Designing Digital Vertigo Experiences

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Many people enjoy "vertigo" sensations caused by intense playful bodily activities such as spinning in circles, and riding fairground rides. Game scholar Caillois calls such experiences "vertigo play," elucidating that these enjoyable activities are a result of confusion between sensory channels.

In HCI, designers are often cautious to avoid deliberately causing sensory confusion in players, but we believe there is an opportunity to transition and extend Caillois' thinking to the digital realm, allowing designers to create novel and intriguing digital bodily experiences inspired by traditional vertigo play activities.

To this end, we present the Digital Vertigo Experience framework. Derived from four case studies and the development of three different digital vertigo experiences, this framework aims to bring the excitement of traditional vertigo play experiences to the digital world, allowing designers to create more engaging and exciting body-based games, and provides players with more possibilities to enjoy novel and exciting play experiences.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**;

Additional Key Words and Phrases: Vertigo, exertion games, exergame, movement-based interaction, virtual reality, augmented reality, head mounted displays, whole-body interaction, bodily play, bodily interaction, social play, sports

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1 INTRODUCTION

Voluntarily experiencing confusion between bodily senses can be exciting, thrilling, and enjoyable. For instance, some sports professionals such as skiers and racing drivers battle against the intense sensory confusion induced from fast movements to remain balanced and in control. Theme parks, too, are home to rides designed to purposefully create intense and powerful sensory confusion in riders [Marshall et al. 2019], all for the sake of providing riders with a thrilling experience.

Such exciting activities illustrate that methods of purposefully confusing our senses are all around us. Have you, for example, ever spun around in circles on the spot for the simple joy of doing so? Rolled down a hill? Or perhaps you are even an avid theme park goer or thrill seeker?

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Whatever your preference, the chances are that at some point in your life you have chosen to experience an enjoyable form of sensory confusion.

Game sociologist Roger Caillois calls such activities "vertigo games," and states that vertigo games "consist of an attempt to momentarily destroy the stability of perception and inflict a kind of voluptuous panic upon an otherwise lucid mind" [Caillois 1961]. Simply, they are physical activities where a player's senses are affected (altered perception and lucidity) such that the player has an enjoyable experience (voluptuous), caused by a sudden change to their senses (panic). Caillois uses sports and physical activities such as rock climbing, dancing, and skiing to help illustrate his definition, and sports psychologists have long suggested that "the pursuit of vertigo" is indeed the main attraction behind many of these popular sports [Alderman 1974; Kenyon 1968].

Despite the suggested allure of the pursuit of vertigo, the purposeful design of digital equivalents has been under-explored in Human–Computer Interaction (HCI) and game design work historically, with some designers arguing that Caillois' vertigo definition of confusing the senses is perhaps not well-suited to digital game design, and even goes beyond the boundaries of such games [Salen and Zimmerman 2004, p. 289]. However, more recently designers have begun to create digital facsimiles of vertigo experiences. For example, several recent digital games allow players to traverse climbing routes within a Virtual Reality (VR) space [Crytek 2016; Dufour et al. 2014].

Often, the advice provided by game and VR designers can be to avoid causing too much sensory confusion in players in case it leads to negative experiences such as motion sickness [Sharples et al. 2008]. Although, some game scholars do contest this guidance, suggesting that vertigo elements could help to enhance digital games [Bateman 2006]. Rutter and Bryce [2006], for instance, describe how the disorientating speed and in which Sonic the Hedgehog [Team Sonic 1991] moves can create a pleasurable vertigo sensation for the player [Rutter and Bryce 2006, pp. 79-80]. We see exploring the design of digital vertigo experiences as an opportunity to use the digital to help create more personal body-based digital vertigo experiences (unlike the Sonic on screen example), but as far as we are aware no advice on how to design such experiences currently exists.

With this work, therefore, we aim to address the gap in knowledge concerning the design of digital vertigo experiences by presenting a design-led exploration of digital vertigo experiences, exploring the research question: *"How do we approach the design of digital vertigo experiences?"* We see this work as an exciting opportunity to help designers shy away from avoiding vertigo in their own games, and hope this work could help to encourage them to explore and expand on what we present here. With that being said, we next describe the contributions our work makes.

1.1 Contributions

Our work makes the following contributions:

(1) This research contributes to design knowledge by providing details on the implementation of, and insights gained from, the design and evaluation of three digital vertigo play experiences and a design workshop. The case studies and game prototypes demonstrate how digital games could be created and designed with vertigo in mind.
(2) This research contributes to design knowledge through the provision of a conceptual understanding of the role vertigo can provide in body-based games and HCI.
(3) The research presents the Digital Vertigo Experience Framework. It is the first theoretical conceptualisation of how to design for vertigo experiences from a digital perspective, and along with practical examples and recommended design tactics, guides designers in developing their own novel digital vertigo play experiences.

1.2 Target Audience

This research presents a suggestion of how we could design vertigo experiences from a digital perspective, and along with practical examples and design tactics, aims to guide designers in developing their own novel digital vertigo play experiences. These insights provide a high-level understanding of the experience and the tactics along with the framework (which we describe later) serve as practical examples for designers to develop digital vertigo experiences and guide them in facilitating their desired user experience.

Although we believe that the wider Computer-Human Interaction (CHI) and CHI PLAY communities could find relevance in our contribution, we particularly think that the Digital Vertigo Experience Framework would be of interest to practitioners who are focused on body-based games and play (e.g., exertion games and uncomfortable interactions [Benford et al. 2012]).

In the following sections, we present relevant related work within these areas, and also expand on the background of digital vertigo experiences.

2 BACKGROUND AND RELATED WORK

To develop the framework presented in this article, we were inspired and guided by prior work on traditional vertigo, bodily experiences and exertion games, and sensory confusion research.

2.1 Vertigo Experiences

To understand what a vertigo experience is let us first consider vertigo as it is commonly understood. In the medical world vertigo has been described as "a sensation of spinning or whirling motion. Vertigo implies a definite sensation of rotation of the subject (subjective vertigo) or of objects about the subject (objective vertigo) in any plane" [Dorland 1901]. Intuitively it may seem as though designers would want to avoid such sensations in digital game design. However, we argue that these sensations can be the basis of engaging bodily-play experiences (play which involves using the whole body), as vertigo games could allow players to experience sensations that are unexpected and different. For example, Stevens suggests that games of vertigo, which allow players to experience sensations beyond their normal day-to-day activities, could even allow players to "more fully be themselves" [Stevens 2007]. Caillois suggested that such games could also be "of merit in furnishing admirable witness to human perseverance, ambition and hardiness" [Caillois 1961].

Further supporting the attraction of challenging the body through experiencing vertigo is the fondness people have for the fair ground. Fair ground rides, or "powerful machines" as Caillois calls them [Caillois 1961, p.26], have been entertaining people since the 19th century. The *Haunted Swing* Illusion [Wood 1895], for example, is one of the earliest examples of a mechanical ride designed to induce sensory confusion by tricking riders into thinking they are swinging a full 360 degrees around a bar. In actual fact, the riders are near stationary and the room the swing is placed in rotates around them, creating confusion between what riders see, and what their vestibular sense of balance is telling them. Tennant et al. [2017] were inspired by the Haunted Swing to create a digital version, where players wearing a Head Mounted Display (HMD) swing on a real, physical swing, and have their sense of movement within a virtual environment exaggerated through the visual feedback. Such work suggests that vertigo experiences, which could result in uncomfortable or unusual bodily sensations [Benford et al. 2012], could be entertaining. As digital technology has improved, it is now possible for designers to elicit greater control over how to digitally induce peculiar sensations in players (as illustrated by Tennant et al. [2017]), and this is an opportunity that inspired our work.

