Limited control over the body as intriguing play design resource

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Interest in combining interactive play and the human body, using “bodily play” systems, is increasing. While these systems primarily prioritize a player’s control over their bodily actions, we see intriguing possibilities in the pursuit of “limited control over the body” as an intriguing design resource for bodily play systems. In this paper, we use three of our bodily play systems to illustrate how designers can engage with limited control over the body by varying the player’s degree of indirect control (for instance, via other bodily activity and external triggers). We also propose four strategies for employing limited control over the body: Exploration, Reflection, Learning and Embracement. We hope our own work and the strategies developed from it will assist designers to employ limited control over the body, ultimately helping people benefit from engaging their bodies through play.

CCS CONCEPTS • Human-centered computing → Interaction design

Additional Keywords and Phrases: Bodily play, games, play, control, exertion, whole-body interaction

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1 INTRODUCTION

Control is a key element in games; without it most games become non-interactive stories, on which, and in which, players have no influence [21]. Games in which the player’s body has a more prominent role – compared to mouse and keyboard or gamepad games –, such as motion-sensed console games, virtual reality games or outdoor pervasive games are no exception (e.g. [27, 73, 76, 89, 105, 137]). The HCI field increasingly uses sensor advances to capture bodily action – by which we mean actions, in our case detected by sensors, that involve movement of parts of the body other than the brain [1] – as game/play input, and these bodily play systems demand a level of *control over the body*. This control over the body speaks to a congruency between intention and action, referring to a sense of agency, the “experience of initiating and controlling a [motor] action” [11]. The concept of control in play and games is complex and has been discussed extensively (e.g., [49]); particularly the question of how much player control is needed for an activity/experience to constitute a game (e.g., [144]). The concept is made more complex because it is used to articulate a wide range of other play aspects; for example, using control to articulate the experience of players dominating other players [72].

While we acknowledge these complexities, we intend to produce practical design knowledge and, consequently, in this article, we take a pragmatic approach to using the term control. Our approach to control also contrasts with conventional approaches to bodily play experiences that have greater bodily control as their primary interest. Our work is also different to research on games for people with disabilities as we consider the limitations of control of one body, rather than any differences between bodies. Furthermore, we acknowledge that all bodily play systems draw on a limited extent of bodily control. If a player had perfect control over their body, there would be no bodily challenge (e.g., [9, 49]). We focus on systems where players usually experience

a more limited degree of bodily control, rather than the more common bodily play systems that allow players conscious motor control over a particular game input. Using such a demarcation to introduce a research area is not new. For example, Mueller et al. used it to compare the physical effort required by exertion interfaces with that required by traditional interfaces [88, 89].

In this article, we are interested in players' experiences of control over the body during bodily play. We find that most contemporary bodily play systems assume a high degree of bodily control, which the game uses as input (e.g., [19, 101, 148]); for instance, tracking arm movements as input to control the movements of a character on screen.

In contrast, our design practice indicates that bodily play systems can also benefit where they consider opportunities for players to experience a limited degree of control over the body, particularly where bodily actions are used as game/play input. One identified opportunity is to leverage heart rate (e.g., [28, 77, 121, 141]). While players have limited extent of control over their heart rate, especially when compared to traditional input methods, this does not mean they have no sense of control. Rather, players can indirectly control their heart rate through other bodily activity, such as exercise or meditation [128], or by employing external triggers, such as exposing themselves to something surprising [44].

With sensors that can capture bodily actions widely available and affordable, we believe now is the time to investigate the potential of limited control over the body, beyond heart rate, as a design resource for bodily play. Our work therefore speaks to the field of embodied interactions that has previously argued that HCI should pay more attention to the human body [23]. In particular, we are inspired by prior work that has argued we should "experience the body as play" rather than regarding the human body as a mere controller [94]. In this article, we focus on unconscious bodily processes and leave the restriction of body movements, which can also result in limited control over the body, for future work.

We reflect on our practice of engaging with the experience of limited control over the body in games and play beyond heart rate. Specifically, we reference three of our bodily play systems, that focus upon the limited control over the body of digestion, balance, and breathing, in order to articulate how game designers can achieve three outcomes: first, increased awareness of limited control over the body; second, reductions in limited control over the body; and third, changes to practices around limited control over the body activities. Using our craft knowledge and our bodily play system studies, we also present design strategies for engaging, playful experiences through limited control over the body broadly speaking about: Exploration, Reflection, Learning and Embracement.

This work aims to make contributions to theoretical and practical knowledge, as well as to individual, social and cultural (through advancing play for its own sake) wellbeing. This article contributes to the field's current understanding of the design of control in games and playful experiences, specifically regarding limited control over the body in bodily play. By more richly conceptualizing how game designers can utilize limited control over the body as an intriguing play design resource, we aim to encourage an expansion to the available range of bodily play systems. This expansion will, in turn, allow more players to creatively and beneficially engage with their bodies: for entertainment [70, 74]; to improve their physical and mental health [37, 51, 68]; to enhance their bodily intelligence [32]; and for personal growth [110].

Our work also provides interaction designers with guidance on how to extend their existing designs around the body, such as wearables, with aspects of limited control over the body and play. Furthermore, our work provides HCI researchers with a language for discussing bodily control limitations when analyzing interactive

technology. Our work might also be a source of inspiration to sports researchers hoping to incorporate digital play components into existing practices around bodily control limitations, such as injury prevention exercises, and rehabilitation. Although we do not yet present a final theory, we believe that we offer an interesting point for moving forward that can serve as inspiration and guidance for future work.

Our key contributions are four strategies for employing limited control over the body, derived from prior work and three of our own bodily play systems. They are: Exploration, Reflection, Learning and Embracement. These strategies are complemented by a set of opportunities for each that hopefully aid designers who aim to venture in the field.

2 RELATED WORK

Our initial investigations into limited control over the body and digital game and play design focused mostly on prior work on the experience of control, especially in play and games [49], biofeedback in games [119], exertion games [83, 84, 86, 91, 93, 95, 97-100, 105, 114] and whole-body interactions [78, 145].

