Ingestible Sensors as Design Material for Bodily Play

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Abstract
Ingestible sensors are pill-like digital sensors performing sensing functions inside the human body. Such technology is becoming increasingly common in clinical uses. However, we believe there exists an opportunity to also investigate ingestible sensors as design material for bodily play to facilitate intriguing bodily experiences. This argument is inspired by a long history of utilizing the intersection of medical technologies and play to bring about intriguing bodily experiences. By designing and investigating the user experience of three playful systems around ingestible sensors, we articulate a preliminary framework showing how ingestible sensors can be used as design material to support the design of playful bodily experiences.

Author Keywords
Ingestible sensors; medical technology; bodily integration; bodily experience; game design; play.

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

Introduction
Ingestible sensors are pill-shaped devices that perform sensing or actuating functions inside the user's body [4].

This technology is becoming increasing common in clinical uses because, compared to traditional medical technologies, ingestible sensors can decrease the physical discomfort in medical examinations, and access more areas of the patient's gastrointestinal (GI) tract [5, 23]. We believe there is a design opportunity to combine ingestible sensors and play to create what we call "ingestible play" in order to facilitate intriguing bodily experiences. This is inspired by the rich history of introducing medical technologies into play to facilitate intriguing bodily play experiences. For example, electric shocks have been used to create painful but playful bodily experiences [7]. Similarly, an ingestible sensor might facilitate intriguing bodily experiences since it literally enters the user's body and collect bodily data which is usually unfamiliar for users.

Ingestible play has many potential benefits. First, ingestible play might make medical examinations more playful and hence improve the patient experience, ultimately benefiting the associated treatment [1, 16]. Moreover, more people might be enticed by the playful experiences to go through ingestible sensor procedures as preventative care, allowing for earlier detection of diseases and contributing to overall health. Ingestible play might also benefit education. Given current media are already teaching bodily knowledge and fostering health awareness [24], we can envision that ingestible play could promote a deeper understanding of the human body through interactive engagement than traditional static and non-personalized video material. In light of these benefits, we believe it is worth exploring the design of ingestible play, and in this article we articulate a framework to reveal how ingestible sensors can be used as design material for bodily play.

Related Work

We approach the understanding of ingestible play from both practical and theoretical perspectives.

Design Practices around Ingestible Play

Although ingestible sensors are rarely explored in HCI design, they have been used in various artworks. Stelarc inserted an ingestible sensor containing a beeping device and flashing light to express his understanding of the human body as "hollow" [21]. Jan Poope designed "Audiopill" which allows the user to experience the music from the inside after swallowing an ingestible sensor [19]. Warnell showed audiences the video captured by an imaging capsule (i.e. an ingestible sensor containing a camera) swallowed by him to highlight the use of internal body pictures beyond medical applications [22]. These art projects highlight the experiential perspective of ingestible sensors and indicate that ingestible play might bring about unique bodily experiences and lead to a deeper understanding of the human body. However, it is still unclear how to design ingestible play.

Theories around Bodily Play

There are also HCI works that investigate the design of bodily play, from which we learn. Current frameworks and conceptualizations related to bodily play usually analyze the design from a technological or bodily perspective. From a bodily perspective, Loke and Robertson [15] presented six concepts of the body for designers to consider the role of the body in design and user interactions. The authors argued that the body can be understood as "anatomy and physiology; expression creative; knowledge; physical skill; felt experience; and social, cultural". Mueller et al. [17] suggested that designers should consider the player's body from two perspectives, i.e., Körper and Leib when designing bodily play. Körper considers the human body from a mate-

Figure 1: The Guts Game uses the animated fire displayed on a mobile phone to visualize the player's body temperature.

Figure 2: HeatCraft supports players experiencing their temperature through localized thermal stimuli via a waist belt.

Figure 3: InsideOut uses a wearable display showing the user real-time video of their GI tract.

rial perspective while Leib highlights the lived perspective. Moreover, Mueller et al. [18] proposed four lenses to understand the human body when designing exertion games: the Responding Body; the Moving Body; the Sensing Body; and the Relating Body. From a technological perspective, Benford et al. [2] proposed a framework highlighting the relationship between physical movements, affordances of sensing technologies, and requirements of applications. Similarly, Rogers and Mueller [20] presented a framework for designing sensor-based play which suggests designers consider the sensor properties, player activities, and how the couplings between player actions and system feedback influence the player experience. However, these frameworks are not dedicated to ingestible play. Learning from these works, we take a technological perspective and approach the understanding of ingestible play from analyzing how the ingestible sensor's characteristics can be used for bodily play in order to facilitate intriguing bodily experiences.

Playful Systems around Ingestible Sensors

We now present three playful systems around ingestible sensors designed by ourselves.

