The Guts Game: Towards Designing Ingestible Games

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ABSTRACT
Ingestible sensors, such as capsule endoscopy and medication monitoring pills, are becoming increasingly popular in the medical domain, yet few studies have considered what experiences may be designed around ingestible sensors. We believe such sensors may create novel bodily experiences for players when it comes to digital games. To explore the potential of ingestible sensors for game designers, we designed a two-player game - the "Guts Game" - where the players play against each other by completing a variety of tasks. Each task requires the players to change their own body temperature measured by an ingestible sensor. Through a study of the Guts Game (N=14) that interviewed players about their experience, we derived four design themes: 1) Bodily Awareness, 2) Human-Computer Integration, 3) Agency, and 4) Uncomfortableness. We used the four themes to articulate a set of design strategies that designers can consider when aiming to develop engaging ingestible games.

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

Author Keywords
Ingestible sensor; Game design; Pervasive computing; Body temperature

INTRODUCTION
In recent years, ingestible sensors have become increasingly popular for medical use [33]. These sensors are self-contained electronic microsystems with the capability of performing functions inside the human body such as measuring body temperature or the pH value of body liquid [8].

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We believe that ingestible sensors have the potential to be used for digital play. We look at wearable devices for inspiration and note that they were initially employed for medical purposes (e.g. heart rate monitors). Later, they became a key component of the quantified-self trend (e.g., Fitbits that measure step counts [9]), yet recently they have been used for play (e.g. see the games available on the Apple watch). We believe a similar trend might emerge with ingestible sensors as they are becoming more common thanks to advances in technology [36].

There are significant differences between ingestible sensors and wearable devices that may enable novel game design opportunities. First, ingestible sensors are inside the human body and can therefore form an integral part of bodily play experiences, providing opportunities for experiencing the body as play [15]. Second, ingestible sensors are always with the users during usage and thus may support continuous play at any time and any place. Third, ingestible sensors might be less of a burden to users who feel uncomfortable with wearable devices touching their skin [22]. Therefore, we believe ingestible sensors might offer unique opportunities for play. However, there is little knowledge on the use of ingestible sensors to facilitate playful experiences.

In this article, we introduce ingestible sensors to the field of game design and propose the concept of "ingestible games", which are games involving ingestible sensors. We believe such games may bring about unique bodily experiences due to the intimacy between the body and the device [24]. Moreover, ingestible games may help players learn more about their body since the sensors can provide players with their body data [29, 33, 39]. In the future, ingestible games may support patients in taking their medication as games can make repetitive tasks more attractive [46]. For people who feel uncomfortable with ingestible sensors, ingestible games may change their attitudes towards the devices [2]. Therefore, we find there is great potential for ingestible games, and in this article we explore this exciting new area.

This research aims to investigate how to design ingestible games. We developed the Guts Game, a two-player mobile game around an ingestible temperature sensor. We conducted a user study with 14 participants, from which we derived four design themes and a set of design strategies to guide future explorations around ingestible games. With this article, we aim to provide an initial understanding for designers who are interested in engaging with ingestible sensors to facilitate playful experiences and enrich bodily interactions.

RELATED WORK

Our work builds on the prior work of four areas: the hobbyist's use of insertable devices, sensor-based play, pervasive games and the body-tool relationship.

Hobbyist's Use of Insertable Devices

Insertable devices are devices that can be implanted under the user's skin [21]. Since both ingestible sensors and insertable devices are inside the user's body during usage, we believe research around insertable devices may help us understand the experiences of using ingestible sensors. Prior work suggests that many people insert digital devices into their bodies for non-medical purposes [22]. For example, Warwick recorded the experiences of implanting a chip in his arm to turn his office light on [54]. Furthermore, Heffernan interviewed the hobbyists of insertable devices and found that they were intrigued by the innovative technology and hoped to expand their bodily capacity [22]. Unfortunately, these works do not delve into practical design details on how insertable devices and ingestible sensors can come together with play and games.

Sensor-based Play

Ingestible sensors are sensors inside the human body. Therefore, we believe that ingestible game design may learn from sensor-based game design. Many games adapt the players' body data to the gameplay, creating dynamic and personalized playful experiences [11]. For example, Stach et al. [50] built a racing game in which the car's speed is determined by the player's heart rate. These studies highlight that letting players control their bio-data may bring about enjoyable experiences [41]. Prior work also investigated the design of sensor-based playful systems. Nacke et al. [41] proposed that designers should consider the mapping between the sensor types and game mechanics when designing biofeedback games. For example, bio-data that can be directly controlled such as breathing rate should match the actions in the game world such as walking and jumping. Meanwhile, bio-data that cannot be directly controlled such as heart rate is suitable to alter the game world such as the weather of the virtual environment. Similarly, Rogers and Mueller [48] argued that the sensor type should match the user's activity type in sensor-based play. For example, controlling activities such as tapping might need a precise sensor while an implicit coupling between the sensor and activity might promote users' reflection. Therefore, the design of ingestible games might need to consider the features of the ingestible sensor. However, what novel experiences can be brought about when the sensor is inside the human body remains unknown.