This article argues to embrace the opportunity digital technology affords to explore the various ways in which such technology can be harnessed to purposefully induce sensory confusion in players. Doing so, we believe, can help HCI and game designers create exciting, novel, and playful vertigo experiences independent of complicated ride machinery and infrastructure, expanding the range of games that people play.

2.2 Digital Vertigo Experiences

Vertigo is a game characteristic that Caillois presents as one of the four main categories of games and play: games of Competition (Agôn), Chance (Alea), Simulation (Mimicry) and finally, Vertigo (Ilinx). Caillois [1961] explains the reasoning for naming the vertigo classification as "ilinx," stating that "for a disorder that may take organic or psychological form, I propose using the term ilinx, the Greek for whirlpool, from which is also derived the Greek word for vertigo (ilingos)" [Caillois 1961, p.24].

Game scholar Chris Bateman [2006] states that "little has been written about the ilinx (vertigo) of video games" and argues that artificially induced states of vertigo could enhance the enjoyment for players in certain "vertiginous" games like snowboarding and car racing games [Bateman 2006]. Importantly, these "vertiginous experiences," Bateman notes, are not "the nausea inducing kind," but rather enjoyable and fun ways of extending what is happening to an avatar on screen to the player in the real world, achieved through digitally induced sensory confusion.

The idea that vertigo games should be enjoyable is true to Caillois' sentiment that the experience should be voluptuous (i.e., pleasurable) when playing vertigo games. We discuss different types of vertigo user experience in this article, and present tactics for designers to help them achieve these experiences. Exploring the design of vertigo games with a digital perspective lends itself to this aim. For example, a system could detect if players appear to be losing their sense of balance too greatly, and any stimulation that is inducing this loss of balance can be immediately reduced by the system to ensure that the player is not placed in overt physical danger and can continue to enjoy the vertigo experience.

To answer our research question, we developed three digital vertigo games. Designing and studying these games has allowed to explore a range of digital vertigo *experiences*. Through a reflection on these experiences we created the Digital Vertigo Experience Framework. Overall, this work aims to inspire designers to explore vertigo by illustrating the range of potential vertigo experiences which can be created with digital technologies. In addition, each study served as a research vehicle to derive design tactics that aim to provide clear guidance for the design of *engaging* digital vertigo experiences.

2.3 Learning from Existing Bodily Interaction Frameworks

In HCI, frameworks can be used to obtain a better understanding of systems or the user experience of using the systems [Hornecker 2010]. Many frameworks, however, do not offer step-by-step guidance on the design process of creating such systems [Hornecker 2010]. In practice-based research, this has been an issue for researchers [Olsen Jr 2007], who have since investigated possible ways of closing this gap to support designers in the design process [Antle 2009; Hornecker 2010]. This has often taken the form of a design framework supported with design guidelines [Mueller and Isbister 2014], strategies [Pijnappel and Mueller 2014], or sensitivities [Jensen et al. 2014]. The contribution of our work is in the form of a theoretical design framework, and we have considered relevant related works in order to guide us in the design of this framework such that it will be useful for designers in creating their own Digital Vertigo Experiences.

The "Exertion Framework" [Mueller et al. 2011], for example, describes how designers should consider the body as play through the presentation of four key lenses: The Responding Body, The Moving Body, The Sensing Body, and the Relating Body. Though this work does not directly explore the role of vertigo in games, the spaces described by the Exertion Framework do highlight that digital, body-based games should consider the placement of digital technology within these spaces, and how useful a framework can be in giving prescriptive design advice to body-based game designers through the language of the framework. This work considers bodily interactions as desirable in games, and further, accentuates that when supporting the body with digital technology there is more than one bodily space to consider.

In *The Taxonomy of Thrill*, Walker [2005] presents a design taxonomy to determine how thrilling an experience can be by scoring it based on Walker's formula [Walker 2005]. Walker later extended this work with design strategies for augmenting theme park rides [2007] in order to support designers in creating thrilling experiences. Schnädelbach et al. [2008] later used this work, extending it in their digitally augmented theme park ride research, and reflect on their design experience in the form of a design discussion. These works illustrate how a design framework, or taxonomy, along with relevant design tactics can lead to researchers creating their own experiences based on the prescriptive advice of the framework in question.

Considering how to design for the spectator experience, Reeves et al. [2005] presented a taxonomy that describes how different HCI experiences can be more magical, more expressive, more secretive, and more suspenseful. The authors provide a description of what designers need to do to create experiences within these spaces. Marshall et al. [2016] drew on movement based interactions, such as proprioceptive interaction [Lopes et al. 2015], to present a taxonomy for use by designers interested in creating mobile interaction systems for use by a user who is in motion at the time of using it. The authors present a design space similar to that presented by Reeves et al. [2005] in that it is split into four distinct experience areas, and the authors also provide design strategies to address the different dimensions of their taxonomy and how future designers can design their interactions based on each of these spaces. We lean on these examples in this work by also contributing four user experience areas for the design of digital vertigo experiences, and also combine our framework with prescriptive examples in the form of design tactics designers can consult when creating their own digital vertigo experiences.

We consider the works here as inspiration for the Digital Vertigo Experience Framework, as they serve as examples of how designers can not only communicate their findings to other designers, but also how they can provide future designers with examples and tactics to follow in the creation of their own novel systems.

2.4 Research Scope

In order to provide a focused and precise contribution, the scope of the research that helped us to construct the framework is limited as follows:

- This work considers vertigo as a game classification as defined by Caillois [1961]. Therefore, this work is not concerned with the clinical condition of vertigo and associated acrophobia (a fear of heights). This work instead considers digital vertigo experiences: games which induce sensory confusion to facilitate engaging experiences.
- As this is an initial exploration into designing digital vertigo play experiences, we have considered two main interfaces for creating induced vertigo: Galvanic Vestibular Stimulation (GVS) and HMDs. It is possible that designers could explore other technologies to create sensory confusion in players, for instance, Electric Muscle Stimulation [Lopes et al. 2015].
- Some body-based games have shown success in also being used as training tools to improve players' performance in certain sports or activities such as learning trampoline moves [Kajastila et al. 2014], and soccer training [Jensen et al. 2014]. In contrast, the main focus

of this research does not consider the utility of training players of vertigo games to, for example, improve their balance or improve their ability to not experience disorientation.

— The digital vertigo experiences presented in this work are designed to induce sensory confusion in players, but were not designed to purposefully induce motion sickness or make players ill. Although we present tactics to help designers of future vertigo experiences dampen these effects, we have not directly studied whether our games and tactics help to reduce motion sickness in players, instead leaving this for future work.

With this scope defined, and inspired by our investigation into the exciting and interesting background of vertigo experiences, we created three digital vertigo experiences which, along with an exploratory workshop in the initial stages, helped us to construct our Digital Vertigo Experience Framework. Before introducing these case studies, we first provide an overview of our research method.

3 METHODS AND DATA ANALYSIS

To answer our research question, we explored four case studies in order to create the Digital Vertigo Experience Framework. In this article, we mainly focus on the presentation of the framework as the core (previously unpublished) contribution, but for completion, we provide a high-level overview of the research methodology we followed in each of the case studies. A more detailed description of our methodology can be viewed in each of the corresponding case study papers.

As the primary research goal was to create a design framework that guides designers of digital vertigo experiences, we followed a predominantly qualitative research approach [Anselm and Corbin 1998; Bryman and Burgess 1999]. As qualitative research can be advantageous when understanding technology as experience [McCarthy and Wright 2004], we considered it to be the most appropriate method, since a deeper understanding of the quality of the vertigo game experience was necessary in the development of the design framework. Qualitative research involves the collection of subjective—yet open ended—data in order to develop a set of common and recurring themes [Creswell 2003]. To gather these themes we followed the data collecting practice of conducting semi-structured interviews about the experience of playing each of the case studies described in this article.

