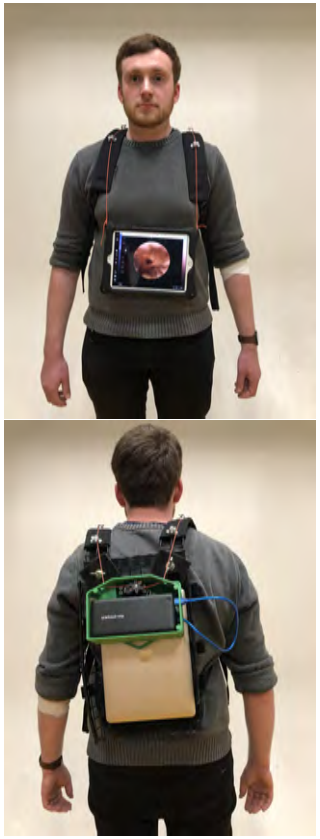

Figure 1: The front and back view of InsideOut. While playing, the player wears an iPad in the front and a backpack containing a data recorder and a MacBook.

InsideOut: Playing with Real-time Video Images of the Gastrointestinal Tract via Imaging Capsules

Zhuying Li
Exertion Games Lab
RMIT University, Australia
zhuying@exertiongameslab.org

Stefan Greuter
Deakin University
Melbourne, Australia
stefan.greuter@deakin.edu.au

Jacob Sheahan
Exertion Games Lab
RMIT University, Australia
s3491510@student.rmit.edu.au

Florian 'Floyd' Mueller
Exertion Games Lab
RMIT University, Australia
floyd@exertiongameslab.org

Yan Wang
Exertion Games Lab
RMIT University, Australia
yan@exertiongameslab.org

CHI PLAY EA'19, October 22–25, 2019, Barcelona, Spain

ACM ISBN 978-1-4503-6871-1/19/10.
https://doi.org/10.1145/3341215.3356291

Abstract

An imaging capsule is a pill-shaped device used to record images of the user's gastrointestinal tract. Existing research mainly focuses on the imaging capsule's functional perspective, while its experiential perspective is usually overlooked. To explore this, we introduce a playful system called InsideOut where the player wears an iPad to display the real-time images of their gastrointestinal tract captured by an imaging capsule. Players can interact with the images by performing bodily movements which are mapped to image transformations such as rotation and scaling. With this work, we aim to inspire game designers and researchers to design playful and engaging experiences around imaging capsules. Our work might further inspire future works using other bodily-integrated technologies to facilitate playful experiences.

Author Keywords

Ingestible sensors; imaging capsules; capsule endoscopy; bodily integration; game design; play.

CCS Concepts

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

Introduction

An imaging capsule is a pill-shaped digital sensor. After being swallowed, the imaging capsule takes a number of pictures per second as it passes along the user's gastrointestinal (GI) tract usually within 24-36 hours. Imaging capsules have the potential to greatly benefit health and clinical areas [16] and to replace the conventional endoscopes in the near future [14]. The conventional endoscopes are relatively invasive since they are inserted into the oral or rectal orifices and might cause discomfort or even pain [14]. Moreover, the rigidity of the conventional endoscope limits access to many areas of the intestines. Thanks to advancements in technology, these problems might be relieved with the emergence of imaging capsules [33].

We note that existing research around imaging capsules mainly focuses on their functional perspective, such as utility and technological advancements. For example, Idden et al. [14] introduce the imaging capsules' design and function; Swain [33] describes their mechanism and clinical values; Li et al. [20] overview their main types and applications. However, the experiential perspective of imaging capsules is usually overlooked.

We believe that there is an opportunity to explore the experiential perspective of imaging capsules. Studies in human-computer interaction (HCI) highlight that appreciating a body-centred technology's experiential perspective may help users deepen their understanding and engagement with their own bodies [34]. In addition, recent works suggest that medical services, including endoscopy procedure, should support patients from both a medical and experiential perspective [13, 25]. Therefore, we believe that there is an opportunity to look into the experiential perspective of imaging capsules. In this work, we explore this opportunity via designing engaging digital play experiences. Hence, we ask:" *How can we design playful experiences around imaging capsules?*"

Figure 2: An iPad is worn by the player showing the images captured by the imaging capsule.