Consistent with our interest in the *experience* of limited control over the body, we draw upon work examining the experience of control in HCI. Recent work has more finely unpacked the experience of control in body-centric computing [92]. Limerick et al. [69] call "the experience of controlling both one's body and the external environment" a "sense of agency". This sense of agency is an important part of human consciousness more generally, and a fundamental aspect of self-awareness [29]. Agency has also been discussed extensively in the games and play literature. For example, Rigby et al. refer to agency as "the capacity or state of acting, or of exertion power", and as relating to "who is responsible for the action taking place" [132]. While we do not go into more details here on the complex topic of agency and control, we point out that "there is a relationship between control and agency" [69], especially insofar as agency can be understood along a continuum or spectrum, and measured by degree, rather than by using a binary "'me' vs. 'not me'" [69]. This understanding aligns with our approach to bodily control as moving along a spectrum, whereby players can have varying degrees of bodily control, ranging from "a lot" to "(almost) none".

Nitsche points out that designers need to consider different spaces when designing for control [122]: a designer can make a game challenging to control in the virtual space (for example, through a complex control schema), or in the physical space. In the physical space, designers can engage with the human body and the limitations to control it (such as heart rate discussed above) or the controller (for example, through a hard-to-use input device [49] like adding liquids to a touchscreen [79]). In this article, we begin with the human body but highlight the opportunity to engage with limited control across these different spaces, facilitating interesting combinations thereof.

Biofeedback research has also investigated the role of control, especially as it relates to bodily sensor data (e.g., [59, 120]). Many of these investigations investigated what physiological measures can be used to research gameplay (e.g., [55]). Instead, our work comes from a perspective of how game designers can utilize limited control over the body in their game design practice. Furthermore, biofeedback research mostly differentiates between "direct" and "indirect" control; defining them in a binary way: as "measures that a user can manipulate and control directly", and measures that are "explicitly influenced" [120]. While we also look at indirect means of bodily control, we focus on the experience of different *degrees* of that control.

Prior work into the degree to which users can control sensors around their bodies [7, 134, 138] and into limited control over the body using breathing sensors [38, 75, 140] has helped us understand how varying the

degrees of control over interactions can shape different experiences of reflection and exploration [134]. We have adopted these terms (reflection and exploration) in two of our design strategies because we found them also pertinent to our focus on bodily play.

We are also inspired by biofeedback work that has been used in order to guide bodily practices, such as meditation [58]. We have taken a similar approach in combining breathing practices with VR in our Life Tree example. Similarly, prior work on limited control of breathing, such as the work by Elias et al. [25], "Lit2Quit" [43] and "In the same boat" [133] and previous projects around limited proprioception as a result of limited sight [149] and limited control over the ability to compensate for subconscious actions [42] have guided us in appreciating the potential of limited control of the body when aiming to create engaging experiences.

We are also inspired by prior work on exertion games [82-84, 86, 87, 90, 91, 93, 95, 97-100, 105, 113, 114] as they often aim to increase bodily control in the form of improved athletic skill [2, 45-48, 85, 96, 101, 113, 123, 129, 130]. For example, Tholander et al. [146] found that athletes both control smartwatches and let the devices control them. Our work complements and builds upon these insights, by offering a structured understanding of how to design for such experiences of bodily control. Further inspiration was gained from guidelines relating to bodily play as they have highlighted that more precise control can actually be detrimental to the overall experience [40, 102]. We consider our work as building on these guidelines as we provide practical implementation opportunities that focus on the experience of limited control over the body.

Closest to our work is probably the framework by Benford et al. [6] that examines issues of control. This framework highlights the journey of control users go through as part of cultural interactions, whereas our work examines how to design limited control over the body as part of play experiences and therefore complements their work nicely.

Overall, our review of prior work highlights that control is important to research at the intersection of technology and play. However, even as advances in bodily action sensing technologies allow us to sense more and with greater precision, our understanding of how to design for limited control over the body remains underdeveloped. Concrete design strategies remain rare. We contend that now is the time to further investigate experiences of limited control over the body, and to establish conceptual and practical foundations on which game designers can facilitate unique and engaging digital play experiences via limited control over the body.

3 BODILY PLAY SYSTEMS ENGAGING WITH LIMITED CONTROL OVER THE BODY

In the following section, we discuss three bodily play systems that we designed and hence have knowledge of the design rationale and a range of informal observations in various cultures, and evaluation data. The systems focus, respectively, upon limited control over the body of *digestion*, *balance* and *breathing* (Table 1). We selected these systems for the following reasons:

- The systems cover different approaches to limited control over the body, which suggests that designers have a wide range of choices: InsideOut increases awareness of limited control over the body; Balance Ninja further reduces limited control over the body; and Life Tree changes practices of limited control over the body;
- The systems were developed with a wide range of aims, which suggests the broad applicability of our framework: InsideOut aims to facilitate play involving the interior body, Balance Ninja aims to facilitate social entertainment, and Life Tree aims to facilitate pursed-lip breathing;

- The systems engage with a range of different technologies, highlighting that bodily control is not restricted to particular implementations: InsideOut uses an ingestible sensor; Balance Ninja uses Galvanic Vestibular Stimulation; and Life Tree uses a breathing sensor;

Attention to limited control over the body emerged through our design practice and our systems were not initially designed to push the concept to its limits. Each system emerged via a research-through-design approach [31] and the process records have been collected and presented as an annotated portfolio, which allows us to look back and reflect on learning [30], speaking to a previous call in HCI for more practical design knowledge [39]. While our approach of selecting our own work for discussion has advantages – such as offering intimate insights into the development process – we acknowledge that this approach may mean that we carry implicit biases shaped by our own research, and by our experiences developing and playing these games. We acknowledge that future work could address these implicit biases. For example, we could incorporate limited control over the body into game design upfront. We could then measure player experiences with these games to test our strategies [147]. We could also examine independent game designs, such as a heart rate-controlled board game from industry [8] or a brain-controlled ball game from academia [36]. Consequently, our work provides just a snapshot of the vast design space available. We hope that the insights provided by our research and systems can offer a foundational, structured understanding of how to design play around limited control over the body, and serve as a springboard for future investigations. Indeed, we expect that technology advancements, particularly sensors, mean that more bodily play systems will emerge, helping us to develop a more complete picture of the design space.

Table 1: The three bodily play systems, their key technologies and original research questions

Bodily play system	Key technology	Original research question
InsideOut	Ingestible sensor	How can we design playful experiences around imaging capsules?
Balance Ninja	Galvanic Vestibular Stimulation (GVS)	How should we design digital vertigo games?
Life Tree	Breathing sensor and VR	How do we design engaging breathing exercise games?