In *Balance Ninja* and *AR Fighter,* we also employed the use of a five-point Likert scale questionnaire [Allen and Seaman 2007] in order to gain quantitative data about players' perception of playing the game.

3.1 Data Collection: Playtesting and Semi-Structured Interviews

In order to garner an understanding of the experience participants had when playing the games, we first made use of playtesting [Fullerton 2008], before asking players about their experience in semi-structured interviews.

Semi-structured interviews [Wengraf 2001] are often used to understand user interactions with given systems. The interviews can provide more in-depth insights on user experience and how it perhaps felt to interact with systems, something that standard quantitative data (such as recording system information) cannot reveal. We opted to use semi-structured interviews since this afforded the opportunity for follow-up questions, which as Neuman [2006] explains, supports a deeper elucidation of participants' responses and thinking processes. Such an approach complemented our research approach by allowing us to gain a deeper understanding of how users interacted with and felt about the digital vertigo experiences they played.

Some common questions we asked included:

- How did you find it?
- What was the best bit, and the worst bit?
- Did you feel disorientated or nauseous whilst playing?

These questions often led to deeper discussions and follow-up questions which varied from player to player. In the case of *Balance Ninja* and *AR Fighter,* players were interviewed in the pairs they played in.

To support the semi-structured interviews and playtests, we took our own paper notes and also digitally recorded audio and video data of the interviews and playtests. We chose to record this data in each case study as related work indicated this was a good approach for research which involves body movement and digital play [Larssen et al. 2004; Moen 2006; Mueller et al. 2003] since it is possible to support what a player says in the interviews, along with the digital recording of the play experience. For example, if a player said they particularly enjoyed when "x happened," we were able to check this in the playtest video and see the player smiling, validating what they had said.

We describe our data-analysis approach in the next section.

3.2 Data Analyses: Inductive Thematic Analysis

The main method for data analyses we followed throughout the case studies was inductive thematic analysis [Braun and Clarke 2006]. This form of analysis is similar to grounded theory [Anselm and Corbin 1998] in that the inductive approach means the themes identified are strongly linked to the data themselves [Patton 1990] and thus, allows for data-driven coding to occur [Braun and Clarke 2006].

Braun and Clarke [2006], suggest that thematic analysis offers an accessible and theoretically flexible approach to analysing qualitative data allowing the themes themselves to be grounded in the data and ensures that important themes are not missed.

The inductive thematic analysis in this article was conducted in the following way in each case study:

- The interview data was first transcribed.
- Two researchers independently coded the transcripts.
- We grouped the codes together in meetings held either in person or over Skype. The groupings were then translated into recurring design themes.

We considered each turn of speech in the interview to be a "Unit," and in total for each of the case studies, we transcribed and coded (not including interviewer questions and follow ups) over 670 Units. The derived themes are introduced below in each relevant case study section.

4 DIGITAL TECHNOLOGY USED IN THE CASE STUDIES

The case studies made use of one of two primary technologies: GVS, or HMDs. Here we provide a high-level description of each technology we used. Specifics of how they were calibrated and controlled during each study are described in further detail in the associated papers.

4.1 Galvanic Vestibular Stimulation

Caillois suggested that affecting the inner ear (i.e., the vestibular system) directly could help to create vertigo games that do not require large machines or infrastructure. GVS is an electrical stimulation technology which does directly affect the vestibular system; it is a simple and safe way of affecting one's balance by applying a small current (+/− 2.5mA) to one's vestibular system [Fitzpatrick and Day 2004], and is reported to have no lasting negative effects from repeated use

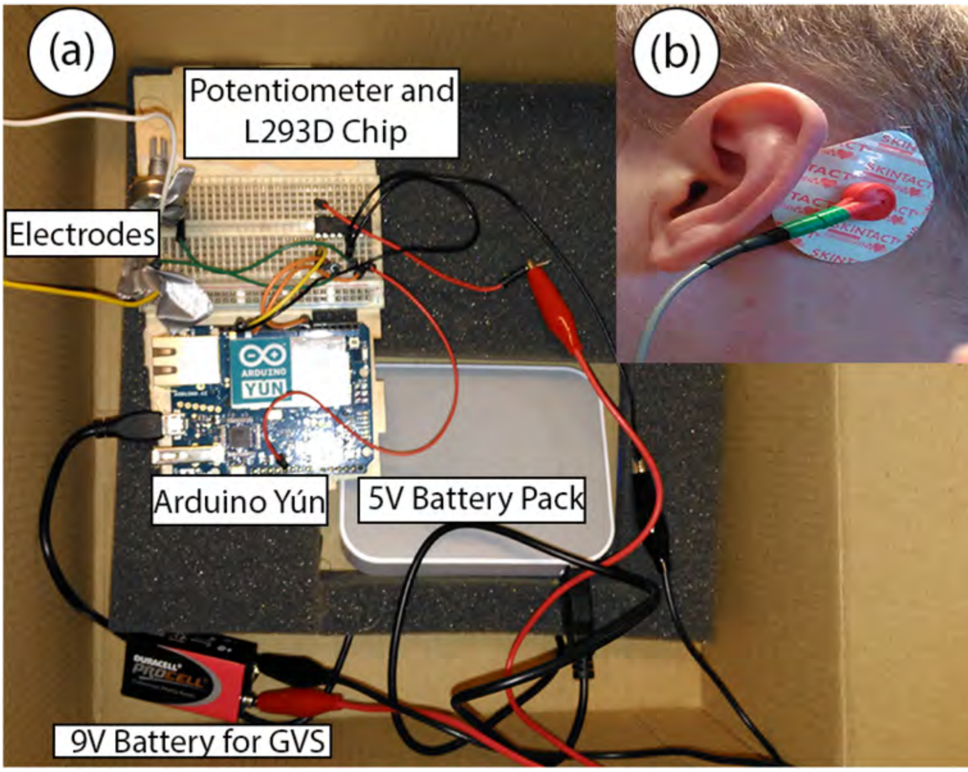

Fig. 1. (a) The GVS system used in the study. (b) GVS Electrode placement.

[Wilkinson et al. 2009]. Electrodes placed behind each ear on a person's mastoid bones deliver a current across the ears, which in turn stimulates the balance organs of the inner ear. The result is that wearers feel a *pull* or *sway* towards the positive electrode, or experience a perception of leaning when they are in fact standing still.

Traditionally, GVS has been used in medical fields such as physiology and psychology to, for example, investigate how walking patterns change when GVS is applied [Fitzpatrick et al. 1999], or as a way of treating neuropsychological disorders [Utz et al. 2010]. Despite the origins of GVS, some HCI designers have appropriated GVS systems for entertainment purposes. For example, Maeda et al. [2005], created a GVS system that allowed an individual to alter the balance of another user via remote control, effectively altering the controlled user's walking direction. Maeda and colleagues found that participants were *"not distracted by the stimulation"* [2005] and were not aware that their altered balance behaviour was a result of the system stimulation. Additionally the work described another prototype in the form of an adapted car racing game that caused a player to feel "centrifugal force" whenever a car turned a corner in the game, adding an extra layer of reality to the racing game by extending the experience directly to the body.

Although we initially investigated the possibility of obtaining an off-the-shelf GVS system, we were unable to readily locate one, so we chose to look to related work as guidance to inform the creation of our own GVS system. Our prototype was built through an iterative design process and the final version used in the studies can be seen in Figure 1.