To explore this, we present a playful system called "InsideOut" (see Figure 1) where we use an iPad worn by the players to show their real-time GI tract images captured by an imaging capsule (see Figure 2). While playing, players interact with the images by performing different body movements, which are mapped to various 2D transformations to the images like scaling and rotation. Moreover, we designed six mini-games to enrich the play experiences. These games are unlocked sequentially during a play session. We believe InsideOut could bring about novel and playful bodily experience, and help the players better understand and engage with their own bodies.

This article begins by presenting related works in the field of interactive art and HCI around imaging capsules, then describes the system InsideOut and the proposed user study. Our work aims to inspire game designers and HCI researchers to design playful experiences around imaging capsules.

Opportunity of Playing with Imaging Capsules

Imaging capsules have been used by artists to express their understanding of the human body and facilitate intriguing experiences for the audiences. For example, the artist Phillip Warnell underwent a live endoscopy procedure using an imaging capsule [35]. The artist argues that this work raises awareness of how GI tract images can be evaluated beyond medical applications [27]. Deep Throat is another art installation that exposes the audiences to the inner appearance of the digestive tract [17]. The installation consists of a dining setting with the endoscopic video projected on to the plate. Corps étranger [2] is another artwork using an endoscopic camera showing the artist's ex-

terior and interior body in turn. The video is projected on the floor of a cylindrical structure which the viewer enters, accompanied with a soundtrack broadcasting heartbeat. This work aims at showing the viewer the unknown parts of the human body and motivating reflections on the violent appropriation of contemporary imaging technologies [31]. These artworks demonstrate the opportunity of exploring the experiential aspects of imaging capsules.

Researchers in medical anthropology and phenomenology argue that seeing the images of the GI tract could mediate the experience of one's own body [11, 31]. For most people, the view of their GI tract is mysterious although they might know the appearance of a GI tract from books, magazines, and TVs. Technologies like imaging capsules allow the users to look into their own living bodies and turn their body interior into an observable surface [31]. Through the view of the inside human body, the viewer could overcome the foreignness and become more aware of their own bodies, leading to deeper body consciousness and therefore improving their well-being [10]. Thus, we believe supporting players in playing with their GI tract images could facilitate intriguing bodily experiences and inspire them to reflect on the understandings of their own bodies.

Existing Related Research

Prior studies in HCI have explored the design of playful experiences around ingestible sensors [22, 23]. Ingestible sensors are digital sensors performing sensing or actuating functions inside the human body [6]. Hence, imaging capsules can be seen as a kind of ingestible sensors [16]. Therefore, we believe that this work can learn from prior studies that explore the design of playful experiences around ingestible sensors.

Similar to imaging capsules, ingestible sensors have also been used in a variety of art projects. For example, Stelarc developed an ingestible sensor containing a beeping device and flashing light and inserted it into his own body. The idea behind Stelarc's art project is to challenge the traditional role of the human body, showing that our body is "hollow" and could be turned into a public space that can exhibit sculptures [32]. The Czech artist Jan Poope designed an audio pill supporting people to experience music's beat "from the inside" [28].

Inspired by these art projects, HCI and game researchers began to explore the affordances of ingestible sensors in digital play. Li et al. [19, 22, 21, 23] designed two games using an ingestible sensor to measure the player's body temperature. In the first game, called "Guts Game", the players play against each other by changing their body temperature to complete a variety of game tasks [19, 22]. The second game, called "HeatCraft", support two players to experience their body temperature via localized thermal stimuli delivered through heating pads [21, 23]. The two projects demonstrate the possibility of using ingestible sensors in digital play and provide insights on how to design playful experiences around ingestible sensors. As the technology and the body is "integrated", the play might be integrated into the player's daily lives and therefore facilitate ubiquitous play [23]. Moreover, playful systems around ingestible sensors might support moving from experiencing the body as a mere controller to experiencing the body as play, which could deepen the players' understanding and engagement with their bodies [23, 26].

We believe our project could further the current understanding of playful experience design around ingestible sensors by exploring the experiential perspective of imaging capsules. To address this, we developed a playful system called InsideOut, which we explain below.

