the digestive system, usually within 24–36 hours. To understand the Guts Game UX, I conducted a field study [190] with 14 participants (7 pairs). The results demonstrate that games can be designed around ingestible sensors to support playful and engaging experiences with the interior body.

HeatCraft (see Chapter 5) is a two-player wearable system for users to experience their body temperature as measured by an ingestible sensor via localised thermal stimuli. I conducted a study with 16 participants (8 pairs) to experience HeatCraft. The results show that HeatCraft could facilitate ubiquitous and spontaneous playful experiences, augment the players' bodily experiences and promot awareness of their body, their daily activities and also the surrounding environment.

InsideOut (see Chapter 6) is a system where the user playfully interacts with a real-time video of their interior body. InsideOut supports players to interact with their GIT video through a display worn on the front of the body showing the video filmed by the imaging capsule in real-time. I investigated the player experience of InsideOut with 7 participants in a field study [190]. The study results show that InsideOut lets players appreciate the experience of seeing, exploring and learning about their interior body.

Based on the results of the three case studies, my craft knowledge gained from designing these systems and prior works in the related fields, I contend that the emergence of ingestible play expands the magic circle of bodily play to the interior body and I have summarised the key characteristics of ingestible sensors for consideration during the design and development of ingestible play. Moreover, by drawing on the phenomenological understanding of bodily experience, I have presented a framework for ingestible play that contains 12 design themes and a set of implementation suggestions. This design framework can serve as a design tool for designers in designing future ingestible play experiences.

## 8.2 Limitations

This section discusses the limitations of the thesis study.

First, the final framework is design-based, derived in parts from my craft knowledge of designing three prototypes. Therefore, the framework could be updated as technology advances. For example, in all three case studies, the ingestible sensors I used do not provide location information, so the players in the studies did not know the sensor's exact location inside their bodies. The user study of HeatCraft shows that the ambiguity of the sensor location could lead to body-scanning activities (see Chapter 5); in other words, the system directed the players' attention inwards as players tended to 'feel' where the sensor was. Such UX might fade if future ingestible sensors provide location information to the users.

Second, this thesis study has adopted the RtD approach, so the knowledge contribution is based on the designs and UX of the three case studies. However, additional case studies might add more details to the framework. For example, in the three case studies, the feedback modalities I have used include visual, thermal and sound feedback. Other modalities such as smell, taste, etc. were not used in this work to enrich the interactive experience.

Third, I have investigated the interaction design around ingestible sensors in the context of play. However, I acknowledge that apart from play, other design approaches might also be used with ingestible sensors to engage with one's interior body. For example, a somaesthetics appreciation design approach [99] could be adopted. According to Höök et al. [99], one design prototype that manifests the idea of somaesthetic design is Soma Carpet, which has the user lie on a carpet and directs the user's attention by providing heat feedback to different parts of the body. I can envision another version of this Soma Carpet combined with ingestible sensors to engage users with their interior body. For example, designers could design the carpet's temperature to be changed by the user's core body temperature as measured by an ingestible sensor and direct the user's attention to different parts of the interior body.

Fourth, in the three case studies I let players engage with their interior body through two types of ingestible sensors: ingestible temperature sensors and imaging capsules. Both of these sensors are single-use and pass through the user's GIT within days. However, other sensors might dissolve in the GIT, which could lead to different UX. Furthermore, both the sensors I used had limited sensing functions. Other sensors offer additional functions such as vibration, which might provide more design opportunities and provide additional insights into the design of ingestible play.

Fifth, in the design of all case studies, I used a literal mapping between the player's interior bodily data and the data representation. This choice was made as I hoped to allowlet players to become aware of their interior body and learnknow more about their interior body. In the future, other non-literal yet playful mappings could be designed to facilitate playful and engaging experiences in ingestible play.

Sixth, in all three case studies, the players werewas only requested to swallow only one ingestible sensor. Players' experience might be enriched, and more interactions could be designed, if two or even more sensors weare swallowed. For example, suppose athe player swalloweds a temperature sensor and an imaging capsule at the same time. In that case, I couldcan design the GIT video's colour to changed based on the player's body temperature. In this research, I did not design a multi-sensor-based game as there is a lack of practical evidence to show the safety of swallowing multiple sensors. In the future, designers can engage with engineers and medical researchers to evaluate the potential of designing ingestible play with multiple sensors.