Pervasive Games

Pervasive games are games that expand the boundaries of play and introduce the player's real life to games [17, 38]. Similarly, as ingestible sensors are always inside the user's body during usage, ingestible games may not be stopped by the player, making the game integrate with the player's real life [1]. Therefore, ingestible game design might learn from research around pervasive games. For example, ingestible game designers might consider including social play in ingestible games since social interactions can lead to better game performances and experiences in pervasive games [19]. Furthermore, Jegers proposed the Pervasive GameFlow Model including eight elements such as concentration and social interactions to guide pervasive games design [30]. However, some criteria of this model may be hard to achieve in ingestible games. For example, providing players with immediate feedback might not be attainable in ingestible games. This is because some bio-data like body temperature does not change rapidly, resulting in a delayed feedback on player actions. Therefore, how to achieve engaging ingestible game experiences within a pervasive context is yet to be explored.

Body-Tool Relationship

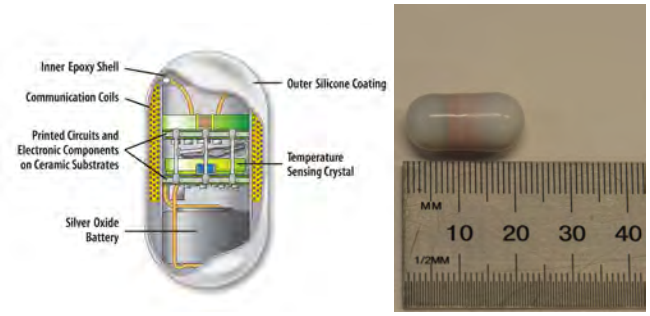
Technology might influence people's bodily experiences and perceptions of their body [23, 51]. Nunez-Pachrco and Loke proposed that a body-centered technology can enhance the user's bodily awareness [42]. Similarly, Ferraro and Ugur argued that wearable devices could affect people's bodily awareness by providing real-time body data to remind the users of their bodily states [14]. Furthermore, Farooq and Grudin suggested designers to consider the context of "human-computer integration" which refers to a partnership between the human and computer for better interaction experiences [13]. Leigh et al. [34] also suggested that body-centric technologies can be perceived as an integral part of the human system as these technologies are usually on the users' body and are always available, contributing to the trend of human-computer integration. Therefore, we believe that ingestible games have the potential to affect a player's bodily experiences and form a close "partnership" with the human body since the sensors are always available and can provide continuous body data. However, how to design ingestible games in the context of human-computer integration remains unknown.

TOWARDS UNDERSTANDING THE DESIGN OF INGESTIBLE GAMES

To better understand the design of ingestible games, we developed a game prototype using the FDA-cleared CorTemp sensor (Fig. 1) and conducted a study. The single-use sensor measures body temperature every 10 seconds as it travels through the digestive tract and transmits the data wirelessly to a Cortemp receiver. The receiver then sends the data to a smartphone. The sensor is originally produced for people such as athletes, soldiers, and firefighters to monitor their temperature in extreme environments. We chose the Cortemp sensor for this study as it can provide a continuous stream of temperature data that the user could act upon since feedback is an important part in digital games.

First Insight

We conducted a pre-study to understand the user experiences of the sensor, which later served as the basis for the game design. We adopted an autobiographical approach [45]: two authors of this article swallowed the sensor and performed a



(a) (b)

Figure 1: (a) The structure of the Cortemp sensor. (With permission from HQInc). (b) Size of the sensor.

series of activities such as drinking water of different temperatures and exercising with various intensity. Both the time of executing the activity and the temperature data were recorded. We adopted the autobiographical approach as it allows for the fullest account of the experience [25]. Moreover, bodily experiences are best understood by going through them oneself [45].

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 [35]. When the sensor was in the user's stomach, the temperature changed 20-40 seconds after drinking or eating. When the sensor entered the intestines, drinking water could affect the data only if the stomach was empty, and there was a delay of three to five minutes to see the change. Additionally, the intensity of exercises also affected the delayed time. For example, one researcher's body temperature began to raise eight minutes after starting to walk at normal speed but only one minute after starting intense exercise.

GAME DESIGN

To understand the design of ingestible games, we built the "Guts Game", a two-player mobile game where players swallow the Cortemp sensor and complete game tasks by changing the body temperature measured by the sensor. The players may explore their own strategies to complete each task. We now explain our design in details.

As players might be nervous before swallowing a sensor, we developed a game story during the initial-stage gameplay since game narratives might encourage good behaviour around players' medication intake [2]. In the Guts Game, a chocolate bar is given to each player initially. Then the researchers, who dress up like medical doctors, tell the players that they have been infected by a parasite, which is sensitive to its environment's temperature, i.e. the body temperature of the player as measured by the sensor. If the environment's temperature reaches a certain value, the parasite will be hurt. The crafty parasite may adapt to the environment so the target temperature might change once reached. The more often the player reaches the target temperature, the bigger possibility he/she will survive. To aid the treatment, the "doctors" developed an application called the Guts Game. Players need to swallow the sensor to measure their body temperature and the application will guide players. Players need to come back to the "doctors" after the game ends to check if the parasite is still there.

The Guts Game ends when one of the players excretes the sensor. We thought about to end the game when both of the players excrete the sensor, however, the player who first excretes the sensor may then need to wait until the end of the game.