The circuit of each system consists of one L293D full bridge motor driver chip, which acts as an H-Bridge, which allowed us to pragmatically change which electrode (left or right) is positive. An isolated 9V battery powers the actual GVS circuit, while a 5V USB battery pack powers an Arduino Yún microcontroller. For calibration we also included a 10k potentiometer, which allows for fine-tuning the effect felt by participants. Two 2.5 meter low-resistance insulated wires complete the circuit and are attached to the electrodes. Further details of the system and safety considerations can be read in the corresponding papers ([Byrne et al. 2016b, 2016a].

4.2 Head Mounted Displays

In order to not constrict ourselves to only one digital technology, we also made use of HMDs in *AR Fighter*. This was following feedback and interview findings from the prior case studies, where participants suggested that having their visual perception altered could also be an intriguing addition to the gameplay.

As shown in related work, HMDs have been used to create engrossing games and experiences related to the pursuit of Caillois' vertigo, (e.g., [Sony Pictures Home Entertainment 2016; Tennent et al. 2017; Wood 1895]).

For our case study, we used a simple of-the-shelf HMD which could house an Android phone running a custom Unity application that we created. We based the game off *Balance Ninja*, and we describe *AR Fighter* later in this article.

5 CASE STUDIES

In the next sections, we provide an overview of each of the case studies, along with the sub-research question they were designed to answer. Each study used different participants, with nine (five female) taking part in the *Design Workshop*, ten (two female) taking part in *Inner Disturbance*, 20 (three female) taking part in *Balance Ninja*, and finally 21 (eight female) took part in *AR Fighter*. For more in-depth discussion on each of the studies, we guide authors to the published works which detail each study, system development, and data analysis in full.

5.1 Case Study 1 –Design Workshop

This first case study explored the question: *"What factors are important to begin creating digital vertigo games?"*

To answer the question, we held a design workshop with nine game design students over a period of 3 hours. During the workshop, the participants were invited to design and build lo-fidelity prototypes of vertigo games (Figure 2) in order to explore the topic of vertigo as a design resource in bodily play [Byrne et al. 2016c]. Participants also had the opportunity to experience and use a GVS system as a technology probe [Hutchinson et al. 2003].

In four groups, the participants described five potential vertigo games in total which, following analysis of transcriptions of the group discussion, led to the creation of five recurring design themes for designers of digital vertigo experiences: Control in the Vertigo Game, Structure of the Vertigo Game, Digitally altering player perception in the Vertigo Experience, Intentionally creating Sensory Confusion vs. accidentally creating Sensory Confusion, and the Immediacy of the Vertigo Effect. This case study helped to narrow the focus of our exploration through highlighting that GVS was capable of confusing the user's sense of balance, and that the amount of bodily control surrendered by players, vs. the affect on a players balance was a key gameplay element in the prototypes presented, such as using the GVS to navigate a blindfolded player around a physical maze (made out of chairs in the workshop).

The workshop followed a rapid prototyping structure. Rapid prototyping has been used in HCI [Dey et al. 2001] and game design [Lopez and Wright 2002] successfully as a way of quickly developing and testing ideas. Rapid prototyping can be achieved with lo-fidelity paper prototypes as well as hi-fidelity more realised concepts. As this was an exploratory workshop in order to gain

Fig. 2. Case study 1 – Design Workshop: Participants are busy sketching designs for imagined "Vertigo games."

design ideas through participatory design, we elected to use lo-fi paper based prototyping, which has been shown to lead to similar results at the conceptualisation stage [Sefelin et al. 2003]. This allowed for all of the participants to take an active role in building or playing with the provided equipment (paper, notepads, stationary, poster tubes, stickers, etc.), without any need for special expertise. The discussion of the games was recorded and we transcribed the presentation and discussions to uncover several initial themes and design ideas for the development of digital vertigo experiences following an inductive thematic analysis approach as described earlier in this article.

5.2 Case Study 2 – Inner Disturbance

Inner Disturbance (Figure 3) [Byrne et al. 2016a] is a digital vertigo experience designed for one player. The game challenges players to remain balanced while an induced internal force, via the GVS system, affects their sense of balance. In exploring this case study, we addressed the sub-research question: *"What kind of experience is created when affecting a player's sense of balance with digital stimulation, such as GVS?"*

In *Inner Disturbance,* a player stands on one leg while GVS is applied in an oscillating, pre-programmed pattern. A player battles against this stimulation to remain balanced. Placing their raised foot back on to the floor causes the player to lose that particular round. Each round (up to a maximum of five) increases the level of simulation applied, making it increasingly more difficult for players to remain balanced. Participants were allowed to rest between rounds for up to a minute before proceeding to the next round. Each round increased the difficulty by increasing the amount of stimulation. This amount was derived during an initial calibration stage up to an absolute total maximum of 2.5 mA. Music signified when the system was activated and a gameplay round was being played. A "losing" sound played to signify when players lost a round.

An inductive thematic analysis of semi-structured interviews of ten participants uncovered four design themes for the development of digital vertigo play experiences as derived from the data: Vertigo and System Engagement, Inner Disturbance Challenges and Gameplay Strategies, Stories and Analogies, and Varying Levels of Bodily Control. These insights, along with those of the

Fig. 3. Case study 2 – *Inner Disturbance*: A player battles against an induced GVS force and their own sense of balance, trying not to place their raised foot back on the floor.

initial exploration, informed and framed the development of the next system and study. For example, some players found the game to be less challenging at lower levels of stimulation, and also found the pattern became predictable and easy to overcome. In *Balance Ninja* (described below), we redesigned how the GVS systems worked so that this was no longer the case.

5.3 Case Study 3 – Balance Ninja

Balance Ninja (Figure 4) [Byrne et al. 2016b] is a two-player vertigo game where players battle against both their own sense of balance and the sensory confusion induced via a GVS system (Figure 1) that is controlled by the opposing player. The main objective of the game is to cause the opposing player to lose their balance first and score a point. The first player to five points wins the game. The study allowed us to answer the sub-research question of: *"What type of vertigo game emerges when a player has to both experience sensory confusion and actively participate in the vertigo experience?"*

Players stand facing each other on wooden balance boards, placed on a wooden beam. Each player is attached to his or her own GVS system and has a mobile phone attached to his or her chest. Players compete to score a maximum of five points by getting the other player to touch their balance board to the floor. Players achieve this by leaning from side to side. The direction and amount that the player leans is recorded by the phone and activates the opposing player's GVS system, such that their balance is affected in the opposite direction. For example, if player 1 leans to the right then player 2's GVS system activates on the left, causing their balance to be affected in that direction. When observing the game being played, it can appear as though the players are mirroring each others movements. Through battling in this way players have to strategically choose when they can lean and when they need to fight the GVS stimulation affecting their own sense of balance, as caused by the opposing player's movement.