3.1 InsideOut

InsideOut (Figure 1) is a playful system designed around an “ingestible”; the ingestible is an imaging capsule – a technology increasingly used in the medical domain to examine the gastrointestinal tract – which wirelessly streams video of a person’s internal digestive system. InsideOut aims to investigate how a person, rather than a medical expert can be encouraged to engage with their health data, by capturing and presenting video data to them. Participants can watch the video and even play with it using their bodies. These interactions aim to allow players to increase their awareness of the extent of control they have over their inner bodily processes, and facilitate an increased appreciation and understanding of their “interior” body.

Figure 1: InsideOut – a game using imaging capsules that increases a player's awareness of the bodily control they have over their digestion.

InsideOut anticipates a future where people can swallow affordable ingestible cameras for experiential gains such as play, not just for medical purposes. We also anticipate a future where fashion displays digital data [52], as has already been hinted at in fashion pieces which incorporate display technology [24, 61]. To demonstrate this possibility, InsideOut includes a top with an iPad sewn into it, displaying the sensor's video stream.

The InsideOut garment displays the video as the capsule travels through the user's gastrointestinal tract. To engage users beyond just watching the video, the iPad's inbuilt sensors capture body movements, such as swaying back and forth and twisting the torso. These movements are linked to scaling and rotation filters applied to the video stream, and the video becomes an interactive performance. The capsule remains inside the body for 8 to 36 hours. To facilitate a long-term engagement with the data and to enrich the play experience [66], six mini-play modes were also implemented.

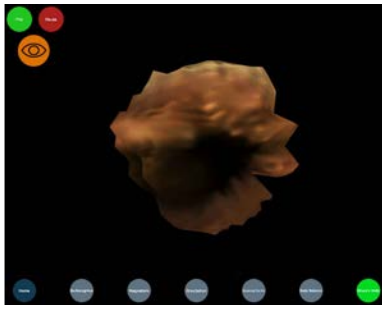

Figure 2a: Gravitation

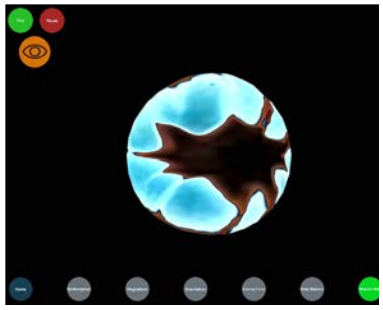

Figure 2b: Magnetism

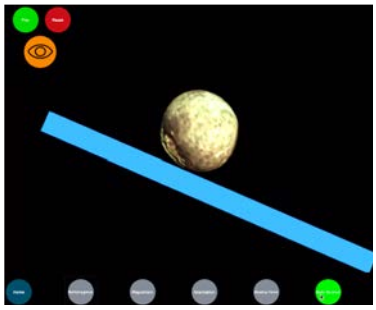

Figure 2c: Body Balance

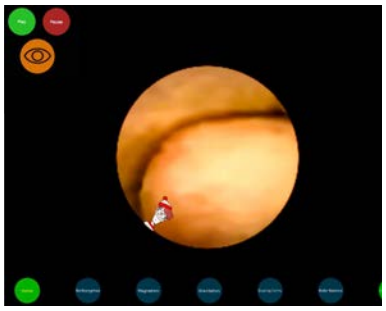

Figure 2d: Finding Wally

Figure 2e: Borborygmus

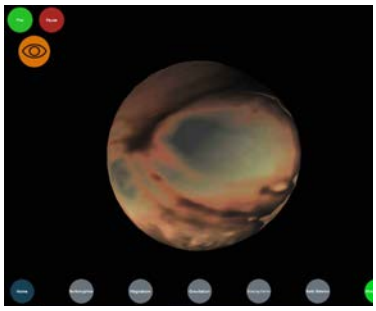

Figure 2f: Bloating Moves

Figure 2: InsideOut's various mini-play modes.

Gravitation and Magnetism transform the video based on the surrounding magnetic field's strength and gravitational acceleration respectively. Body Balance turns the video into a rolling ball and requires the player to move their body to balance the ball on a seesaw. Finding Wally requires the player to search for hidden gems, and identifying them results in a visual effect and a rumbling sound. Borborygmus moves the video on the display based on the player's body movements. When the image touches any of the four arcs, a rumbling sound is generated. Bloating Moves maps the video onto the surface of a flexible 3D ball and the player's body movements change its shape.

These modes were based on prior work's design guidelines for ingestible interfaces [64, 65, 67], including "Consider designing various playful interactions across the play duration"; and "Design appropriate feedback to regulate the player's bodily awareness". The design of the six mini-play modes was also based upon the "Four Keys" for creating emotions in play [62]: Easy Fun; Hard Fun; People Fun; and Serious Fun. Gravitation (Figure 2a) and Magnetism (Figure 2b) were designed to facilitate Easy Fun: embracing ambiguity and environmental data to evoke players' curiosity and facilitate interaction, exploration, and imagination. Body Balance (Figure 2c) and Finding Wally (Figure 2d) were designed to facilitate Hard Fun: offering game challenges and directing players' attention to the associated goals. Finding Wally also facilitates People Fun by supporting other people to interact with the display video. Borborygmus (Figure 2e) and Bloating Moves (Figure 2f) were designed to facilitate Serious Fun: using exaggerated simulations of the sound of intestinal rumbling and changes to intestinal shape, we intended to motivate players to reflect on how imaging capsules might change their understanding and relationship with their interior bodies. Overall, we intended for players to engage with the mini-play modes and consequently realize that their associated body movements not only controlled the game elements but also affected how the ingestible camera and the food around it travelled. The aim was for players to become more aware of the degree of bodily control they have.

We conducted an in-the-wild study with 7 participants who wore and freely interacted with their system for a day [66]. We prohibited strenuous physical activity as per the ingestible camera's instructions. Players experienced limited control over the body as one cannot directly affect the digestive system. However, the gastrointestinal tract shown as the video can be indirectly influenced by:

- Engaging in other bodily activity, such as movement when using the mini-play modes (which our study participants tried out extensively), or through meditation [53] (which our study participants did not try); and

- Exposing themselves to external triggers, such as eating different types of food (our participants tried out a wide range).

3.2 Balance Ninja

Balance Ninja [13-15], a two player balance game (Figure 3), was inspired by the appeal of vertigo (the destroyed stability of perception [18]), which is often experienced by participants in adventure sports such as rock-climbing or skiing [14, 16, 17, 35] as they try to respond to external forces and stay in control of their bodies. Unlike in traditional vertigo experiences, in Balance Ninja, the two players take control of each other's bodies, and affect each other's balance via Galvanic Vestibular Stimulation (GVS).