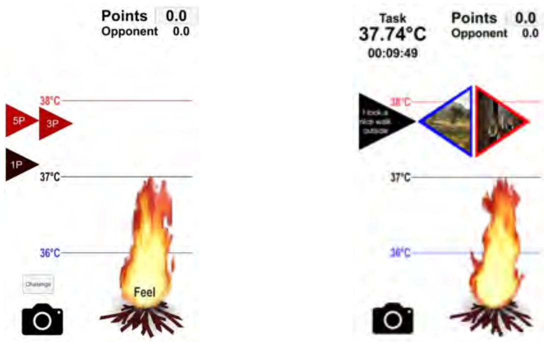
Since the accuracy of the Cortemp sensor might be influenced by the interference of electrical currents and obstructions [4], the raw temperature data is filtered using a threshold, and then downsampled every six points using a first-order derivative edge detector. We use the height of an animated flame to represent the temperature data (Fig 2). The flame height is more ambiguous than the real number, which ensures the fluctuating signal does not confuse the players (thinking their temperature has such fluctuations). This approach is also in line with prior work that suggests to not always provide plain numbers when it comes to body data [20].

Players are encouraged to interact with each other through sharing pictures as the pre-study suggests that social interactions may facilitate positive social experiences: the two researchers felt curious about the other person's experiences and they chose to take the same activities and compare their data when they were together. Similarly, prior work confirms that social interaction may motivate players to engage in pervasive games [19]. Therefore, we encourage players to take and share pictures by tapping the camera icon in the bottom left corner of the game interface (Fig. 2). In addition, after players complete a task, they are asked to enter what they did and how they felt via text messaging, while the co-player receives an invitation to express his/her feeling on the player's progress using a picture. All the pictures and text sent by the players can be seen by both players. We hoped this may help facilitate a shared experience.

The Guts Game adopts a task-based gameplay. The game asks players to complete a series of tasks to gain points. After the player completes/aborts a task, he/she can choose the next one. Fig. 2 (a) 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, the target temperature will also be shown at the top left corner of the screen. 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, his/her points will decrease by one and the other player cannot see his/her flame changing within the next one minute. To enrich the game experience, we designed three task modes.

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, three or five points after completing the task. All goals are meant to be achievable for most people



(a) (b)

Figure 2: (a) is the game interface before the player chooses a task. (b) is the game interface when the player is performing a task. The pictures and texts inside the triangles are sent by players.

as they are between 36 °C and 38 °C. The tasks can only be aborted ten minutes after being received as we hope to encourage players to try their best to complete the tasks. There is no time limitation for each task.

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. The player can then tap one of the three triangles to receive a feeling mode task. In this mode, the flame stays fixed and the player can only tap the flame once to peek at his/her temperature for 20 seconds before the flame becomes stable again. The player can tap the flame again when he/she feels the target temperature has been reached. The points are given to the player based on his/her performance: the closer the player's temperature (T_p) is to the goal (T_g), the more points will be awarded. We define $\Delta t = |T_p - T_g|$. If $\Delta t \leq 0.1$, players could get the full points. If $0.1 < \Delta t < 0.5$, the points the player could get is $0.001/\Delta t^3$. If $\Delta t \geq 0.5$, no point will be given.

Challenge Mode — Social Play

Players can challenge each other by setting customized tasks. After tapping the "challenge" button, the player chooses 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 the opponent. The opponent's normal gameplay will be locked for up to 1.5 hours once the challenge mode task is received. During the lock time, the player has to complete the challenge to get unlocked. The length of lock time depends on the difficulty of the challenge task: 30 minutes for an easy task ($36.7 < T_c \leq 37.3$); 1 hour for a medium task ($36.3 < T_c \leq 36.7$ or $37.3 < T_c \leq 37.7$); 1.5 hours for a difficult task ($36 \leq T_c \leq 36.3$ or $37.7 < T_c \leq 38$). We believe this may encourage players to challenge their opponents.

USER STUDY

We conducted a study similar to a technology probe investigation [28] to understand the experience of playing the Guts Game. We recruited 14 healthy participants (9 males and 5 females, M age = 27.4, SD=1.2) 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. No financial compensation was provided. The study had received ethics approval from the university. To minimize any safety risk, we required players to complete a risk factor assessment questionnaire before the study for determining their eligibility for participation. A paper document explaining the guidance for any potential first aid was also provided.

Player's Initial Briefing

Before the game, we gave a briefing and provided the following equipment to players: the Cortemp sensor, the Cortemp receiver, an iPhone, a waist bag, a charging cable for the phone, and a power bank. The waist bag provided the best position for picking up the sensor signals allowing players to wear the receiver on the back. As it usually takes 24-36 hours for the sensor to pass through the body, we expected the game might run for one to two days. The power bank was provided to guarantee the game could operate continuously.

We previously installed the Cortemp app and the Guts Game on the iPhones. The Cortemp app is a mobile application that receives the data from the Cortemp receiver. Players can see their real-time body temperature data through the Cortemp app. The Cortemp app also transmits the data to Dropbox every minute, from which the Guts Game downloads the data as the game input. Players were encouraged only to run the Cortemp app in the background and focus on the game.

A printed game manual and an instruction sheet for solving technical issues were provided, both in the form of image and text. The technology of ingestible sensors is still in its infancy so that the Cortemp receiver occasionally loses connection with the sensor. This might happen when the receiver moves in the bag, or the bag moves during everyday movement, or because of external interference or simply because the user's body affects the signal. Consequently, the temperature data may stop updating. When these technology issues happened, players were advised to refer to the troubleshooting instructions or contact the researchers to seek help.