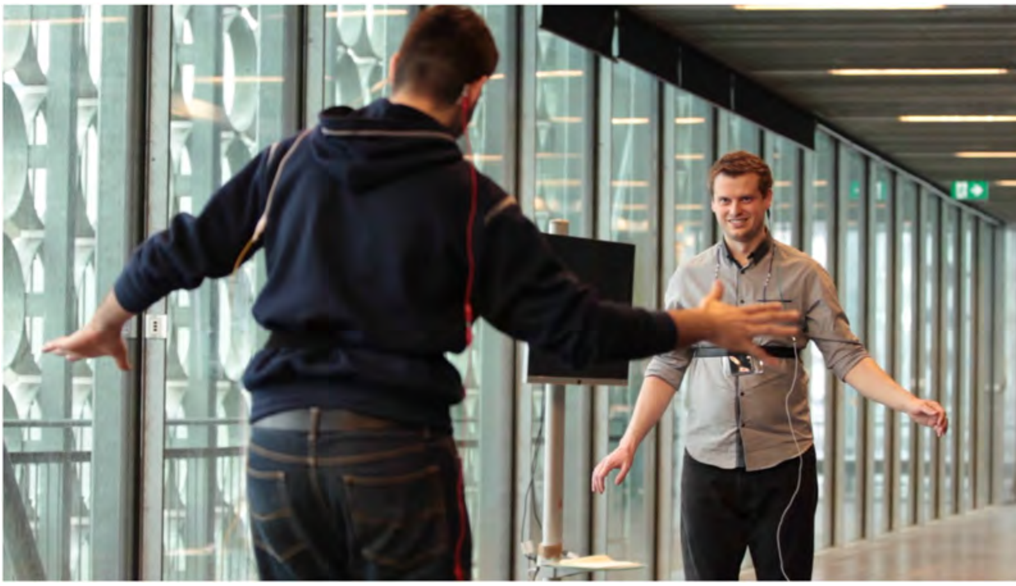

Fig. 4. Case study 3 – *Balance Ninja*: Two players affect each others' sense of balance, as one player leans the GVS of the opposing player is triggered in the same direction of lean. Players attempt to remain balanced and not step on to the floor, battling their own sense of balance and the induced loss of balance from the GVS system.

The first player to cause their opponent to lose five times through touching their balance board to the floor wins the game. The score was displayed on a TV, which was visible to both players and spectators, and music and voice-overs indicate when the game is playing and when a player scores a point.

An inductive thematic analysis of *Balance Ninja* further refined the design themes with three recurring themes total: Experiencing sensory confusion, Vertigo Gameplay Strategies, and finally, Technology to create a vertigo experience. Some of these findings correlate with those that emerged from the previous case studies. Additionally they suggested that another type of vertigo game to consider could make use of a form of visual stimulation instead of GVS. Therefore, these findings encouraged the development of the final case study and further helped us to develop the Digital Vertigo Experience Framework.

5.4 Case Study 4 – AR Fighter

AR Fighter (Figure 5) [Byrne et al. 2018] has a similar premise to *Balance Ninja*, requiring players to try and make their opponent lose their balance first and thus win themselves a point, but uses HMDs to induce sensory confusion instead of GVS systems. The sensory confusion in *AR Fighter* is a result of players' visual perception being manipulated by the HMDs, which is in conflict with their sense of balance. From the results of the previous case studies and design workshop, we opted to experiment with affecting players' visual perception in order to answer the sub-research question of: *"How does using a different method of facilitating sensory confusion, such as an HMD, change or support what we have understood so far about designing digital vertigo play experiences?"*

Players of the previous games had suggested that when playing *Inner Disturbance,* closing their eyes made the game harder, and that in *Balance Ninja,* focusing on visual points of reference was considered a winning gameplay tactic. Therefore, we thought that if we could use a visual method

Fig. 5. Case study 4 – *AR Fighter*: Two players try to keep their balance while their screen view rotates based on the movements of the opposing player.

of inducing sensory confusion it could lead to intriguing insights for the framework as it allowed us to explore an additional method of inducing sensory confusion in players.

The goal of *AR Fighter* is similar to the game's predecessor, such that players battle to keep their own balance, while attempting to cause the opposing player to lose theirs and thus score a point in the process. Once again, the first player to score five points wins the game. Due to the limited field of view when wearing an HMD, *AR Fighter* does not use the balance boards used in *Balance Ninja*. Instead, players stand on one leg in much the same way as *Inner Disturbance*. Players stand facing each other on one leg when the rounds start. As one player tilts their head the horizontal perspective of the opposing player is altered to match the head tilt of the first player. For example, if player 1 tilts their head to the right, then the view of player 2's HMD is mapped to that same angle, creating the impression that they are leaning. This creates sensory confusion in the players as their visual perception communicates that they are leaning, but in reality they are not. Results of the interviews from *AR Fighter* allowed us to consider the previously discovered design themes and tactics and see how they differed when the stimulation method was altered from GVS to visual. The results from this study, in conjunction with the previous studies, allowed us to fully develop the Digital Vertigo Experience Framework.

6 THE DIGITAL VERTIGO EXPERIENCE FRAMEWORK

We now present the Digital Vertigo Experience Framework. This theoretical framework is an abstract understanding of the findings we have obtained through designing and building the case studies described earlier, and in the following sections, we will discuss the framework's creation in full by discussing its component parts: the framework axis, four user vertigo experience areas, and the recommended design space and risk areas to avoid.

Fig. 6. The framework axes.

To support designers and guide them in the creation of their own digital vertigo experiences, we also present a summary of the design tactics as derived from the case studies, and describe them using the language of the framework. We begin by describing the framework axes (Figure 6).

6.1 Y-Axis: Amount of Surrendered Bodily Agency

Body agency is defined as the feeling that "I am in control of generating or causing an action" [Gallagher 2000; Tsakiris et al. 2007]. In HCI, Coyle et al. [2012] describe that the *sense* of personal agency is the distinction between controlling an action and the immediate sense or experience of having done so, i.e., the feeling that "I did that" [Coyle et al. 2012]. The authors also suggest that there are times where this sense of bodily agency can be exaggerated or dampened based on the experience at hand, for instance even though a person's hand moves a stone on a Ouija board there is a dampened sense of bodily agency where that person believes they are not responsible for the movement.

Such instances where an individual knows that they are moving an object, or being moved, but do not know why it could create a disturbing effect, or a sense of panic. With digital technology, such as GVS, we have shown that players found it exciting, if not a little "strange," to have their sense of bodily agency challenged in this way. As the sensory confusion increased, so did the surrendered bodily agency as players found themselves feeling less like "I did that."

Caillois describes this as surrendering to a "momentary shock, which destroys reality" [Caillois 1961]. If players are not willing to surrender their sense of bodily agency then the ability to experience vertigo could be diminished, and with digital technology, we believe designers may have incredible power to manipulate events to create an engaging experience.

Designing to remove one's sense of bodily agency has been explored in similar work and our work has highlighted that players can enjoy the experience of surrendering bodily agency, which is a finding also supported in the work of uncomfortable interactions [Benford et al. 2012], where control is surrendered to another person. In Marshal et al.'s breath-controlled amusement ride work [2011], riders surrender agency to a digital system that monitors their breathing patterns and spins the ride they sit on based on that breathing pattern. The players obviously have to breathe which creates a strange sensory experience as breathing does not usually make you also spin around.

Players of our digital vertigo experiences suggested that the technology made them more willing to feel this strange sensation of dampening or exaggerating their sense of bodily agency, surrendering it as they became more willing to also experience sensory confusion as induced through the digital technology: *"I think I was expecting to experience a loss of control. So I was opening up"* [P2, *Inner Disturbance*]. This feeling was, for some, quite powerful: *"<player 2> essentially threw me off and I stumbled - that was kind of powerful"* [P18, *Balance Ninja*].

Another player expressed that for them the *"best experience is, <when> you're trying to knock over the opponent but at the same time you have to be a bit cautious - it is a fun experience"* [P8, *Balance Ninja*]. This was also apparent in *AR Fighter*: *"so you are trying to mess up your buddy but you are trying to keep yourself in control, yeah that was fun!"* [P7, *AR Fighter*].

In addition to being "fun," it also appears allowing players to experience a loss of bodily agency, and allowing them to regain it led to them questioning and appreciating their understanding of their own senses: *"I tried to feel my balancing senses somehow differently, and <use> different senses to experience, or to, compensate for the <game>, and this is very interesting"* [P2, *Inner Disturbance*].