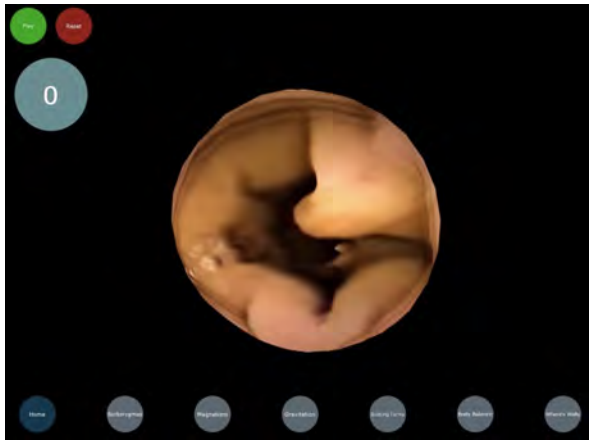

Figure 3: The interface of InsideOut. The green and red buttons on the top left corner are "play" and "reset." The number shown in the juniper green circle on the top left represents how many games have been unlocked. Players can select an unlocked game to play by tapping a circle on the bottom of the interface.

InsideOut

InsideOut (see Fig 1) is a playful system that enables players to interact with the real-time images of their GI tract captured by an imaging capsule. While playing, the player wears an iPad in the front and a backpack containing a data recorder and a MacBook. The working of the system is as follows.

Capturing the images of the GI tract

With InsideOut, images of the player's GI tract are captured by an OMOM® imaging capsule [15]. The capsule takes photos and transmits the images to a data recorder through a wireless transceiver module when the imaging capsule travels through a user's GI tract. The data recorder then processes, displays and stores the images in real-time. The OMOM® imaging capsule is TGA and CE approved and has been used on over 1 million subjects [20]. The play with InsideOut starts when the player swallows the OMOM® imaging capsule and ends when the player excretes the capsule or when the capsule runs out of battery, which is after ca 12 hours.

Displaying the images

We use a MacBook connected to the OMOM® data recorder via a USB cable to collect the images and stream them into the Touch Designer software [8] for composing and interactivity. The transformed images are transmitted to an iPad wirelessly. The MacBook and an assorted power bank are put in the backpack worn by the player. The iPad is attached to the front straps of the backpack.

Positioning the iPad for image display

We place the iPad in front of the user's chest. As the play progresses, the iPad drops from the player's chest to their belly to mimic the movement of the imaging capsule inside the human body. To achieve this, we use an Arduino Mega to control the length of the strings connected between the backpack and the iPad in order to change the iPad's position. We believe that this changing position of the iPad might bring about engaging play experiences. First, the iPad is very close to the player's skin under which hides the player's GI tract. Therefore, it might create a feeling that the skin becomes transparent and the body boundary is blurred, which might facilitate engaging experience when playing with ingestible sensors [23]. Second, wearing the iPad in front of the body does not hinder the player's movement, and the player can easily lower his/her head to view the screen at any time, which is good for facilitating always-available play. Third, this position allows other people around the player to see the images on the iPad screen. Players can also invite others to interact with the system,

Figure 4: The interface of Borborygmus.

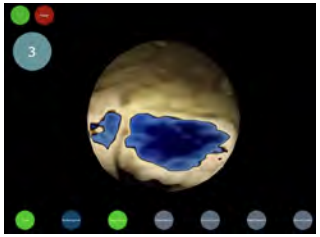

Figure 5: The interface of Magnetism.

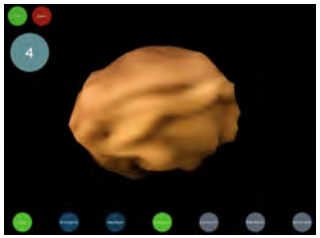

Figure 6: The interface of Gravitation.

which may facilitate a playful experience of fellowship [24]. Meanwhile, it might also result in uncomfortable interactions through intimacy [3]. The discomfort might inspire the players to reflect on the dark themes of modern technologies [12]. We also acknowledge that in certain occasions, the player might not want others to see the images. Hence, we designed a "Hide" button. Once it is pressed, the iPad screen is turned dark.