Analysis

For each play session, a semi-structured interview was conducted with the two players in a team before the game, asking how they felt about ingesting the Cortemp sensor and what they expected from the game. This interview took about 15 minutes. During the game, data such as the body temperature, points, texts and photos sent by players was logged. After the game ended, another semi-structured interview was conducted with the two players, focusing on their play experience, and lasted about 40 minutes. All interviews were audio recorded. Thematic analysis [5] was conducted to analyze the collected data. We considered each turn of speech in the transcripts to be a unit, and thus, excluding interviewer questions, there were a total of 653 units, each of varying length (short answers and longer responses). Two researchers analyzed the interview data three times independently. Each of them identified every unit with a code. These codes were discussed and refined by the two researchers until they reached an agreement on a total of 12 codes. The two researchers then iteratively clustered related codes into higher level groupings, representing the major themes relating to players' experiences.

FINDINGS

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 of 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*". We now unpack the game experience as follows.

F1. Body Awareness: The Game Made Players More Aware of Their Bodies

Participants suggested that playing the game made them more aware of their bodies. For example, participant 8 (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*". In the Guts Game, all participants said that they liked to learn more about their body and the game made them be aware of their daily activities. For example, p4 said: "*I want to explore the relationship between my body and activities like eating, exercising, sleeping and so on. The pill made me pay attention to my drinks and food*".

F2. Emotion: The Sensor Facilitated an Emotional Response

Six participants felt initially nervous about swallowing the sensor. For example, p1 said: "*At the beginning, I felt a little bit worried because I had to swallow something*". Participants mentioned that the game narrative reduced their nervousness. 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*". We found that players' emotional response to the sensor might be affected by a) their professional background, for example, p12 said: "*I feel excited. I work on IT so I am interested in this game*"; b) whether they are experienced gamers, for example, p8 said: "*I have played games for 20 years. This game will be a new experience for me. I feel curious and excited.*"; c) whether they take pills regularly in their daily life, for example, p11 said: "*I often take pills so I am not afraid of swallowing the sensor*". Table 1 shows the participants' information and their emotional response to the sensor.

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*".

F3. Four Phases: Players Experienced Four Phases During the Game

We learned that participants experienced the game differently as gameplay progressed. We define four phases as part of the gameplay. Phase 0 started when the user unwrapped the sensor package. Phase 1 began when the sensor was swallowed.

Table 1: The information of the participants and their emotions before ingesting the sensor.

Players	Professions	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

Phase 2 began when the sensor left the user's stomach and entered the intestine. Phase 3 referred to the time after the sensor left the user's body. We refer to the start point of the four phases as P0, P1, P2, and P3. In this study, we could not determine the exact time when the sensor left the participants' stomach. Instead, we estimated the time point P2 based on the variation of the player's temperature data.

Although the game did not tell the player when Phase 2 started, players perceived that there was a change: they found it more difficult to change the temperature during Phase 2 compared to Phase 1. For example, p7 said: "*You can discover which stage the pill is 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*". Fig. 3 shows one of the player's temperature during the play. We gathered the temperature data of all participants and found out the maximum/minimum data during different phases. During Phase 0, the temperature data was equal to the environment temperature. During Phase 1, the drink/food consumed by players might directly get in contact with the sensor and therefore the temperature data was not the player's real body temperature, but highly affected by what food/drink the player consumed. During Phase 2, the temperature data was much closer to the player's real body temperature compared to Phase 1. In this study, the range of the temperature data during Phase 1 was [25.64, 42.9] and [35.64, 39.11] in Phase 2. Although some data during Phase 1, like 25.64 °C and 42.9 °C, seems to be too low/high for body temperature, all the participants understood that they were healthy and the extreme data was affected by the food they ingested. We figuratively present the possible temperature data range across different phases in Fig. 4.

The gameplay of the Guts Game does not change across the 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*". Meanwhile, 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*

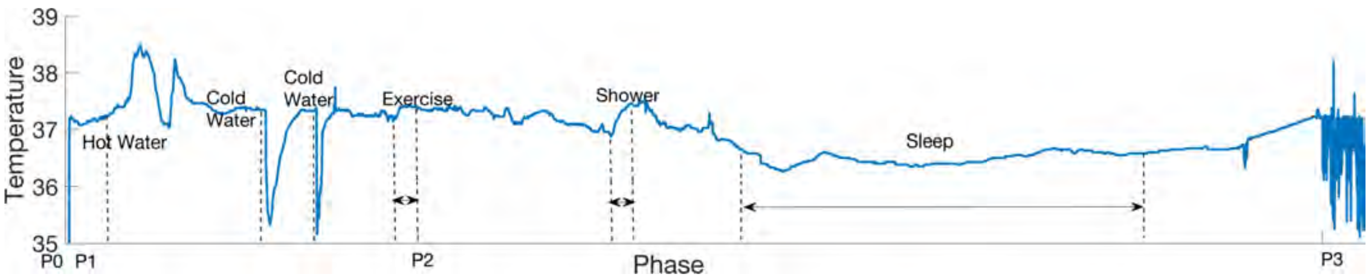


Figure 3: One of the players' temperature data during the play. We know the activities the player did based on the photos and texts he sent out and the interview data. This figure is only a rough illustration to give an impression rather than a detailed representation.