Seventh, the design framework still lacks other designers' validation. A long-term study that lets game designers use the framework to build ingestible play systems may further improve the framework.

Eighth, this dissertation study has mainly approached ingestible play design from a practical rather than a critical perspective. However, I imagine that the design of ingestible play could also affect a users' perceptions of their body. It can also be envisioned that if ingestible play becomes popular, it might even shape the collective view of the human body in society [227]. For example, prior works indicate that the ubiquitous presence of the interior body in public media might lead to people perceiving invasive surgery as harmless. Moreover, the increased level of body transparency might lead people to believe that 'seeing is curing', which is not accurate [227].

Ninth, this dissertation does not intend to motivate players to use ingestible devices and interact with their interior body. I acknowledge that there are people who feel uncomfortable with using invasive technologies or getting to know interior body information. In all case studies, I only recruited volunteers to experience ingestible play. Therefore, with the three studies I did not obtain enough data to discuss how designers might motivate people to engage with ingestible interactions and play. However, the studies have shed some light on this design challenge. For example, with the Guts Game players reported that both the game narratives and the presence of their co-player helped them relax before the study. InsideOut players reported that they appreciated having a filter making the GIT video abstract when they felt uncomfortable with the video. In the future, more work could be done to investigate how design might motivate players to participate in ingestible play. Moreover, I believe that with the popularity of ingestible sensors, people will be more accepting towards the technology and hence ingestible play. Furthermore, the media might also help popularise ingestible play. For example, as we often see pictures of X-rays and CT scans on TV etc., we do not consider these medical images confronting [227]. However, I can imagine that when these imaging technologies initially emerged, people might have been 'shocked' to see their bone structures for the first time. A similar situation might apply to ingestible technology. With people knowing more about the technology and being more familiar with the interior body, more people may be interested in ingestible play.

## 8.3 Discussions and Future Work

I believe explorations around the interior body are timely for the field of HCI. Intracorporeal devices that provide users with opportunities to engage with their interior body might become increasingly common in our everyday lives. The global market for ingestible sensors was valued at USD 3030 million in 2020 and is expected to reach USD 6842 million by 2025[1]. The current popularity of ingestible sensors is mainly due to their value in medical applications. However, I believe ingestible sensors could have great potential in future interaction design. These sensors would be always inside the human body, sensing or actuating on the human body and continuously connecting to a network, which corresponds with the vision of ubiquitous computing that technology will be seamlessly integrated into everyday life [239].

Using the insights gained from the three case studies, I now speculate upon several future research directions that relate to interior bodily interaction and play.

### Technology

The current ingestible technology limits the potential of ingestible interactions. First, the current price of ingestible sensors is relatively high, which might hinder the popularity of ingestible interactions. In my studies, the price of a CorTemp temperature sensor was about 73 USD and the OMOM imaging capsules cost 562 USD each. Future research around ingestible technology could be done to reduce the cost of the device. For example, developing ingestible sensors powered by stomach acid might reduce the sensor cost [245]. Second, the battery life of ingestible sensors limits the duration of ingestible play. Advancement in battery technology might prolong a sensor's battery life. Also, new ways of powering the sensor might also prolong the interaction duration. Other methods might include supporting charging the sensors from the outside of the body [62]. Third, the lack of robustness of ingestible technology might limit the UX. For example, with the CorTemp temperature sensor its accuracy decreased when there was electromagnetic interference. Future work could be conducted to improve the robustness of ingestible technologies. Fourth, the accessories of ingestible systems might limit the interaction scenarios. For example, with current technology one usually needs to wear a data recorder to receive the data from the ingestible sensor. As a result, it might be challenging to design ingestible play in scenarios like swimming pools where users get wet.