Figure 3: Balance Ninja – a game that reduces a player's sense of balance control through GVS controlled by another player.

Before the game begins, players attach a tight-fitting pouch to their chests. This pouch contains a mobile phone which wirelessly transmits accelerometer data, allowing the system to sense a player's torso movement when they lose control of their balance and lean left or right.

Small electrodes are also placed behind each player's ears. Our organ of balance, the vestibular system, is found inside the inner ear and can be affected through GVS. The GVS system delivers a small current of 2.5 mA to the vestibular system. In response, players feel a pull towards the positively charged electrode of the GVS system and a loss of control over their balance in that direction. Each player is positioned opposite the other player and balances on a wooden board that rests on a beam. This setup creates an unstable platform that limits each player's bodily control over their balance.

The sensors and the GVS systems communicate with one another wirelessly. If, for example, player A leans to the left, the accelerometer sensor on the player's body picks this up and triggers the GVS system of player B, so that player B experiences a pull to the right, and vice versa (mirroring the movements of the opposing player). The more player A leans to one side, the higher the level of GVS stimulation applied to player B.

The goal of the game is to make the opposing player lose control over their balance, resulting in them either stepping off the balance board or touching their board to the floor. Each time this happens, the player still on their board wins the round and gains a point. The first player to reach five points is considered the winner.

In everyday life, balance is automatic: we do not need to consciously think about it. Our body is always slightly swaying, as our inner ear, eyes, muscles, joints and the brain are communicating, and feeding an ongoing process of position detection, feedback and adjustment. However, balance, as a form of limited control over the body, can be affected by external triggers, such as the intake of alcohol. Balance Ninja's balance board and GVS function as external triggers, challenging a player's limited control over the body over balance. To manage this challenge to limited control over the body, players engage in what we have called "other bodily activity", often flailing their arms (Figure 3).

In an associated study [13], 20 players reported that the system induced a sense of vertigo. However, as it was within the context of a game and a safe environment, it resulted in a positive, playful experience of vertigo. Players reported that they found the opportunity to wirelessly affect another player's ability to control their balance very intriguing.

3.3 Life Tree

Life Tree offers a playful VR experience of controlling one's breath using a breath sensor attached just under a VR headset (Figure 4) [125-127]. Unlike our lack of direct control over our heart rate, direct control over breathing is possible, though still limited: we can choose to increase or decrease our breathing rate and also stop breathing altogether for a limited time. Furthermore, we are often not aware that we are breathing and how we are breathing, despite the potential of proper breathing techniques to reduce stress, promote feelings of relaxation and improve the overall quality of life (see [126] for an overview). Life Tree aims to support people to become more aware of how much control they have over their breathing and guide them in practicing pursed-lip breathing: inhaling through the nose, and exhaling through the mouth with pursed lips.

When players put on the VR headset and breathing sensor, they see a colorless tree in the middle of a body of water. When players exhale, they can see leaves blown towards the tree. A soft voice, delivered through the headphones, suggests that the player sits down, cross-legged. As the player sits down, an animation of the tree getting submerged into the water is triggered through the headset's motion sensors, replicating the participant's bodily action. As the player breathes, virtual leaves blown towards the tree simulate the player's exhalation. If the player's breathing is rhythmic, the leaf colors change to a blue-green shade; otherwise, the color is green-brown. At the same time, the bark of the tree expands and contracts to reflect the motion of the lungs, indicating

inhalation and exhalation. The more control players gain over their breathing towards proper pursed-lip technique, the more colorful the tree becomes. If the player's breathing is out of rhythm, the system responds, and the visuals become slightly blurred. An Indian instrument ("Veena") which is commonly used to enhance the effect of practicing yoga, plays in the background [20].

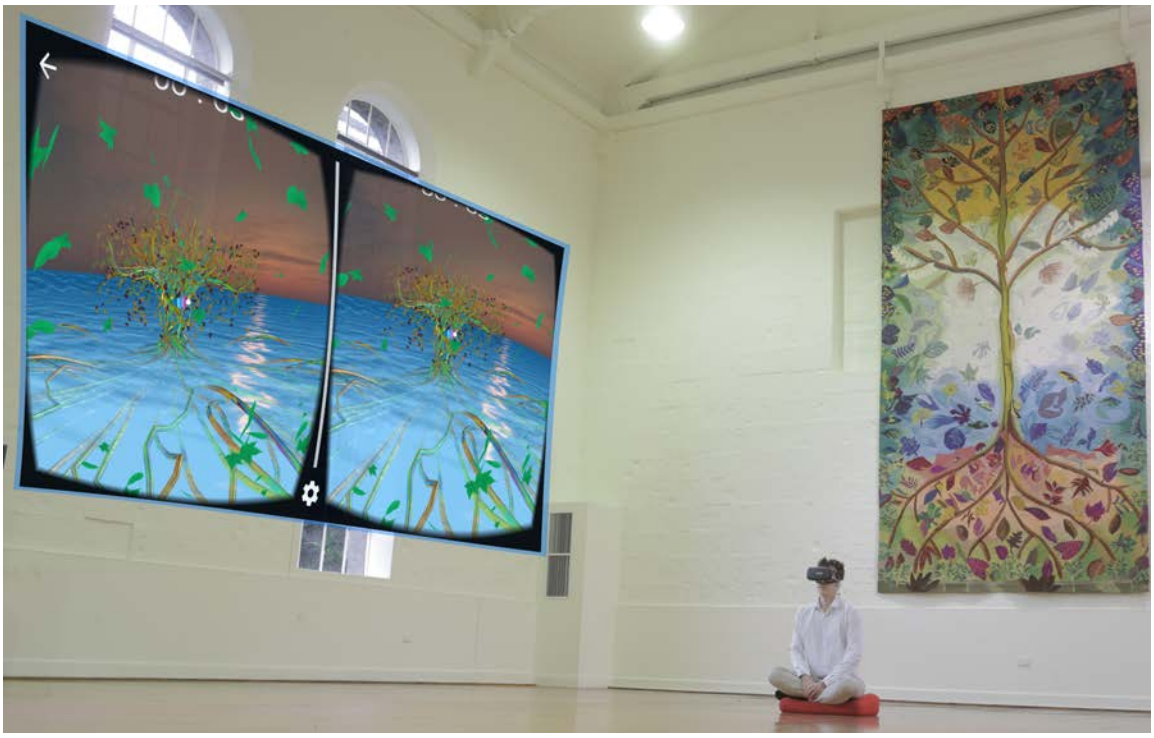

Figure 4: Life Tree - a playful VR experience around breath control.