Guts Game

The Guts Game [9, 11] is a two-player mobile game (Figure 1). To play the Guts Game, the player swallows an ingestible sensor measuring temperature in real-time. The Guts Game challenges players with various game tasks including changing the body temperature to a certain degree and guessing the current body temperature. The game also allows players to challenge the co-players with customized temperature goals. Completing a task can increase game scores. In addition, the Guts Game supports players sending twitter-sized messages and pictures to the co-player. The game ends when one of the players excretes the sensor, which is usually within 24-36 hours. The player who gains higher game scores wins the game. The Guts Game has been studied with 14 participants, leading to 12 findings.

HeatCraft

HeatCraft [10, 14] is a two-player system supporting users to experience their body temperature via localized thermal stimuli on the waist (Figure 2). The thermal stimuli's temperature is directly proportional to the player's body temperature captured by an ingestible sensor. We see HeatCraft as a toy for players to explore and play with. Players can enjoy exploring the relationships between daily actions and body temperature. They can also design game rules themselves to enjoy various gameful experiences. We did a user study with 16 participants and articulated 18 findings.

InsideOut

InsideOut [12, 13] is a system where the users playfully interact with the real-time video of their interior body (Figure 3). With InsideOut, the player swallows an imaging capsule and wears a display in front of the body showing his/her GI tract's video in real-time. The player can explore various actions, e.g., eating, drinking and moving, to influence their GI tract. We also designed six mini-games to enrich the play experience and engage players with body movements. For example, we designed "Body Balance" in which the image is mapped to a rolling ball and the player can move his/her body to balance the ball on a springboard. We investigate the player experience of InsideOut with seven participants and articulated 20 findings.

Four Key Characteristics of Ingestible Sensors

We gathered the 50 findings generated from the user studies of the three systems [11, 13, 14] and conducted a thematic analysis [3], aiming to analyze how the character-

istics of ingestible sensors could support bodily play and facilitate intriguing bodily experiences. Two researchers independently coded the data and iteratively clustered them into higher-level groupings until reaching an agreement, which leads to four key characteristics of ingestible sensors: Sensing, Shifting, Symbiotic, and Social. The sensing sensor refers to the sensing ability of ingestible sensors. After being swallowed, ingestible sensors can measure certain kinds of bodily data of the user. The shifting sensor refers to the fact that ingestible sensors move along the user's GI tract after being swallowed. The moving speed depends on the user's digestion rate which can be slightly influenced by ingesting food. The symbiotic sensor highlights that ingestible sensors are always inside the human body after being swallowed. Before excreting the sensor, ingestible sensors are symbiotic with the user's body. The social sensor highlights the affordances of ingestible sensors for social play.

The Ingestible Play Framework

Since we situate this work within bodily play, we borrow the four Fun Keys proposed by Lazzaro: hard fun, easy fun, altered states, and the people factor [8]. Each key represents a set of play experiences, providing motivations for players to play games and showing how designers create emotions for players. In the following sections, we will elaborate on each characteristic of ingestible sensors and discuss how can we utilize this characteristic to facilitate a certain kind of fun key.

The Sensing Sensor & Hard Fun

People enjoy "hard fun" when they achieve personal triumph over adversity. In games, hard fun is associated with game challenges, strategic thinking and problem-solving. Players might experience frustration and "Fiero" with hard fun [8]. In the bodily play context, hard fun is usually related to bodily challenges. We argue that the bodily challenges are closely related to the sensing sensor. In our works, the Guts Game provided players with hard fun by challenging the players to change their body temperature to a certain number. In HeatCraft and InsideOut, we did not set game challenges for players but they spontaneously challenged themselves to change their body temperature or their GI tract view [13, 14].

To support or even amplify the hard fun with the sensing sensor, we suggest designers set game tasks or challenge the player to influence his/her bodily data sensed by the ingestible sensor. Moreover, we suggest designers choose ingestible sensors with measured bodily data that can be influenced by multiple factors. For example, in our works [9, 14], we chose to measure the player's body temperature which can be influenced by the player's body movements, surrounding environments, eating and drinking behaviors. By doing so, players enjoyed exploring how can they change their body temperature and investigating the most efficient way to complete game tasks.

The Shifting Sensor & Easy Fun

Players enjoy "easy fun" when the playful system evokes his/her curiosity. In bodily play, players might experience easy fun with bodily exploration. Through our three case studies, we found that players appreciated the opportunity of exploring their "mysterious" interior body thanks to ingestible sensors. For example, players were interested in exploring their digestion rate and guess when the sensor can be excreted [14]. Players also felt fascinated to see the video of their GI tract since they usually had never seen their own interior body before the study [13]. Moreover, the sensor moves along the player's GI tract, providing opportunities for players to explore different parts of their bodies. For example, players found it intriguing to see the wall of

their stomach was smooth while their small intestines' wall looked more "fluffy".

To support easy fun with the shifting sensor, we suggest designers make use of the entire ingestible sensor procedure for play, letting players explore different parts of their interior body. Both HeatCraft and the Guts Game end when the player excretes the sensor and InsideOut ends when the sensor runs out of battery (which is quicker than excretion due to the power-hungriness of the video camera's flash). Moreover, to support bodily explorations, we suggest designers design always-available play in order to let players know their bodily changes at any time and any place. For example, in HeatCraft, we designed thermal feedback generated on a wearable device, notifying players the changes of their body temperature anytime and anywhere.