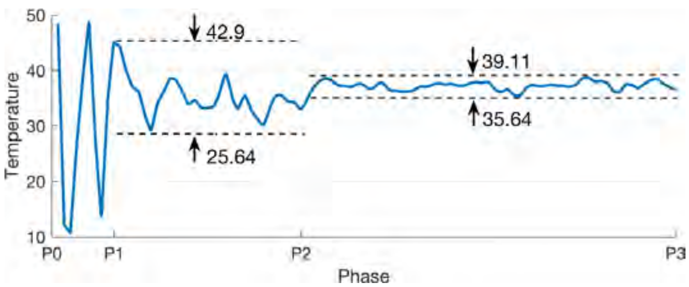


Figure 4: The possible temperature data range across the different time phases.

more conscious of it on the second day and thinking: 'is it still there?'".

F4. Limited Control: Participants Experienced Limited Control Over the Sensor Data and Mobility

Players reported that they experienced a low degree of agency during the game. First, the body temperature a player can reach is limited, and participants felt frustrated when they could not achieve a 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*". Meanwhile, 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*". Indeed, players could slightly control when they excreted the sensor by consuming specific items such as banana and 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*".

F5. No Presence: Players Appreciated They Could Not Feel the Sensor after Swallowing

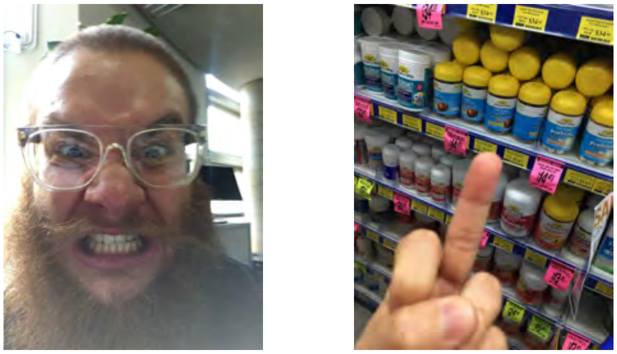
After players swallowed the sensor, they usually tried to feel the sensor. For example, p10 said: "*I am feeling it*". Players felt more relaxed after a while as they actually could not feel the sensor. P9 said: "*It's not an intrusive device because I'm not aware of it anymore. It's nothing attached 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*".

F6. Body Interface: Players Appreciated the Body Being the Game Interface

In the Guts Game, the 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 game, we only need to tap. 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*".

F7. Cheating: Tricking the Game Seemed to be Difficult Since the Sensor was Inside the Body

Participants expressed that cheating was challenging. 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, 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 would have 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).



(a) (b)

Figure 5: Participants send out photos to express their feelings. (a) is a selfie sent by a player. (b) is sent by a player when she could not complete a challenge mode task sent by her opponent.

F8. Social Play: Social Play Contributed to Engagement

The social features were deemed to be important for players in ingestible games. For example, p1 said: "*I think it's very good to know somebody is playing this interesting game with you at the same time*". Participants enjoyed sharing their game experiences with others, including outsiders. 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*". P11 said: "*When I went back to the office, everyone was very interested in and talking about it and then later in the day people wanted to know what the waist bag was. It's fun to share and people found it interesting*". Players also learned from the other player's winning strategies. For example, p14 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*". Furthermore, the social gameplay appeared to help participants become less nervous about playing ingestible games. 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 enjoyed sending photos to each other. For example, p5 said: "*I think pictures are good as it gives you a quick snapshot to see what the other person is doing*". We noted that the photos sent by the players were mostly selfies, gestures and their surroundings. Fig. 5 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*".

F9. Feedback: Players Expected Explicit Feedback

While participants liked the ambiguous feedback through the flame, they were also curious to see their exact temperature. For example, p8 said: "*I can see the connection between the temperature and the flame. It's a good idea. But I want more details*". The feedback also seemed important to help players ensure that the system was working. For example, p5 said: "*The real-time feedback is essential to make sure that it is working*".

F10. Social Environment: Player's Actions were Affected by Cultural Norms

Players appreciated that the 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*". Moreover, players suggested that they felt more comfortable when playing at 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*".

F11. Technology: The Limitation of Technology Led to Negative Game Experiences

As the sensor occasionally lost connection with the receiver, players needed to troubleshoot the system, which they felt was a nuisance. For example, p4 said: "*There were some bugs with the receiver. I had to check the connection. It cost time and was boring*". Moreover, six players reported that they did not like carrying the receiver all the time. For example, p3 said: "*At first it was interesting but for a long time, you needed to carry the receiver all the time, especially when I slept, which was cumbersome*".

F12. Novelty: The Novelty Attracted Players

All the participants mentioned that the novelty of the game was the primary reason why they wanted to play this game. For example, p1 said: "*I think the sensor is quite innovative. It is inside my body. To me, it's very good*". Playing ingestible games 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 a new trend in the future*".

DISCUSSION

In this section, we present four themes around the player experience based on the findings, which might provide a theoretical basis for researchers to analyse ingestible games. For each theme, we propose one to two design strategies which are aimed towards guiding game designers when creating future ingestible games.