Life Tree demonstrates the limited control over the body one has over breathing and shows that interactive systems can both help users become more aware of their breathing and aid them to change their breathing patterns. Unlike in Balance Ninja, where the everyday practice of balancing (which is second-nature to healthy individuals) is disordered, the assumption for Life Tree is that everyday breathing is already disorderly and that one benefit of interactivity is to bring it back to "order".

With Life Tree, we aim to show that a game not always needs to engage with "limited control over the body" as a "given" but can be designed with the aim of changing a user's ability to subconsciously vary their bodily control in the future. In this respect, our design thinking is not limited to entertainment games but can also include serious games [22, 80].

Life Tree's VR headset was used to block out external distractions, helping players to focus "inwards" [37] and focus on their ability to control their breathing. This "blocking-out" could be described as an external trigger to control one's breathing indirectly. Furthermore, players also engaged in "other bodily activity" to indirectly affect their control over their breathing. In essence, they were sitting down cross-legged, resulting in the yoga

Sukhasana pose that is believed to aid better breathing. This posture was encouraged by the soft voice over the headphones, and sensed by the headset's inbuilt sensors.

A study with 32 participants [126] highlighted how players enjoyed engaging with limited control over the body through breathing, and found the experience relaxing and contributing positively to their mental health and overall wellbeing.

4 STRATEGIES FOR DESIGNING LIMITED CONTROL OVER THE BODY

As a response to the previously articulated desire for more design guidance in HCI [39], we now present a set of strategies aimed at designers who want to engage with limited control over the body as a way to facilitate novel and engaging play experiences. We present these strategies as practical do's and don'ts. We also detail implementation opportunities based on our craft knowledge in the form of bulleted lists at the end of each strategy, as previously suggested [103]. These implementation opportunities detail design options for realizing the strategies, although we reiterate that they are not the only ones available [103]. The strategies emerged organically; through the design process for these systems outlined above, the associated studies, team discussions, and through iterative cycles of review and design practice response, all of which are common practices for design research labs.

We used mainly data from the interviews with participants and complemented it with log information together with demographic surveys to arrive at our insights. We also engaged in whiteboarding sessions, thinking-through-writing, and clustering sessions with the original authors as well as additional members from our design lab. Through this process, we were able to group key insights and find larger themes, akin to thematic analysis.

We also drew from annotated portfolio research (based on our prior experience with it [94, 99, 103, 104, 106-109, 112, 115]) and combined it with autoethnography (again based on our prior experience [110, 118]). We reflected on our experiences by first looking at our designs again, re-watched the associated videos, and presented the work again. This included re-reading our prior notes and writing down our findings individually before discussing them in online meetings, to which we invited the original primary designers. We used affinity diagrams to group the results in online collaboration tools, combined with an online whiteboard, before keeping only those that came out most prominent. Somaesthetics and Shusterman [139] were very much at the forefront of our discussions: we leaned on our experiences from other, related bodily projects [60] to help us reflect on our self-awareness which fed into our reflection process. We were also inspired by prior work [12] that previously aimed to understand game experiences and adopted the approach of presenting the key findings as preliminary findings for future work. We concluded by grouping the final insights into the 4 strategies we present below, refining their wording through collaborative writing online. The entire process took over a year.

Our approach was theoretically agnostic, as we did not begin with a particular theory nor was our aim to contribute to a particular theory, but rather to let theoretical design understandings emerge as part of the process. While the strengths and weaknesses of this approach have been highlighted previously [7, 104, 111], we point out that applying such an approach has already successfully resulted in design strategies for application domains that are similarly concerned with the coming together of interactive technology and the human body [7, 94, 99, 104, 106-109, 111, 112]. Hence, we contend that this approach can also be beneficial for research into limited control over the body in bodily play systems.

We acknowledge that our strategies can be characterized as being of exploratory nature as they are derived mainly through prior work and our three projects. As such, they are not yet evaluated through follow-up studies,

for example, we could hold design workshops, some with the strategies, some without, as in A/B testing, to collect further empirical evidence that the strategies are useful for designers. We leave this for future work. We also acknowledge that we could have also developed new projects to arrive at additional strategies or evaluate the existing ones, however, decided that this was outside the scope of this work. We summarize the strategies and associated opportunities in table 2 below.

Table 2: The four strategies along with their opportunities

Strategy	Opportunities
Exploration: Support players in exploring limited control over the body	Support players in exploring what the limits of control over their body are and the different ways to reach these limits.
	Reward control over the body explorations through the ability to manipulate aesthetically pleasing sensor data representations such as visuals.
	Promote explorations of bodily control through gameplay that makes the effects on the body visible.
	Make visible where on the body any sensor is placed and provide instructions on how the sensor works as a way to facilitate bodily control explorations.
	Amplify sensor data representations in order to support bodily control explorations.
Reflection: Support players to reflect upon how they feel about limited control over the body	Enable players to experience the body from novel perspectives, so as to prompt visceral reactions that elicit reflection upon limited control over the body.
	Employ interactivity to strengthen the link to bodily data and facilitate reflection on limited control over the body.
	Consider incorporating dialogue and questions into gameplay: ask players how they feel about limited control over the body to facilitate reflection.
	Offer players the capacity to make bodily data public as a way to elicit reflection on limited control over the body.
Learning: Support learning how to increase bodily control	Consider always-on functionality to let everyday circumstances teach players how to increase bodily control.
	Provide safe physical and virtual environments where players can learn how to increase bodily control by going to their limits without real-world consequences.
	Provide multiple game rounds so that players can compare strategies to support learning on how to increase bodily control.
Embracement: Support players in embracing their bodily control limitations	Facilitate awareness of the "work" players' bodies perform without requiring conscious and directed effort as a way to help players embrace their bodily control limitations.
	Provide players with information on how they can benefit from limited control over the body.

4.1 Exploration: Support players in exploring limited control over the body

This strategy is concerned with the extent to which the system supports players to playfully explore the nature of their limited control over the body, and helps them discover previously unknown abilities to affect that control. Supporting exploration has been previously described as a key ingredient for playful experiences in general [72] and bodily play in particular [104]. Furthermore, play has been regarded as a way to try to figure out "how things work" [10]. Indeed, prior work [104] contends that players might gain an increased understanding and appreciation of their bodies through bodily exploration in the constructionism tradition [124], which might, in turn, facilitate an enhanced self-understanding [116, 117]. We see our explorations around limited control over the body as offering participants new ways to figure out how the human body "works". The opportunity exists to

build on our findings and use playful design elements to support player's explorations of their bodily control, and to help them discover previously unknown abilities to influence their bodies, using, for example, "other bodily activities" and "external triggers".