Therefore, encouraging players to be open to surrendering bodily agency is one of the core challenges for designers to consider when creating their digital vertigo experiences, since if players are not able to surrender much agency, then the type of experience that designers create is limited.

6.1.1 Incorporating the Surrendering of Bodily Agency Into the Design. It is possible to view this initial surrendering of bodily agency as a form of *contract* that the player makes with the game [Salen and Zimmerman 2004], where they agree that they are open to having their bodily agency reduced. This is similar to riders stepping into the cart on a rollercoaster, whereby they are making a contract to experience a ride. When riding rollercoasters, riders do not have the opportunity to regain their bodily agency until the very end of the experience.

We designed each of our digital vertigo experiences to encourage players to surrender at least a small amount of bodily agency from the start. In two of the games, players stand on one leg, surrendering some agency in the process. In *Balance Ninja* we facilitated the surrendering of bodily agency through having the players stand on a balance board, which for players who were not very good at remaining balanced for long periods, created an extra challenge (e.g.,: *"I found balancing on the board quite hard anyway, but it's probably not my naturally good skill set"* [P18, *Balance Ninja*]).

In digital vertigo play experiences, designers also need to consider how to introduce players to the digital technology that will control the extent of facilitated sensory confusion (explained below). To this end, we encourage designers to implement practice rounds into their games, which serve the dual purpose of (1) encouraging players to surrender bodily agency and be more open to the sensory confusion to come and (2) could act as a calibration stage for digital technology that requires it. Players were sometimes apprehensive of the GVS systems, and in the case studies that made use of GVS, the calibration stage served the purpose of gently introducing players to the sensation and guiding them towards surrendering bodily agency. Often, after the players had experienced the GVS sensation for the first time and were affected by it, players were excited to surrender bodily agency further and the experience at hand.

In *AR Fighter,* there was no need for an in-depth calibration stage, but the process of adjusting the headsets to make them fit securely and comfortably went someway to serving this purpose.

Calibration is and of itself an interesting aspect to digital vertigo experiences, present in a variety of experiences. For example rollercoaster carriages are often weighed before launching to ensure the cars reach the top of the ride, and bungee rope tension can be adjusted to match different jump weights. In their paper, Tennent et al. [2019] describe how individuals have different levels of tolerance for extreme sensory misalignment, and how this posed a challenge for the author's to design and recommend different ride experiences for each individual level of thrill. We believe our framework could help guide designers of such experiences by illustrating potential spaces within which designers can gauge how to keep players at their tolerance based on the experience the designers are trying to achieve.

6.2 X-Axis: Extent of Facilitated Sensory Confusion

The sensory confusion axis refers to the extent of sensory confusion being induced in players as a result of the digital stimulation (in our games, this was through the GVS or HMD systems). The higher the level of stimulation, the higher the sensory confusion being induced. When this is combined with reduced bodily agency, different types of vertigo experiences may emerge.

The ability to control the extent of facilitated sensory confusion is extremely important to ensure an enjoyable user experience. Digital vertigo experiences afford this opportunity extremely well since the digital technology allows for fine-grained control over the experience through the use of stimulation technology to confuse the senses, or to sense how disorientated a player has become (for example through the use of body tracking cameras that trigger and alert the system when a player stumbles).

In *Inner Disturbance*, the GVS stimulation oscillates from the left to the right, and through slowly increasing the GVS intensity players start to lean in the direction of stimulation. Therefore, players are no longer directly responsible for this bodily action, and experience a reduction in bodily agency. After a short time, the stimulation switches sides. However, we also made sure that the intensity could not go too high, and thus, did not aim to induce an intense level of sensory confusion, in order to keep the game enjoyable. This also facilitated the ability to allow players to regain a sense of bodily agency (and not be immediately pulled over by the stimulation). Essentially the sensation is strong enough to affect players, but weak enough that people can fight it in an engaging way. In *Balance Ninja* and *AR Fighter*, the ability to regain agency and combat the sensory confusion led to some play rounds lasting longer as players became familiar with combating the sensory confusion. For instance, in *AR Fighter,* some players chose to close their eyes in order to regain some bodily agency, whereas in *Balance Ninja,* players tried to focus on something in the distance in order to distract from the GVS sensation.

The extent of facilitated sensory confusion is the second key factor (in addition to surrendered bodily agency) to consider when designing digital vertigo experiences, and key to the enjoyment of these experiences. As one player remarked, for example: *"being able to have my sense of spatial awareness and balance taken away from me so easily is what I enjoyed"* [P12, *AR Fighter*], suggesting how the ability to digitally induce sensory confusion led to an enjoyable loss of bodily agency.

7 FOUR DIGITAL VERTIGO USER EXPERIENCES

We now revisit the framework (Figure 7) to discuss four specific user experiences and associated risks related to the design of digital vertigo experiences. Each quadrant considers one type of user experience afforded by different amounts of facilitated sensory confusion vs. surrendered bodily agency. We also discuss the risks that designers may face when designing within each user experience area.

Related HCI work, such as the Interaction in Motion Framework [Marshall et al. 2016], and the Spectator Experience Framework [Reeves et al. 2005], have shown that extending the framework language in this way can be a useful method of denoting different types of user experience or design principles afforded to designers. We borrow from these works, and apply their understanding in extending the Digital Vertigo Experience Framework by considering the four areas and different type of experience that designers could create for players, based on the extent of sensory confusion and the extent of bodily agency, the user is required to surrender.

In vertigo play experiences, designers need to balance the extent of facilitated sensory confusion with the reduction in player's bodily agency such that the experience is pleasurable and not too uncomfortable. For example, removing too much bodily agency could lead to players injuring themselves, or creating overwhelming sensory confusion could lead to players feeling nauseous.

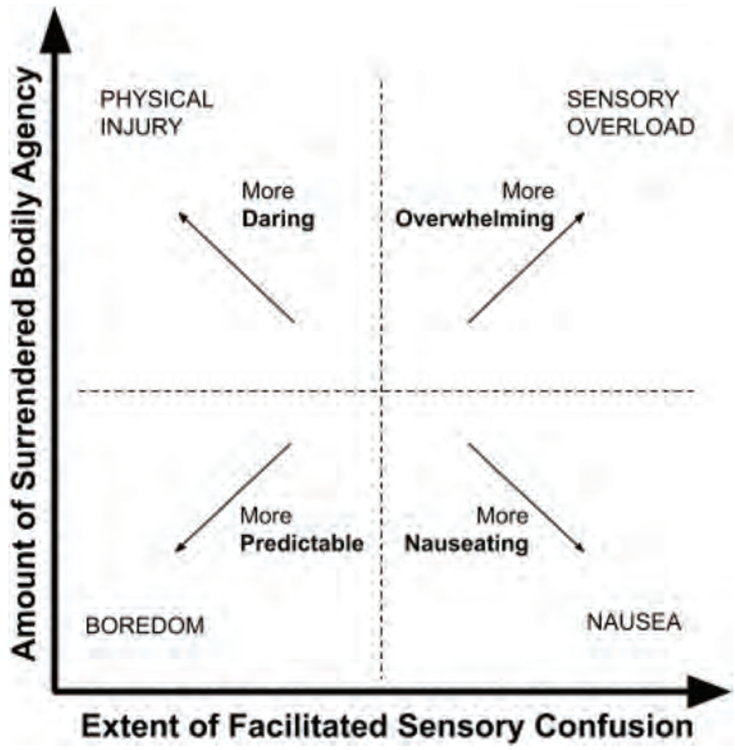

Fig. 7. The framework user experience spaces, and the four possible risks to users if designers go to the extremes of these spaces.