Theme 1: Bodily Awareness

Mehling et al. suggested that bodily awareness involves the awareness of internal body sensations [37]. F2 (Emotion), F3 (Four Phases) and F5 (No Presence) indicate that the user's bodily awareness changed across the four phases. As F2 and F5 suggest, players might experience nervousness about swallowing a sensor and could still psychologically feel the sensor after swallowing it. Thus, the player's bodily awareness might increase in response to the sensor during Phase 0, which might result in a higher than usual level of anxiety. Therefore, we consider the extent of player's bodily awareness as "high" during Phase 0 and at the beginning of Phase 1. F3 suggests that players were interested in knowing their body temperature at first, but gradually felt less engaged. The initial interest in understanding body temperature confirms prior theory that the real-time feedback in biofeedback systems helps users become more focused on the interaction system [14, 44]. In the context of ingestible games, the real-time feedback seems to help players better understand their body and increase their bodily awareness. Meanwhile, the loss of focus on their body and the decrease in bodily awareness might be a cause of their mind wandering [6]. Therefore, we consider the players' extent of bodily awareness to be "low" when they tend to lose attention of the sensor being present inside their body. In addition, F3 suggests that players might be vigilant when they go to the toilet at the end of Phase 2. We believe this might lead to an increase of bodily awareness in players.

So far, we discussed bodily awareness mostly in regards to the sensor, we now discuss it in regards to the ingestible game design, which includes the sensor and associated game design. For example, F2 (Emotion) and F8 (Social Play) suggest that the game narrative and the social play helped players relax and thus dampened their bodily awareness during Phase 0. F3 (Four Phases) and F6 (Body Interface) indicate that the game tasks motivated players to think about their body and explore the relationships between body temperature and daily activities, which appeared to increase their bodily awareness during Phase 1 and Phase 2. This confirms the theory that bodily exertion leads to increased bodily awareness [40, 44] and we extend it to the design of ingestible games.

In light of the above, ingestible games may be a powerful tool for regulating players' bodily awareness. Fig. 6 represents the change of the player's bodily awareness across the four phases. As with the other figures, it is to be understood as a visual sketch to illustrate how we can understand the player's experience using the ingestible sensor and associated gameplay, rather than a true representation. The blue line represents what we think the extent of bodily awareness affected by the Cortemp sensor would have been if they would have not played the game. We believe that the type of ingestible sensor used might affect the change in bodily awareness across the four phases. For example, the bigger the sensor, the higher the level of bodily awareness could be during Phase 0. The red line represents what we think could be the extent of player's bodily awareness when they played the Guts Game. By drawing these two (which we acknowledge are speculative, yet informed by data), we aim to highlight for game designers how to understand bodily awareness over time when it comes to ingestible sensors and what potential lies in game design to affect this.

Design Strategy 1.1: Consider Designing a Narrative for Regulating Bodily Awareness

Prior work suggests that promoting bodily awareness is important for people [26] while being too aware of the body might cause anxiety [16]. We believe that ingestible game designers should consider gameplay carefully in terms of whether and how to regulate the player's bodily awareness. In the Guts Game, the narrative helped dampen the player's bodily awareness during Phase 0. In particular, researchers dressing up like doctors appeared to help players engage with the sensor-ingesting. This confirms the prior theory that designers may act as characters embedded in the story to engage players. For example, Yule et al. used the role of docents to improve the player experience [56]. Therefore, we recommend designers to consider designing a narrative as a way to regulate bodily awareness.

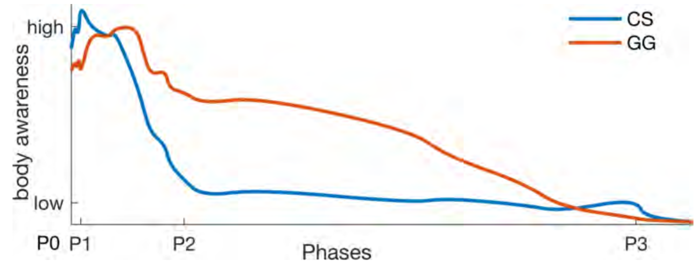


Figure 6: Illustration of the extent of bodily awareness affected by the sensor and the game. CS stands for Cortemp sensor and GG for Guts Game.

Design Strategy 1.2: Consider How Game Feedback Can Regulate Bodily Awareness

In the Guts Game, the players' bodily awareness seemed to decrease at the end of Phase 1. This might be because of the game being played on the mobile phone, which does not produce game output inside the player's body. Previous work suggests that sensory experiences that are perceived inside the body could be better to increase bodily awareness compared to those outside the body [31]. For example, heat stimuli may increase bodily awareness since heat has the potential to permeate the skin and be perceived inside the body [31]. Therefore, we recommend designers to consider how any game feedback can regulate the player's bodily awareness.