In the InsideOut study, we found that players appreciated the opportunity to explore their abilities to control what they saw on the video of their intestines as captured by the capsule's image camera. For example, participants reported eating different foods to see the results on the wearable display. They also reported how they could identify food residue in the video. Furthermore, participants said that they bent and twisted their upper torso to attempt to direct the camera's view. They also used the video to check whether being physically active or resting would influence their intestines.

The design facilitated these explorations through multiple means. Firstly, participants were not limited in what they could eat and drink, unlike medical procedures with imaging capsules where patients are limited to a strict diet and clear fluids. Secondly, the mini-play modes encouraged movement, while the video simultaneously showed the effects of movement. Thirdly, the filters applied to the video rewarded movement with enhanced aesthetics. These design decisions helped players to realize that they had some control over their intestines through eating, drinking and moving. All players reported their surprise at how much control they had. For example, one player said: *"I knew little about my interior body before the study […] At first, I just moved my body because I was playing with some play modes. Then I was surprised to see my intestines' shape changed! So, I began to try different activities, not because of the play modes' rules, but just for exploring my own body"*. Another player said: *"I twitched my abdominal muscles and it was amazing to see the fluid in my intestines sloshing immediately!"* And another player said: *"When I sat down, my intestines looked folded but when I stood up, it looked smooth. I was surprised that I can easily influence my body['s] interior."*

In Balance Ninja, players enjoyed exploring how they could better control their balance. They experimented with different strategies, such as spreading out their arms or closing their eyes. Participants also tried to twist their lower torso in relation to their upper torso, because they knew that the sensor attached to their chest would only sense upper body movement. The wearable body-sensor facilitated these explorations (we could have also sensed the movement with a camera).

We did not enforce any rules on players, other than the goal of trying to knock their opponent off their balance board. To win, players were free to make any bodily movements they wished and use any strategies they chose. For instance, many players closed their eyes, to find that this change enhanced the GVS effect, reduced their bodily control, and that they quickly lost their sense of balance. Despite this, players sometimes enjoyed closing their eyes as it added an extra level of challenge to their gameplay. On the other hand, some players focused on an object in the distance to orientate themselves, or moved their upper body to regain bodily control. For example, one participant said: "*Well, [I] was looking at the ground, because that then made me regain my balance every time I looked at a new spot, so if I [did] it quickly enough, I could maintain a balance."*

Life Tree participants reported that they enjoyed exploring how to use the system to control their breathing. Because the system advocates a specific technique for bodily control – pursed-lip breathing – players were not entirely free to explore how much control they had over their breathing. However, they appreciated that the system guided them in gaining increased control. The visuals in the virtual world facilitated the change by making participants more aware of the duration of their exhalation: the leaves increased in numbers and the trunk of the tree expanded. Unlike, for example, observing one's belly under loose clothing, where the movements are rather small and difficult to identify and hoping to see it expand when breathing in, Life Tree's

visuals amplified the movement. This system design was to provide information on participants' breathing control through visual feedback in the form of pleasing color changes. Lastly, the system supported explorations by providing feedback through subtle changes in the animation, rather than communicating stern "rights" or "wrongs".

We identified a number of opportunities to implement the Exploration design strategy:

- Support players in exploring what the limits of control over their body are and the different ways to reach these limits.
- Reward control over the body explorations through the ability to manipulate aesthetically pleasing sensor data representations such as visuals.
- Promote explorations of bodily control through gameplay that makes the effects on the body visible.
- Make visible where on the body any sensor is placed and provide instructions on how the sensor works as a way to facilitate bodily control explorations.
- Amplify sensor data representations in order to support bodily control explorations.

4.2 Reflection: Support players to reflect upon how they feel about limited control over the body

This strategy is concerned with the extent to which the system playfully supports players to reflect upon how they feel about their limited control over the body. Prior work on bodily play [94] has highlighted that designers can benefit from seeing the human body from two perspectives: the material perspective, captured by the German term "Körper", and the lived perspective, captured by the term "Leib". These two perspectives suggest that although we might encounter our bodies from a material perspective to be "satisfactory", we might feel very different about them. This is particularly pertinent when it comes to issues such as body image. For example, a doctor's examination of the Körper might conclude that there is nothing wrong with a person's body. Yet, the person might feel very differently about it (Leib). In keeping with this prior work, we suggest that designers should not only design for the Körper perspective but also the Leib. They can do so by supporting players to reflect upon how they feel about their limited control over the body, including any newly discovered abilities they might have gained through gameplay.

We have found that designers often find it easier to engage players with the Körper perspective, as most sensors are designed to track changes to the material body. Supporting the Leib perspective is often more challenging. Yet, we stress that designers could support players in reflecting on how limited control over the body makes them feel as it is believed that such reflection can increase the appreciation of one's body [94].

InsideOut players reported that they learned how their internal body works from a mechanical perspective (Körper). For example: *"It taught me a lot about my body. After several hours, I saw my intestines' wall being fluffy and then I searched online. Now I know that it was my small bowel."* The interviews also suggested that participants started to reflect upon the control they have over their body (Leib). One participant said: *"After the procedure, I think I recognized the digestive system as part of my own body"*. Another participant said: *"My digestion rate is slower than I thought. I could see the food I had several hours ago in my stomach. This made me eat slower and more mindful"*.

We believe three design features facilitated such reflection. Firstly, the high-resolution video of the imagining capsule results in a vivid video that can elicit visceral reactions. For example, one participant commented: *"At first the video was a bit shocking. But later I was absorbed in the images and felt like traveling inside my body."* Secondly, interactivity helped participants identify that it was "their" personal bodily data, rather than, for

example, a video of someone else's gastrointestinal tract. For example, one player noted: "*After picking the capsule out of the [packing] box, I saw the video showing the room view. When I swallowed it, I saw my teeth, my tongue and I saw it entering my stomach. This was very different from seeing some internal body images online. It made me realize: 'Ah, it was my body!'*" Another player explained: "*After I swallowed the capsule, I had some beef for lunch and I clearly saw it through the video. I think it motivated me to try more activities afterwards because it let me know this is my body and I can influence it*". Thirdly, making the display part of the clothing and hence potentially revealing one's body data to others, further encouraged reflection. For example, one participant said: *"I enjoyed showing my friends the video during the first several hours because then my intestines looked clean. But later the video became messy when the capsule was in the large bowel, and I did not want to show it to others"*.