As discussed, it has been suggested that nausea can be reduced in VR games by allowing the player to maintain a level of agency over their movements within the game world [Sharples et al. 2008]. This suggests that for digital vertigo experiences, as the amount of sensory confusion increases, and the longer it lasts, the greater amount of bodily agency should be returned to the player to avoid an unpleasant experience.

For example, in the popular activity of Zorbing, people experience intense sensory confusion for a momentary period of time while rolling down the hill. To recover, they exit the ball and rest until they regain their sense of bodily agency. This is similar to the vertigo activity of spinning in circles until falling over—in order not to become sick, the activity needs to be of limited duration, with a prescribed rest period to return bodily agency when sensory confusion becomes too great.

We see parallels between this "voluptuous" vertigo experience (as Caillois calls it [1961]) and flow theory [Csikszentmihalyi 1991], in that there is an optimal space to keep players in to ensure they experience flow, or in our case, vertigo. With our work, we suggest that digital technology affords the opportunity to optimise the voluptuous vertigo experience. This can be achieved by either altering the amount of facilitated sensory confusion, the amount of surrendered bodily agency, or both.

Designers need to carefully consider the trade-off between reducing a player's bodily agency and increasing sensory confusion, to avoid causing nausea. Additionally, designers could also inadvertently create a "boring" vertigo experience through being overly cautious. Games within the "predictable" area do have their place, but vertigo experiences require some risk to play

[Caillois 1961], and if there is no risk then the designer may not actually create a true digital vertigo experience.

In the following sections, we now expand on each of the design spaces and possible risk areas associated with each.

7.1 More Daring, But Possibly a Risk of Physical Injury

Digital vertigo experiences in this area consist of those that do not facilitate a large quantity of sensory confusion, but do require a large amount of bodily agency to be surrendered. Rock climbing, for instance, would fit within this area and designers can cater to players who want to experience what it is like to surrender a large extent of bodily agency.

In this area, players have surrendered a high degree of bodily agency. As such, they are at risk of losing bodily control and could fall or stumble in gravity-based vertigo games, or crash in speed-based vertigo experiences. The end result is that players are at risk of physically injuring themselves. For the *daring* vertigo experience player, the attraction to experiences within the "more daring" user experience area will be in part due to the reduced agency afforded by experiences within this space, which allows the players to lose more control and take greater risks. To ensure an engaging experience, designers should detect when players are becoming dangerously out of bodily control and are at risk of injury, and can immediately return some agency to the player if the player requests it (some players may choose to take greater risks and not want the game to tell them when to stop playing). Further, designers would need to make clear the risk of playing digital vertigo experiences within this danger area.

7.2 More Predictable, But Possibly a Risk of Boredom

This area is for the novice or more apprehensive player. Designers could choose to start their experiences within this space to help ease players into the experience. By being able to predict what may happen within this area, players would become more open to surrendering bodily agency and perhaps experiencing greater sensory confusion. Therefore, designers could start and end games within this space, or program their games to return to this space if they notice players are getting too out of control or appear to be becoming distressed when playing.

The risk of designing within this area is that designers could end up creating a boring user experience (and are at risk of not creating a digital vertigo experience at all). If designers are too cautious in the designs, then the players may not have the opportunity to enjoy the experience as they will either not be able to reduce agency, or very little facilitated sensory confusion.

7.3 More Overwhelming, But Possibly a Risk of Sensory Overload

Digital vertigo experiences in this area run the risk of being very intense for players. If a large extent of bodily agency is surrendered and a large extent of sensory confusion is facilitated in players at the same time, then players could experience sensory overload, both physically and mentally. This is akin to when you spin around for too long on the spot and then try to walk in a straight line: your bodily senses are telling you that you are going one way but this is confused with your bodily actions of going another way.

This could be an extremely intriguing experience; however, it is one that designers should be careful of keeping their players experiencing for too long. With digital vertigo experiences, designers can choose if they want to overwhelm their players, or try to detect when players get too close to this space, and reduce the facilitated sensory confusion to also allow them to regain more bodily agency. This could be fun for players who enjoy intense sensory confusion and want to repeatedly experience it.

The risk in this area is that it can lead to the most intense of all the digital vertigo experiences, since players could experience intense sensory confusion resulting in sensory overload. Staying too long in this area without helping the player transition back towards the "voluptuous" area could result in the player feeling extremely unwell and unable to carry on playing.

7.4 More Disconcerting, But Possibly a Risk of Nausea

Within this area, players will be generally aware of their bodily agency, but start becoming confused due to the increased sensory confusion. Most VR and HMD games sit within this space where player's proprioceptive and vestibular senses report that they are sitting at their desk and moving their head, but the game starts to trick their visual senses (such as the display going faster than their actual head movement, or even in the opposite direction).

The risk in this area, however, is that of nausea as a result of experiencing intense sensory confusion. This is often what occurs when players experience motion-sickness when playing some VR games, since players know that they are not physically moving (i.e., they have bodily agency), but their visual senses conflict with this information [Sharples et al. 2008]. Again, this is an undesirable area to remain in for too long.

8 CREATING AN ENGAGING SPACE THROUGH EMBRACING A "VOLUPTUOUS PANIC"

The " voluptuous panic" [Caillois 1961] of vertigo can be akin to creating an engaging experience; one that is enjoyable and promoted through changes in sensory confusion. We believe that the "voluptuous panic" Caillois describes is not a negative experience, but an enjoyable one. In vertigo games, there is an inherent disorientation or confusion involved, which can be exciting, or perhaps also *scary* at times. But, as shown by the allure of horror games and films, or daredevil activities, the sense of momentary panic can be engaging for those who enjoy it. We believe that this is also the case for digital vertigo experiences, and that different players will have different desires of how much sensory confusion to experience, or how much bodily agency they are comfortable in surrendering. However, for the experience to remain enjoyable we believe that designers need to be careful not to move too far into the extremes of the framework (even those who enjoy being scared could tire of repeat frights!).

In our framework, we denote an "engaging space" (dotted line in Figure 8) which serves to illustrate the boundary that we encourage designers to stay within for each of the four "risk areas" previously described. We recommend designers to avoid allowing players to venture too far into these risk areas, and encourage designers to detect if players approach these areas. Based on the type of experience designers wish to achieve, they could then choose to have the game immediately alter the facilitated sensory confusion and/or allow players to regain bodily agency to promote an engaging experience.

We believe that creating an engaging experience is core to Caillois design thinking around non-digital vertigo experiences. We can see similar challenges within our own design space and believe that digital technology can present opportunities to help designers to keep players within an engaging space. Although, we do admit that it could be interesting to see what designers create when purposefully moving players out of the suggested engaging space, but wold discourage designers from doing this too often.