[1]Source: www.marketdataforecast.com/market reports/smart-pill-technologies-market

Future work could explore how to remove the need for accessories outside the body to support ubiquitous interactions. Fifth, the current ingestible sensor functions are limited, which prevents designers from creating certain engaging and playful experiences. During my design process, I hoped that pills could be designed to generate playful sounds inside the GIT, for example. Sensors that can perform actuating functions, for example, providing haptic feedback, might also bring about intriguing opportunities. In the future, developers might think beyond medical contexts, needs and applications during the sensors' ideation process. For example, developers could embed additional sensors to provide more information about the user's interior body and support playful exploration. This might require developers to work with designers and potential ingestible gamers to create the future of ingestible technology.

### Design

This dissertation represents a starting point for exploring the design of ingestible interactions. There are plenty of opportunities to further the research in interaction design. Here I present two directions. First, design researchers could continue the research by exploring the potential of intracorporeal devices in interaction design. In recent years, HCI and design researchers have begun to explore how intracorporeal devices, mostly implants, can be designed for interactive purposes. However, compared to extracorporeal devices such as wearables, our design knowledge around intracorporeal device–based interactions is rather limited. More work could be conducted to introduce various intracorporeal devices to the field and investigate the devices' full potential for the field. Moreover, designers could prepare for the emergence of new types of intracorporeal devices and consider how these emerging technologies might influence future designs. This could help designers anticipate future design alternatives and make ethical design choices when these technologies become available. For example, with the advancement of nanotechnology intracorporeal devices may even become part of our food and enter our tissues and cells after being ingested. Designers might need to consider what this would mean if we could interact with our cells.

Second, design researchers could explore different design approaches to support users interacting and engaging with their interior body. This direction focuses less on the technology, while putting the experiential body in a more central role. For example, how can interactions be designed to make users become more intimate with their interior body? In conventional bodily interactions, activities such as yoga and tai chi can help people achieve 'oneness'. This oneness refers to liberation from the burden of being an 'I' and supports intimate familiarity with one's own body [166]. Recently, many HCI designers have started to consider how digital technologies could support users to perform these activities [123]. Some activities such as meditation may increase one's interoception level, a sense of one's internal body conditions. Future work might explore how interaction design can increase one's interoception and further engage users with their interior body. Moreover, future work could further investigate how to relate one's experiential interior body to others' bodies. In my work, I demonstrate that social play can engage players. Future work could explore interaction design at a larger societal level. For example, if everyone has a sensor inside their body in the future, could the sensor be designed to support social interaction among citizens? Would this change the way we interacted with each other? Furthermore, design researchers could investigate the UX of interacting with the interior body in different contexts and with different user groups. In my studies, all the participants were healthy and voluntarily participated. Future work could investigate how interaction design might engage patients more in medical procedures in a clinical setting. Also, my work has not aimed to improve the participants' health, although the interview data in my studies indicates that ingestible play might improve players' health behaviours. Future work could be conducted to explore how to encourage people to take better care of their interior body health, considering that most people only have limited knowledge regarding their interior body parts.

### Cultural and Ethical Issues

Future work could explore the cultural and ethical issues associated with interactions with intracorporeal devices. Most of the current research only investigates the ethical issues of intracorporeal devices in medical contexts [76,86,118]. There is a need for more work investigating the ethical issues of using these devices in interaction design and for non-medical purposes. Also, future work could investigate the cultural effects of intracorporeal device–based interactions. For example, my work opens up a future design space investigating how intracorporeal devices might support players' interaction with Hertzian space. The term 'Hertzian space' refers to a holistic view of digital devices and their cultural interactions [43]. In HeatCraft, the surrounding electromagnetic field influenced the ingestible sensors and led to erroneous data, which was revealed via beeping sounds. As a result, players explored their space and reflected how the technology in the space might influence their body and health. In the future, intracorporeal devices could be designed to better support players experiencing Hertzian space. For example, an implantable could be designed to vibrate when sensing electromagnetic waves and the intensity of the vibration could change based on the intensity of the surrounding electromagnetic field. Furthermore, more cultural issues could be considered around the interior body. For example, future work might explore how culture shapes our understanding of our interior body. Potential questions could be: How does culture influence our acceptance of intracorporeal devices? How might the advancement and popularity of intracorporeal devices shape our culture in turn?