The Balance Ninja system itself did not directly facilitate reflection on how limited control over the body made the participants feel. However, reflection was facilitated through the interviews that followed. Participants welcomed this trigger and freely reported on how they felt about the limited control over the body they experienced. For example, one participant reflected: "*The best bit was when I did feel it, the kind of visceral feeling almost when you actually [realize]: 'Actually, this thing has made me unbalanced'."* Similarly, another participant said: *"It was really funny. It kind of made me laugh, looking at [player] trying to balance and trying to throw me over at the same time, and me trying to do the same, it was kind of comical really"*.

We believe that incorporating such questioning into the bodily play system experience to facilitate reflection could be achieved straightforwardly. The system could use digital means (possibly in the same way that the game score is digitally announced through speakers) to ask players questions, such as: *"How did you feel about losing your control?"*.

Life Tree elicited rich, reflective responses about the experience of limited control over breathing. The system's design aimed to facilitate the experience through a soft voice recording that introduced players to the experience and showed them an animated reflection of their body in the form of the tree. Although participants could not verbally respond (as they were concentrating on their breathing), the voice's content was framed to elicit player's reflection on their breathing. In particular, we aimed to foster player reflection upon how taking a different approach to breathing could help them relax.

We identified a number of opportunities to implement the Reflection design strategy:

- Enable players to experience the body from novel perspectives, so as to prompt visceral reactions that elicit reflection upon limited control over the body.
- Employ interactivity to strengthen the link to bodily data and facilitate reflection on limited control over the body.
- Consider incorporating dialogue and questions into gameplay: ask players how they feel about limited control over the body to facilitate reflection.
- Offer players the capacity to make bodily data public as a way to elicit reflection on limited control over the body.

4.3 Learning: Support learning how to increase bodily control

This strategy is concerned with the extent to which the system supports players to learn how to increase their bodily control, not only during gameplay, but also in-between game sessions, thereby facilitating long-term learning. Learning how to increase bodily control is not new. Many sports-inspired digital experiences support

such learning to help players improve. For example, early Kinect exercise games used progress reports, fitness apps incorporate sports trainer instructional videos, and interactive bouldering systems include increasingly more difficult challenges to enhance climbing skills [50]. Because we are interested in limited control over the body, supporting learning needs to pay particular attention to both direct and indirect bodily control. As sensors becoming increasingly more wearable, and battery capacity is expanded, learning can be facilitated both during gameplay and in-between game sessions. This allows designers to employ pervasive game design approaches [81] that blur the boundary between gameplay and everyday life, thereby facilitating players' ongoing learning engagement.

InsideOut can be regarded as a pervasive game [81] as it blurs the line between everyday life and gameplay. Once the InsideOut activity is commenced, the camera captures video and cannot be stopped, often for more than 8 hours. Our participants reported how they interspersed their everyday life with gameplay, with one informing the other. For example, one participant said: *"I tried different postures and I remembered that when I lied down on the sofa like this, the capsule was moving very fast"*. Another participant said: *"After I found that different posture might influence my intestines' shapes, I began to think about what postures might be good for my digestion."*

As the InsideOut system was always on, players were able to check the effects of their everyday activities at any point in time. Furthermore, because the display's sensor data constantly registered ongoing movement and moved the image around on the screen, players always had something new to look at, even if the video stream did not change much. As a result, players were engaged and willing to let circumstances teach them what indirect actions could increase their limited control over the body.

Balance Ninja provides a safe environment in which players can test how far they can lean, helping them learn how to improve control of their balance. Games have previously been described as "safe environments", and, in this regard, digital games use virtual environments which allow players to try out actions "without real-world consequences" [135]. Balance Ninja is not played in a typical visual virtual environment, but players do act within a shared virtual space informed by their movements and their connected sense of balance. This allows them to learn from each other how much they can lean on the balance board, without fear of falling and injuring themselves (the balance beam is only a few centimeters tall), and without fear of social ridicule, given the task seems easy. As the balance activity is happening within a magic circle of play [135], players form a social contract in which losing control of the body is acceptable. Furthermore, as the GVS signal is "invisible", it is not obvious if a player is thrown off by the other player or simply not very good at controlling their balance, further reducing chances of social ridicule. The use of multiple rounds affords learning across rounds, where players are free to try out and compare different tactics. We therefore highlight that considering safe physical as well as virtual environments is something that designers should be thinking about.

Players recognized Balance Ninja's value as a balance training tool, and reported that they would like to see the system further used elsewhere, including for sports training and rehabilitation exercise. While many of the players had previous experiences of other balance exercises, and described them as unengaging, they considered Balance Ninja to be very enjoyable.

While pursed-lip breathing is relatively easy to do, it can be challenging to adopt in everyday life. Life Tree was designed to be played over multiple, short sessions, in order to teach people pursed-lip breathing for everyday life, rather than as a one-off experience. VR was useful in blocking out any outside distractions. However, the use of VR made it challenging for participants to transfer their in-game learning to the real-world.

The removal of the VR headset demarcated a clear distinction between in-game breathing and everyday breathing. We aimed to minimize the effects of this demarcation by guiding the players through the headset removal process. However, we believe improvements could be made. For example, we point to the notion of exit trajectories [5] that could facilitate such a transition and hence support further learning to increase bodily control.

We identified a number of opportunities to implement the Learning design strategy:

- Consider always-on functionality to let everyday circumstances teach players how to increase bodily control.
- Provide safe physical and virtual environments where players can learn how to increase bodily control by going to their limits without real-world consequences.
- Provide multiple game rounds so that players can compare strategies to support learning on how to increase bodily control.

4.4 Embracement: Support players in embracing their bodily control limitations

This strategy is concerned with the extent to which the system supports players to embrace their bodily control limitations. Although we previously advocated supporting the increase of limited control over the body, we also need to help players acknowledge that there will always be limitations.

While one might assume that having more control over one's body is always better, especially in bodily play, we propose that game designers consider opportunities to highlight to players that we cannot and should not always expect to have a high degree of conscious bodily control. Limited control over the body is sometimes natural and necessarily so. For example, bodily control over digestion is autonomic and unconscious. If managing the functions of our digestive system required our direct and conscious attention and effort, we would have little capacity to attend to any other things we might need or wish to do. We need to embrace our limitations and game design is uniquely positioned to support this embracement, as digital games have a rich history of engaging with agents that act without control of the player, highlighting that external control can be beneficial.