Theme 2: Human-Computer Integration

Human-computer integration refers to a partnership between the human and computer, where human and computer tightly integrate [13]. Inspired by this, in our work, we consider the level of human-computer integration as the extent to which the players perceived the sensor as part of their body. F3 (Four Phases), F5 (No Presence), F6 (Body Interface), F7 (Cheating) and F11 (Technology) indicate that players perceived the sensor as part of their body during the game. In addition, any disconnection occurring between the receiver and the Cortemp sensor might make the game less engaging (F11) because the technical problems reminded participants that the sensor was not "really" a part of their body, leading to the breakdown of the "partnership" between the sensor and the user. This also confirms the theory about the body-tool relationship that users may view a tool as an extension of body, but this perception could be interrupted when the tool fails to function [23, 51]. We consider the extent of the sensor-body integration in Phase 1 and 2 as "high", however, this could fluctuate due to such disconnections.

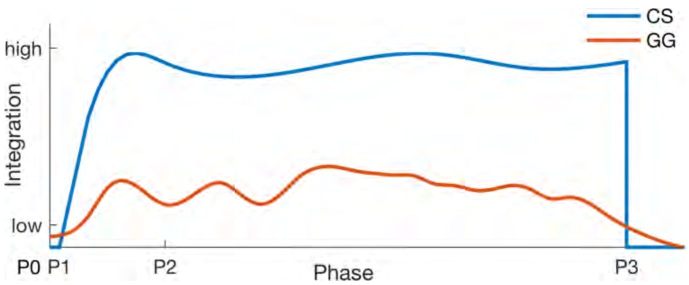


Figure 7: The extent of the sensor/game being part of the body. CS stands for Cortemp sensor and GG for Guts Game.

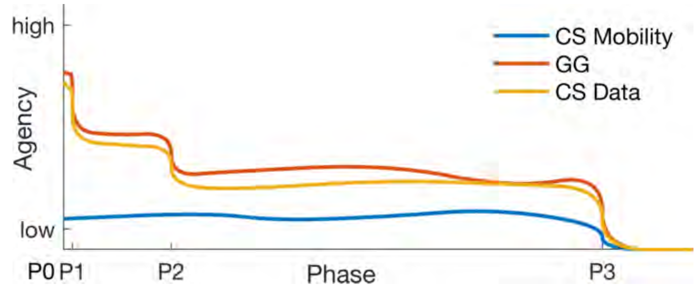


Figure 8: The extent of the agency for the sensor data, sensor mobility and the game perceived by players. CS stands for Cortemp sensor and GG for Guts Game.

With the Guts Game, players played it on the mobile phone, which was not part of their body. Moreover, the game app waited for interactions with players passively, which did not contribute to the "partnership" between players and the game. In addition, having to carry the Cortemp receiver might have led to a feeling of cumbersomeness (F11). Therefore, we consider the extent of game-body integration during the play to be relatively "low". Fig. 7 illustrates this figuratively. The blue line represents the extent of sensor-player integration. The extent is low during Phase 0 and Phase 3 because the sensor is outside the player's body at these two stages. In Phase 1 and 2, the extent may fluctuate due to various reasons such as any disconnection between sensor and receiver. The red line represents the extent of integration between the Guts Game and the player. Again, with this, we aim to highlight for designers the opportunities to change the extent of human-computer integration through game design.

Design Strategy 2.1: Consider Attention Demand to Facilitate Integration

Prior work suggests that insertable device hobbyists might perceive these devices as part of their body [54]. In response to our findings, we extend existing theory to the design of ingestible games and suggest game designers to make players feel like they are playing with their body, leading to the increasing degree of perceived human-computer integration. One way to achieve this is designing "eyes-free" interactions in ingestible games [43]. In the Guts Game, the input data is body temperature measured by the sensor and is eyes-free, however, the output is displayed on the screen of an iPhone. This representation prevents players from engaging in the game when their visual attention is occupied. The game therefore did not make players feel that the game is part of their body "very much". We recommend designers to consider designing alternative outputs beyond the screen with its attention demands. We believe that such a design would help players to improve their perception of the extent to which an ingestible game is part of their body.

Theme 3: Agency

In this article, we regard agency as the level of control that the player perceives to have in a game. F3 (Four Phases) and F4 (Limited Control) suggest that the extent of player's agency may change across the four phases. Here we discuss the players' extent of control over the temperature data and sensor mobility separately as their changes across the four phases are different. Here the sensor mobility refers to the ability of the sensor to be moved through the digestive tract. In the Guts Game, the sensor mobility affects when the game ends.

When it comes to the temperature data, F3 (Four Phases) and F4 (Limited Control) indicate that the extent of player's agency during Phase 0 is high since the temperature data is equal to the environment temperature and therefore players might affect the data easily. For example, some players blew on the sensor to increase the temperature data before they swallowed it. We use PA_x to represent the extent of players' agency during Phase X. As F3 suggests, $PA_3 < PA_2 < PA_1 < PA_0$. When it comes to the sensor mobility, F4 suggests that players might only slightly affect the sensor mobility and therefore the agency during Phase 0-3 is relatively low. The sensor gets excreted by players in Phase 3, and consequently, we say that the player's agency for both the temperature data and sensor mobility during 3 is low. In the Guts Game, players controlled their body (e.g. eating, drinking and exercising) to affect the temperature data and the sensor mobility. From our findings, we believe that the extent of players' agency for their temperature with and without the Guts Game is higher and lower respectively. This is due to the fact that the game gives an end goal to players and provides them with ambiguous visual feedback. While this holds true, we also noted that this task-based gameplay amplifies the feeling of losing control when players do not reach their goal. The end of the game when players excrete the sensor also amplifies their feeling of having limited control over the game.