The Symbiotic Sensor & Altered States

Altered States means that players enjoy their internal state changes during and after play. This key of fun highlights that play produces emotions and other internal sensations such as excitement and relief by influencing the player's perception, behavior and thought. When it comes to bodily play, altered states is often caused by the changes of players' bodily behaviors, perceptions, and experiences. We found that the symbiotic sensor has the potential to support altered states by facilitating intriguing and playful bodily experiences. First, since the ingestible sensor is physically integrated into the user's body, some players felt themselves as being cyborgs. Second, by letting players know their bodily data which they would not have known without ingestible sensors, players reported that they felt they were superheroes since the system extended their capabilities pervasively. Third, by adding localized sensations to the interaction loop, players might behave and perceive their bodies differently. For example, in HeatCraft, players' decreasing body temperature could lead to more intense thermal stimuli, resulting in some players reporting that they drank some ice water in order to warm them up in the winter. Forth, the symbiotic sensor could evoke the player's emotion changes. For example, players might feel nervous to swallow a digital sensor before the play, feel anxious during the play periodically, and feel relief after the play. Certain design choices might mediate the players' emotions evoked by the sensor. For example, we designed game narratives in the Guts Game before swallowing the sensor, which made players feel less nervous [9].

To support altered states via the symbiotic sensor, we suggest designers consider using localized sensations as feedback in ingestible play. By doing so, the ingestible play system has the potential to extend the player's capability continuously. Moreover, because of the intimacy of localized sensations, ingestible sensors could facilitate a symbiosis relationship with the player's body, leading to intriguing bodily perceptions and playful behaviors. We also suggest designers consider the player's emotion changes throughout the play. For example, to cope with the player's anxiety before swallowing the ingestible sensor, designers can design interesting game narratives to help players relax.

The Social Sensor & The People Factor

The people factor highlights that many people enjoy playing with others inside or outside the game. Players not only enjoy the social interactions through in-game chat, but also love the cooperative and competitive play with other players. Some people even play games that they do not like because of social interactions [8]. In ingestible play, almost all the players reported that they enjoyed the social play. Both Guts Game and HeatCraft are two-player systems. The Guts Game lets players compete with each other and supports players sending in-game messages and pictures

to each other. HeatCraft encourages collocated play and players can experience the co-player's body temperature by touching the co-player's wearable belt. Although InsideOut is a single-player system, it allows spectators to see the player playing and interact by tapping the display worn by the player. Players reported that social interactions in ingestible play could 1) motivate them to swallow the digital sensor and let them feel more relaxed; 2) enrich their play experiences; 3) facilitate spontaneous play; 4) gain more bodily knowledge by comparing the play experiences with the co-player; and 5) feel more connected with the co-player because of the intimate bodily data sharing.

To support the people factor, we suggest designers enable social fun in ingestible play. Enabling players to compete with each other by changing their bodily data sensed by ingestible sensors might facilitate bodily challenge, while encouraging players to collaborate might facilitate bodily explorations, leading to gained bodily knowledge. Supporting players to communicate with each other and show others their bodily data might bond the players more closely. Designers should also be aware that social contexts might influence play experience in ingestible play. This is because the player's social context might change during the play as ingestible play usually lasts for 8-36 hours depending on the sensor's battery life and players' digestion rate. In the Guts Game, two players reported that they thought taking game actions such as jumping looked silly since spectators could not know that they were playing a game due to the sensor being inside their bodies, invisible to others. In InsideOut, players might feel uncomfortable showing their private bodily data to the public. In our design, we see the discomfort as an opportunity to provoke players' reflections on the technology and their body. Meanwhile, we also provide options for players to avoid the discomfort. The Guts Game did not set time limits for completing tasks, hence players could take actions when they felt comfortable while InsideOut has a button allowing players to hide the video. Therefore, we suggest designers be aware of the potential influences of social contexts on play experience in ingestible play.

Limitations

We acknowledge the limitations of this work. First, investigating the design affordances of other kinds of ingestible sensors [6] might enrich our findings. Second, more design practices might enhance this framework. Third, we acknowledge that the four characteristics of ingestible sensors and the four fun keys are not one-to-one corresponding relations. For example, the sensing sensor not only can bring about hard fun, but also can facilitate easy fun if we design the feedback to be aesthetic and ambiguous. In the future, we will articulate how each characteristic of ingestible sensors can support the four fun keys to improve this framework. Moreover, based on the theory of bodily play [8, 17, 18] and our proposed four characteristics of ingestible sensors, we can articulate more design tactics in the future, which could make the framework more complete.

Conclusion

This article presents an initial framework detailing how ingestible sensors can be used as design material to facilitate intriguing experiences in bodily play. The framework is generated based on the authors' craft knowledge from designing three playful systems around ingestible sensors and the associated user studies. We believe this framework could help designers design future engaging bodily experiences around ingestible sensors. More broadly speaking, this work expands the range of bodily play experiences by introducing ingestible sensors into play.

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