## 8.4 Final Thoughts

This work has introduced ingestible sensors to the design of bodily play, suggesting how ingestible play might engage players with their interior body. The presented design framework could guide game designers to create future ingestible play experiences.

Looking to the more distant future, I expect this work might open up more critical questions, including: What does a future of interaction look like as technology gets closer to and even enters our body? What design opportunities and challenges arise if electronics can be produced at nanoscale levels and enter any parts of our body? What if users gain more agency over the mobility of ingestible devices? What if the ingestible devices could wirelessly connect to devices inside other people's bodies? This thesis study is a call for further research into questions like these.

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# Appendix A
# Participants Screening

## A.1 Inclusion and Exclusion Criteria for Participants Screening

The study includes:

1. men and women aged between 18 and 70 years living independently in the community and who consider themselves in good health.

The study excludes the participant if the participant:

1. is pregnancy;
2. is under 18 or above 70 years old;
3. less than 37 kilograms;
4. has an implantable device such as a heart pacemaker;
5. has a history of disorders or impairment of the gag reflex;
6. has experienced swallowing disorders and/or experiences difficulty swallowing the sensor;
7. has a history of diabetes or other hormone diseases;
8. has a history of abdominal surgery;
9. is currently suffering from nausea or vomiting;
10. is currently suffering from abdominal pain;
11. is currently suffering from any chronic condition;
12. is currently suffering from high blood pressure;

13. is currently taking daily medication;
14. has a heart condition or suffers from chest pains while exercising;
15. has asthma or experiences any breathing difficulty while exercising;
16. has experienced severe heat exhaustion after exercising;
17. has any bone or joint problem that could be aggravated by exercise;
18. experiences pain in any area of your body during movement;
19. will undergo Nuclear Magnetic Resonance (NMR) / Magnetic Resonance Imaging (MRI) scanning during the period that the ingestible sensor is within the body;
20. plans to have abdominal or other surgery during the study;
21. has pathological diseases including any physical disease. This includes but not limited to any known or suspected obstructive disease of the gastrointestinal tract such as diverticulitis and inflammatory bowel disease and felinisation of the esophagus;
22. has a condition that prevents from surgery.

Additional exclusion criteria for InsideOut study:

1. is allergic to high polymer material;
2. needs to take iron tablets within one week before swallowing the imaging capsule;
3. has any mental disease;
4. could not confirm that the potential bystanders (e.g. people who live/work with the participant) feel comfortable with seeing the images pf their GIT.

## A.2 Screening Procedure

### Pre-screening Call

After potential participants expressed their interest in participating in the study, I emailed/phoned the participants to initially assessed for their eligibility to be included in the study. This was based on a few primary questions including age, potential pregnancy and implantable device information.

Upon successful completion of the pre-screening call, I explained the study in plain language and provided potential participants with the Participant Information Sheet and Consent Form. These documents introduced the research project in plain language, outlining the topic of the research and its purpose, study procedure, risk and benefit, and complaints about the process if any and contact information. These documents also described the involvement requested of potential participants and their rights and responsibility in the research process. I communicated with the participants if they had any question regarding the study.

In the InsideOut study, a cooling-off period of greater than 24 hours was given to the potential participant to decide whether or not to continue in the study. I also told potential participants that they could seek advice from their doctors to decide whether to participate in the study.

### Questionnaire Screening Procedure

After the participant agreed to continue, they were asked to fill out a Risk Assessment Questionnaire. The questionnaire was based on the exclusion criteria of the studies I presented in section A.1. This questionnaire generally took approximately 10 minutes to complete. The participant could stop immediately if feeling uncomfortable answering any of the question. However, the participant would be excluded from the study.

In the InsideOut study, a health professional communicated with the participant verbally to further evaluate whether the participant was suitable to participate in the study after a participant completed the questionnaire.

Once a participant had been deemed eligible to take part in the study, I further highlighted all the potential risks to the participants. Then I asked the participant to sign s consent form if the participant agreed to participate in the study. I then scheduled a time and invited the participant to the lab for the study, and confirmed the participant instructions again with the participant, highlighting what they should and should not do before and during the study.