Transforming images based on body movements
Figure 3 shows the interface displayed on the iPad. If the player is not moving the body, the iPad displays the original images captured by the imaging capsule without modification. If the player performs body movements such as rotation and shaking, the movements are sensed via accelerometer embedded in the iPad, transmitted to the MacBook via Open Sound Control (OSC) [1], and mapped to 2D image transformation like rotation and scaling via *Transform Top* [9]. In this way, the player can interact with the images in real time.

We use body movements as the primary interaction mode to engage the player's body as much as possible. The accelerometer measures the player's body movements including translation and rotation in any direction. Thus, the player can explore the full range of body movements to interact with the images. We believe this could make the player become more aware of their body movements. As such, bodily actions hopefully become a part of the play experience rather than a means to control the images [26]. This might deepen the player's understanding of their own body by building a relationship between their bodily actions and the interior body [23].

Mini-games to enrich play experiences
To enrich the play experiences, we additionally designed six mini-games for players. The games are unlocked sequentially every 1.5 hours. Once a mini-game becomes available, the player is notified by a vibration and bell sound from the iPad, and visual instructions are shown on the screen, indicating how players can play the mini-game.

We designed these mini-games for two reasons. First, encountering a new mini-game might bring about a surprising experience, which is a crucial part in games to facilitate pleasurable experiences [30]. Second, prior studies [22] suggest that the player might experience reduced engagement after a period of time when playing with ingestible sensors. Considering that the play session of InsideOut might last about 12 hours, we believe that designing these mini-games could motivate players to explore the interactions and therefore heighten engagement during the play.

Here is the list of mini-games:

- Borborygmus: the image moves on the display based on the player's movements, and if it touches certain areas, as signified by four arcs on the screen (see Figure 4), a rumbling sound is generated. We designed this game to provide a multi-sensory playful experience to increase the player's immersion with the system [18].
- Magnetism: a filter overlays the footage; the filter's threshold is controlled by the magnetic field strength surrounding the player (see Figure 5). This game is designed to make players become more aware of their surrounding environment, hence facilitating positive play experiences with ingestible sensors, as prior work [23] suggested.
- Gravitation: the gravitational acceleration and body acceleration are visualized through the augmentation of a 3D model of the images (see Figure 6). This game is designed to motivate the players to reflect on

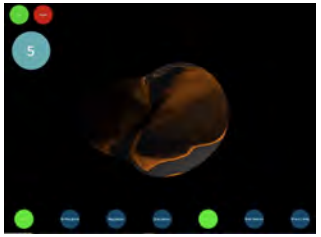

Figure 7: The interface of Bloating Moves.

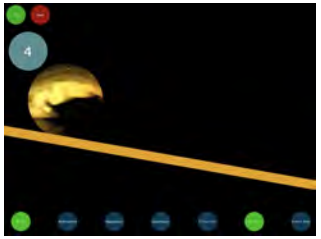

Figure 8: The interface of Body Balance.

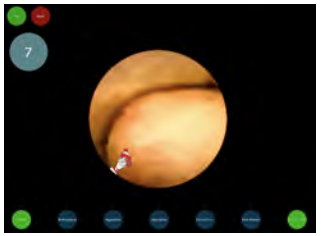

Figure 9: The interface of Where's Wally?.

the relationships between their body and the environment [23].

- Bloating Moves: the player's movements affect the form of the images (see Figure 7). We designed this game to create a playful fantasy experience [24] to motivate players to imagine how the shape of their GI tract might change as a response to their body movements. This might contribute to positive game experience and facilitate players reflecting on how can they treat their bodies better through physical activities [23].
- Body Balance: the round camera image needs to be balanced on a lever through the player's movements or else it will fall off the lever's edge (see Figure 8). The design of this game is inspired by [5] which demonstrates that balancing could be a resource for creating engaging bodily play experiences.
- Where's Wally?: the player searches their digestive image for hidden gems (see Figure 9), identifying them results in sound effects. This game is inspired by the puzzle books "Where's Wally?" which is considered engaging as it involves a problem-solving process [7] and therefore might facilitate playful experiences of exploration, challenge and completion [24].