Fig. 8 shows the extent of the player's agency for the Cortemp sensor data with a blue line, the sensor mobility in red and the Guts Game in yellow. Various types of ingestible sensors measuring different bio-data may affect the trend of the agency as the degree of control over different kinds of bio-data are different [41]. The level of agency for the sensor mobility also depends on the sensor type. For example, the ingestible sensor "PillCam patency capsule" dissolves in the GI tract about 30 hours after being swallowed so that it's mobility is different from that of the Cortemp sensor [47]. The yellow line may be changed by playing with the game design. For example, players usually require a high degree of agency in a first-person shooting game but may appreciate a low extent of agency in bodily games such as digital vertigo games [7].

Design Strategy 3.1: Consider Different Gameplay across the Four Phases

Prior work suggests that players should feel a sense of control over their game actions [52]. We believe that designers should create appropriate game design to match the player's rather low level of agency often caused by ingestible sensors. We noted that the design of adaptive gameplay leads to an engaging experience in games [18, 10]. In the Guts Game, the extents of players' agencies are different in the four phases. For example, our players experienced reduced engagement when their agency decreased during Phase 2. We confirm the theory around adaptive gameplay [18] and extend this concept to the design of ingestible games. In doing so, we suggest designers consider adapting gameplay to respond to the extent of agency experienced by players through the ingestible sensors across the four phases.

Design Strategy 3.2: Consider Communicating the Low Agency to Players

F3 (Four Phases) and F4 (Limited Control) suggest that players can experience disengagement if they cannot reach a particular goal. Many kinds of bio-data such as body temperature and genomic data are difficult for users to control, leading to a feeling of low agency. Prior work has demonstrated the importance of communicating the uncertainty to users when they do not have much control over the data [49]. For example, Joslyn et al. found that including an uncertainty estimate in weather forecasts may retain user trust [32]. We confirm this theory, extend it to the design of ingestible games and suggest designers communicate to players about the agency they may have over the sensor data.

Theme 4: Uncomfortableness

Uncomfortable interactions when managed carefully and ethically may become an important tool for designers, promoting entertainment, enlightenment (possibly in the form of bodily awareness in the context of the Guts Game), and sociality [3]. Uncomfortableness in ingestible games might be caused by violating cultural norms [53]. F2 (Emotion) indicates that players might feel uncomfortable if they are required to swallow a digital sensor, which challenges the social norm of not ingesting inedible devices. Furthermore, F10 (Social Environment) suggests that while some players felt embarrassed to play the game in public, they also liked the attention that they received. Therefore, while ingestible games may fight against the cultural norm to engage players, designers might need to consider designing uncomfortableness in ingestible games.

Design Strategy 4.1: Consider Uncomfortable Interactions in Ingestible Games

We believe that ingestible games might learn from uncomfortable interactions [3]. Although uncomfortableness can be perceived as a negative factor in game experiences [55], many novel games such as "Musical Embrace" have explored how to change uncomfortableness to a positive design aspect [12, 27]. In the Guts Game, players wear the receiver around their waist, visible to the external world. While the receiver may make players uncomfortable, it also served as conversation starter and functioned as social facilitator. We therefore confirm the theory around uncomfortable interaction and extend it to the design of ingestible games. In doing so, we suggest designers consider uncomfortable interactions in their games to facilitate playful experiences. For example, motivating players to experience their body in an uncomfortable way may engage players and make them become more aware of their body.

LIMITATIONS AND FUTURE WORK

In this study, the sensor we used was only able to measure the body temperature, the ability of using other sensor data might enrich our findings further. We see our work not as a complete investigation into ingestible games, but believe that this work could serve as a springboard for future investigations. The findings of this work are largely based on qualitative data. Thus, it would be relevant for future work to empirically validate the proposed strategies. With increasing popularity of ingestible sensors, we expect they become more financially accessible, more reliable and capable of measuring more bodily functions to facilitate playful and engaging experiences. Moreover, this study only investigated the traditional task-based gameplay in ingestible games. In future work, we can explore other novel forms of games with ingestible sensors. For example, we believe that ingestible games without a screen might help players to further experience their body as play.

CONCLUSION

Designing playful experiences around ingestible sensors is an unexplored area. Our work offers the first understanding towards the design of games around ingestible sensors through the design and study of the Guts Game. We argue that the Guts Game provides a compelling example of ingestible games: the work not only puts forward the idea that a playful and engaging experience can be designed when using ingestible sensors but also introduces ingestibles to the game design, which may help us step a bit closer towards the future that promotes to experience our bodies as digital play [15]. This is important because it may engage the human body through games and contribute to a more humanized technological future.

We hope this work also opens up opportunities for interdisciplinary collaborations amongst different fields: medical science, electrical engineering, design and HCI. Medical practitioners could use this work to create better experiences for their patients who need to use ingestible sensors. Engineers could use this work to get an understanding of the kinds of ingestible sensors they may need to develop for non-medical use and how to design playful ingestible sensors. Inspired by this work, designers could use ingestible sensors to facilitate novel and playful experiences. Researchers in HCI could use ingestible sensors to create more playful interactions as a result of this work. Furthermore, our work aims to propose an intriguing new game genre that expands the design space of digital games by introducing ingestible sensors as a novel opportunity for game designers.

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