InsideOut makes the intense activity of the involuntary muscles in the intestines visible to the human eye. Players reported that this made them more appreciative of how much their intestine is working "for them", increasing their appreciation of their bodies.

Our work highlighted that giving up bodily control can have benefits, including entertainment. Indeed, prior work on interactive rollercoaster rides [136] found that giving up control, allowing yourself to be strapped in and thrown around, is not necessarily a "bad" thing. The experience is welcomed when it provides a benefit to the user. For the rollercoaster rider, this benefit is the visceral which people associate with the feeling of vertigo and find delightful. Similarly, Balance Ninja rewards players with a joyful social experience in return for giving up control of their balance. For example, one player said: "*It was fun, as a game perspective trying to make the other person feel what I was feeling*." Because players observed others play a game round before they participated, they knew in advance that they would be trading off bodily control for a social and fun experience.

In Life Tree, participants experienced limited control over their breathing. For example, they could not exhale forever or create a beautiful virtual tree with just one breath. One participant said: *"It made my body feel good while I exerted pressure on my diaphragm and lungs. It was also nice to see the game's response towards my breathing."* It appears that players were willing to engage with this limited control over their breathing just to create a visually pleasing virtual tree. Furthermore, they participated with the assumption that pursed-lip

breathing is beneficial for their mental health. 21 of 32 participants spoke about becoming calmer and feeling good about their body after their session. One participant said: *"After I finished playing the game, I feel quite good and happier than I was before playing the game."* These outcomes were facilitated by the study instructions which suggested that they might find the pursed-lip breathing activity beneficial for their health.
We identified a number of opportunities to implement the Embracement design strategy:

- Facilitate awareness of the "work" players' bodies perform without requiring conscious and directed effort as a way to help players embrace their bodily control limitations.
- Provide players with information on how they can benefit from limited control over the body.

5 LIMITATIONS AND FUTURE WORK

We acknowledge that all design work has its limitations [30] and we appreciate that the work presented in this article provides only an initial impression of a bodily control design space. We also acknowledge that additional theories could complement our work. For example, engagement with Merleau-Ponty's "motor intentionality" [143] could enrich our notion of bodily control. For instance, Merleau-Ponty describes people's accounts of being under the influence of drugs like "my body had a mind of its own" [41] which resonates with our concept of limited control over the body. Future work could therefore investigate what role drugs play in people's experiences with limited control over the body. Similarly, somaesthetics [139] could also complement our approach, possibly resulting in more design strategies, as this would include a Feldenkrais practitioner's knowledge about bodily limitations.

At this point in time, we have focused on a design lens, and examined the practical implications of limited control over the body for game design practitioners. We believe our work can actively shape the future of interactive, playful systems that engage with limited control over the body. For example, if we examine sleep from the perspective of limited control over the body, we could ask: can controlling sleep become a bodily game?

We could also ask: could sneezing be a game? Our work suggests that we can use external triggers to engage with the limited control over the body players have over sneezing (it is a reflex, so an involuntary movement outside conscious control [131]). Specific smells might constitute a trigger (e.g. [57]) and future work might explore a game in which players have to try to make each other sneeze first, as many times, or as loud as possible by "feeding" each other different smells; with the first, the loudest or the most frequent sneezer losing the round. Given that some people describe sneezing as pleasurable [33], it seems conceivable that game designers could develop playful experiences around it. We might even imagine future work creating such games that teach people when and how often they sneeze, or highlighting the need for proper sneezing-in-elbow technique, which could be useful as an intervention activity to reduce the spread of viruses.

We also believe that, in the future, technology will become increasingly smaller, and with advances in biodegradable electronics [63], it will also become more body-friendly. These advances will facilitate a future in which the human body and technology increasingly fuse, enabling tighter human-computational machine integration [3, 26, 34, 89, 104]. This integration will allow us to further experiment with limited control over the body, and ask intriguing questions, such as: "Who is in control of the user's body: the computational machine, or the user?"; and, "If the control is shared, what does it do to the user experience?" [56]. We believe issues of limited control over the body will play a key role in such conceptual investigations. We hope that our work will

be able to contribute to such investigations by focusing upon both the instrumental and the experimental possibilities of these technologies. As part of these investigations, our work will also contribute to related initiatives which argue that the game design community needs to move past considering the human body as a controller to play with, and toward embracing the human body *as* play [94]. A better understanding of limited control over the body will better help us explore and develop this concept of the human body as play.

We also note that the term "bodily control" has been used in sports contexts, such as weight training, to describe the extent to which participants can control their bodies (and where they lack such control and the weights "win" in result) [71]. As such, future work might also investigate how our insights can be applied to sports and exercise, specifically where interactive technology moves into the gym.

Similarly, bodily control has been used in health care settings to describe strategies for patient empowerment as a way to "activate" patients [4] so that they are "more knowledgeable about, satisfied with, and committed to their treatment regimens" [142]. Future work might, therefore, explore how our work can contribute to patient empowerment in health care settings.

We note that limited control over the body can also be pathological. For example, seizures can result in uncontrolled shaking movements. It is, therefore, important that future work examines the ethical and medical implications of designing for limited control over the body. Furthermore, when investigating control over the body, concerns can arise over an individual's self-perception. Affecting bodily control raises questions about how to ensure the user can regain control before undesirable consequences such as discomfort, injury or long-term damage to the body occurs. Such investigations will require careful ethical considerations as they address the topic of human dignity as part of gameplay [94].

We also acknowledge that we are aware that focusing on automatic bodily processes can become an obsession for some [54]. Investigating if our systems could support associated treatments (such as mindfulness exercises) [54] could be an interesting avenue for future work.

6 CONCLUSIONS

Thanks to technological advances, there is an increasing interest in supporting bodily play through interactive technology. Responding to the limitations of existing bodily play systems, we have argued that game designers can benefit from considering limited control over the body as a way to facilitate novel playful experiences. Our conceptualization of limited bodily play, and our practical design strategies (including design opportunities) should be welcoming additions to game designers' toolboxes when they wish to develop engaging bodily play systems. Discussing three design exemplars, we have articulated an initial set of design strategies, which provide game designers with concrete guidance for engaging with limited control over the body during the design process. We complemented these strategies with implementation possibilities based on our craft knowledge. We hope that this work inspires designers to pursue this exciting new area, and that it raises awareness that our technological future can both include and actively facilitate playful experiences involving limited control over the body, and that these experiences can contribute positively to human culture.

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