Proposed Study

To understand the associated user experience, we will recruit participants to experience the proposed system InsideOut. Participants will be invited to our lab to swallow an OMOM® imaging capsule and put on the system. Then they are allowed to leave the lab and experience the system in a real-world setting [29]. After the play session, the participants will be asked about their experience in semi-structured interviews. Thematic analysis will then be used to understand the interview data [4]. Design themes will be generated and later be used to articulate design strategies to guide the future designs of playful and engaging experiences around imaging capsules.

Conclusion

In this article, we present a playful system InsideOut that enables players to interact with the real-time images of their GI tract captured by an imaging capsule. We believe this work can bring about intriguing opportunities for digital play by introducing imaging capsules to the field. Ultimately, this might inspire future works using bodily-integrated technologies to facilitate a broader range of play experiences.

Acknowledgement

We would like to thank Prof. Finlay Macrae and Ms Stephanie Mei Shi Quah from the University of Melbourne for their insights on this project. Thanks also to Cellmed Pty Ltd (Australia) and Jinshan Science & Technology (Group) Co., Ltd (China) for their support.

REFERENCES

1. 2019. Open Sound Control. `http://opensoundcontrol.org/introduction-osc`. (2019). Accessed Jul 5, 2019.
2. Frédérique Baumgartner. 2019. Corps étranger. `http://www.newmedia-art.org/cgi-bin/show-oeu.asp?ID=150000000007761&lg=GBR`. (2019). Accessed Jul 5, 2019.
3. Steve Benford, Chris Greenhalgh, Gabriella Giannachi, Brendan Walker, Joe Marshall, and Tom Rodden. 2012. Uncomfortable Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 2005–2014.

4. Virginia Braun and Victoria Clarke. 2006. Using Thematic Analysis in Psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101.

5. Richard Byrne, Joe Marshall, and Florian Mueller. 2016. Balance Ninja: Towards the Design of Digital Vertigo Games via Galvanic Vestibular Stimulation. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. ACM, New York, NY, USA, 159–170.

6. Colm Mc Caffrey, Olivier Chevalerias, Cian O'Mathuna, and Karen Twomey. 2008. Swallowable-Capsule Technology. *IEEE Pervasive Computing* 7, 1 (Jan 2008), 23–29.

7. Jen-Wei Chang and Hung-Yu Wei. 2016. Exploring engaging gamification mechanics in massive online open courses. *Journal of Educational Technology & Society* 19, 2 (2016), 177–203.

8. Derivative. 2019a. Derivative TouchDesigner. `https://www.derivative.ca/`. (2019). Accessed Jul 5, 2019.

9. Derivative. 2019b. Transform TOP. `https://www.derivative.ca/wiki088/index.php?title=Transform_TOP`. (2019). Accessed Jul 5, 2019.

10. Elisabetta Di Stefano. 2018. Cosmetic Practices: The Intersection with Aesthetics and Medicine. In *Aesthetic Experience and Somaesthetics*. Brill, 162–179.

11. Joseph Dumit. 2009. Visions of Illness: An Endography of Real-Time Medical Imaging by Maud Rastake. *Medical Anthropology Quarterly* 23, 3 (2009), 350–351.

12. Colin M. Gray, Yubo Kou, Bryan Battles, Joseph Hoggatt, and Austin L. Toombs. 2018. The Dark (Patterns) Side of UX Design. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 534, 14 pages.

13. Ruth Sancho Huerga, Jennifer Lade, and Florian Mueller. 2016. Designing Play to Support Hospitalized Children. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. ACM, New York, NY, USA, 401–412.

14. Gavriel Iddan, Gavriel Meron, Arkady Glukhovsky, and Paul Swain. 2000. Wireless capsule endoscopy. *Nature* 405, 6785 (2000), 417.

15. JinShan. 2019. OMOM Capsule Endoscopy. `http://english.jinshangroup.com/capsuleendoscopy.html`. (2019). Accessed Jul 5, 2019.

16. Kourosh Kalantar-zadeh, Nam Ha, Jian Zhen Ou, and Kyle J. Berean. 2017. Ingestible Sensors. *ACS Sensors* 2, 4 (2017), 468–483. `DOI: http://dx.doi.org/10.1021/acssensors.7b00045`

17. Meredith Kooi. 2010. Some Art to Look at Today: Mona Hatoum. `https://meredithkooi.us/2010/09/25/some-art-to-look-at-today-mona-hatoum/`. (2010). Accessed Jul 5, 2019.

18. Martijn J.L. Kors, Gabriele Ferri, Erik D. van der Spek, Cas Ketel, and Ben A.M. Schouten. 2016. A Breathtaking Journey. On the Design of an Empathy-Arousing Mixed-Reality Game. In *Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '16)*. ACM, New York, NY, USA, 91–104.

19. Zhuying Li, Felix Brandmueller, Florian Mueller, and Stefan Greuter. 2017. Ingestible Games: Swallowing a Digital Sensor to Play a Game. In *Extended Abstracts Publication of the Annual Symposium on*

Computer-Human Interaction in Play (CHI PLAY '17 Extended Abstracts). ACM, New York, NY, USA, 511–518.

20. Zhaoshen Li, Dan Carter, Rami Eliakim, Wenbin Zou, Hao Wu, Zhuan Liao, Zhaotao Gong, Jinshan Wang, Joo Won Chung, Si Young Song, Guohua Xiao, Xiaodong Duan, and Xinhong Wang. 2014. *The Current Main Types of Capsule Endoscopy*. Springer Netherlands, Dordrecht, 5–45.
21. Zhuying Li, Weikang Chen, Yan Wang, Ti Hoang, Wei Wang, Mario Boot, Stefan Greuter, and Florian 'Floyd' Mueller. 2018a. HeatCraft: Playing with Ingestible Sensors via Localised Sensations. In *Proceedings of the 2018 Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts (CHI PLAY '18 Extended Abstracts)*. ACM, New York, NY, USA, 521–530.
22. Zhuying Li, Rakesh Patibanda, Felix Brandmueller, Wei Wang, Kyle Berean, Stefan Greuter, and Florian Mueller. 2018b. The Guts Game: Towards Designing Ingestible Games. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY '18)*. ACM, New York, NY, USA.
23. Zhuying Li, Yan Wang, Wei Wang, Weikang Chen, Ti Hoang, Stefan Greuter, and Florian Floyd Mueller. 2019. HeatCraft: Designing Playful Experiences with Ingestible Sensors via Localized Thermal Stimuli. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19)*. ACM, New York, NY, USA, Article 576, 12 pages.
24. Andrés Lucero, Evangelos Karapanos, Juha Arrasvuori, and Hannu Korhonen. 2014. Playful or Gameful?: Creating Delightful User Experiences. *interactions* 21, 3 (May 2014), 34–39.
25. Deborah Lupton. 2013. The digitally engaged patient: Self-monitoring and self-care in the digital health era. *Social Theory & Health* 11, 3 (01 Aug 2013), 256–270.
26. Florian Mueller, Richard Byrne, Josh Andres, and Rakesh Patibanda. 2018. Experiencing the Body As Play. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, Article 210, 13 pages.
27. Andi Nahmias. 2010-2011. Phillip Warnell. `http://istanbulmuseum.org/artists/phillip%20warnell.html`. (2010-2011). Accessed Jul 5, 2019.
28. Jan Poope. 2015. Audiopill. `http://www.audiopill.net/en/`. (2015). Accessed Jul 5, 2019.
29. Yvonne Rogers. 2011. Interaction Design Gone Wild: Striving for Wild Theory. *interactions* 18, 4 (July 2011), 58–62.
30. Jesse Schell. 2014. *The Art of Game Design: A book of lenses*. AK Peters/CRC Press.
31. Jenny Slatman. 2007. *Recognition beyond Narcissism: Imaging the Body's Ownness and Strangeness*. Palgrave Macmillan UK, London, 186–204.
32. Stelarc. 2019. Stomach Sculpture. `https://stelarc.org/?catID=20349`. (2019). Accessed Jul 5, 2019.
33. Paul Swain. 2003. Wireless capsule endoscopy. *Gut* 52, suppl 4 (2003), iv48–iv50.
34. Jakob Tholander and Stina Nylander. 2015. Snot, Sweat, Pain, Mud, and Snow: Performance and Experience in the Use of Sports Watches. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems (CHI '15)*. ACM, New York, NY, USA, 2913–2922.

35. Phillip Warnell. 2006. Endo Ecto.
http://www.phillipwarnell.com/Performance.
(2006). Accessed Jul 5, 2019.