8.1 Digital Opportunities in Vertigo Play Experiences

Below, we list some example opportunities afforded by digital technology that could be used by designers to help players remain within an engaging space. Although not an exhaustive list of

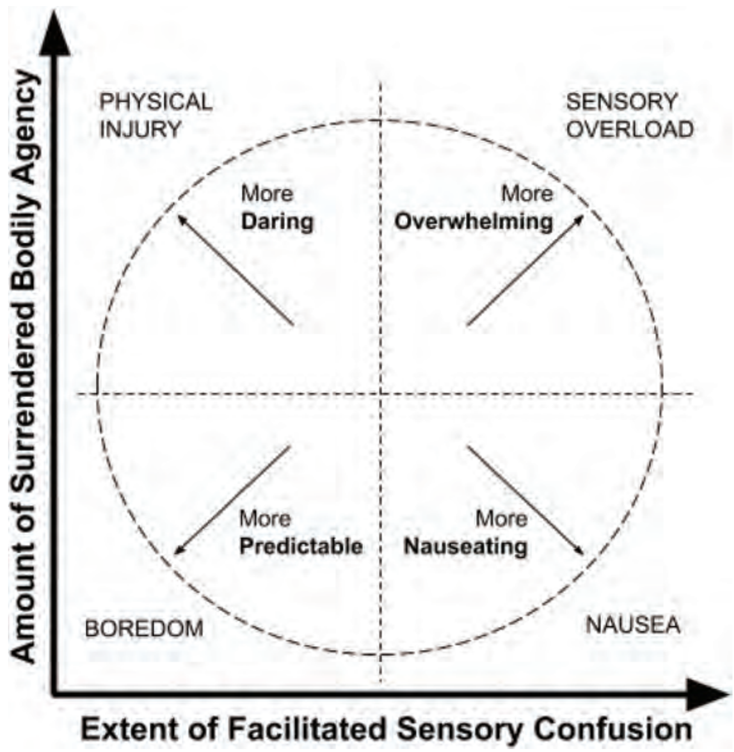

Fig. 8. The framework user experience spaces, and the recommended space for designers to remain within (dotted line).

suggestions, we hope that they serve as initial inspiration which, alongside using the Digital Vertigo Experience Framework, could inspire the creation of their own digital vertigo experiences.

8.1.1 Digital Opportunity 1: Make the Sensory Confusion Public. The sensation of vertigo is a personal one that is felt internally. Although in extreme cases, this disorientation is visible externally through swaying when walking, or discolouration if severely nauseous, in vertigo experiences, the sensation is usually private. If the GVS system of *Inner Disturbance* would be bundled inside of a hat, for example, then spectators would not know why the player was not able to balance with ease. Reeves et al. [2005] would refer to this as a "secretive" experience.

Alternatively, designers could choose to create what Reeves et al. consider an "expressive" experience through displaying the sensory confusion to others. For example, when building the early prototypes, we programmed an LED to illuminate when the GVS stimulation was activated. We could easily have extended this functionality to a larger display, allowing the sensory confusion to be witnessed by the spectators who watched our participants playing *Balance Ninja*, or shown what each player was seeing in *AR Fighter* on a big screen outside of the play area.

Although it is possible to judge how individuals may be enjoying rides (for instance queues are designed to allow waiting riders observe what is to come and build anticipation), the work of Walker et al. [2007] goes further by displaying the riders' telemetry and personal bio-metric data (e.g., heart rate) to observers. Showing such personal and *internal* sensations or feelings is something the digital affords over simply observing the external. For example with digital vertigo experiences perhaps designers could even combine GVS and HMDs to allow spectators wearing

HMDs to observe an augmented reality view of the GVS stimulation being applied to the players in real time. Extending the experience to observers or more players means that designers also have the opportunity to create interesting multiplayer type experiences, or include audience members in the game by having them vote for who the stimulation should be applied to and the number of votes denoting the intensity. Such interactions are an opportunity that are mostly afforded by the digital relative to non-digital experiences, and we believe it is exciting that designers can be imaginative in designing how they display or extend the sensory confusion to spectators.

8.1.2 Digital Opportunity 2: Create an Automated Sensory Confusion Feedback Loop. Digital technology is able to not only induce levels of sensory confusion, but also able to sense body movement as a result of this confusion. In theme parks, ride operators observe the riders and have control over whether to speed up or slow down the ride based on how the riders are enjoying it. Naturally, researchers have considered how technology could be appropriated to also do this job and even create personalised ride experiences [Rennick-Egglestone et al. 2011]. Similarly, digital vertigo experiences could take advantage of the opportunities afforded by digital technology to automatically monitor a player and adapt the game's sensory confusion according to their actions.

For example, HMDs can affect an individual's sense of balance, causing them to sway, and this amount of sway can be monitored through technology such as a Kinect sensor. Designers could either choose to automatically reduce or increase the level of stimulation based on what the Kinect observes, creating a sensory confusion feedback loop. For example, if *AR Fighter* would be setup in this way, players could battle a mirror version of themselves e.g., their sideways movements would be detected by the sensor which would in turn alter the visuals based on this information. If this was also combined with another stimulation technology like GVS, then designers could create games that combine both *AR Fighter* and *Inner Disturbance's* gameplay mechanics.

Similarly, designers could choose to reduce the stimulation if the technology detects that the player is starting to lose too much bodily agency, and automatically detect the losing condition of the player placing their raised foot back to the floor. Recent work has examined automatically calibrating digital stimulation systems [Knibbe et al. 2017] and designers could extend these works to not only automatically calibrate digital vertigo experiences, but to adjust them based on a user's performance. For example, exertion games have taken advantage of the subtle adaptive opportunities afforded through digital technology by having games adapt to player ability, and even balancing the games in such a way that allows an experienced player to play a novice with both having an engaging experience [Altimira et al. 2016; Mueller et al. 2012b].

Through inducing an automated sensory confusion feedback loop, designers are offered the opportunity to design varied and adaptive play experiences into the same game.

8.1.3 Digital Opportunity 3: Share the Sensory Confusion Across Players and Observers. Using digital technology to control the sensory confusion affords designers the opportunity to explore novel vertigo game experiences where sensory confusion is shared across players, as we did in *Balance Ninja*. This is something we believe is only achievable with digital technology and could be expanded to create digital vertigo play experiences that involve more than two players, such as a three-player game where the sensed movements of two players affect the movements and confuse the senses of the third player.

Sensing and stimulating across players can be further explored, including allowing players to re-experience previous game attempts, or even the attempts of another player through the stimulation technology replaying recorded sessions. This expands on popular racing games which often show a "ghost" image of a friends lap, or a player's previous attempt as a mechanic to encourage said player to beat their time. Similarly, digital vertigo experiences could allow players to also "feel" their previous attempt.

Additionally, the portability and low cost of some digital technology mean that stimulation devices could be reproduced on a large scale quite easy, and when connected together wirelessly would allow for each device to be triggered simultaneously. For example, we can imagine it being quite exciting and engaging to be a spectator watching someone risk a daring climb and in addition to watching the experience, "feeling" it as well.

The experience does not even have to be localised and could be shared over a distance, as HCI work has shown this is possible with sporting activities [Mueller et al. 2003, 2007, 2010], and Computer Supported Cooperative Work work suggests that networking is good at scaling to large numbers over both distance and time [Johansen 1988]. Therefore, players could even challenge their friends to a game of *Balance Ninja* even though they are not in the same geographical location.

We hope designers see the above as initial examples of potential digital opportunities. Of course vertigo experiences do not have to be purely digital, and traditional (non-digital) vertigo games can be fun as shown by "powerful machines" [Caillois 1961], and the plethora of traditional vertigo experiences. However, we are excited by the possibility of extending vertigo experiences to the digital realm, and investigating how to take traditional game experiences and apply vertigo elements to them is also an exciting space to explore, (e.g., persuasive games where players can get a "sense" of the avatars movements). We encourage designers to think of their existing experiences and use the above, along with the Digital Vertigo Experience Framework to either create new and engaging digital vertigo experiences or augment their own games with vertigo elements, and are excited to see what different types of experiences emerge in the near future.

8.2 A Question of Time

Not represented in the framework is the parameter of "time." Generally speaking, existing vertigo experiences can last for a long time (e.g., rock climbing) or have short moments of intense sensory confusion (e.g., Zorbing). Usually the difference with whether an experience should be lengthy or short is due to how great the extent of facilitated sensory confusion is, along with how much bodily agency has been surrendered.

For example, the related works plotted in Figure 9 move within the design space over time, so are generally plotted where their intended outcome is likely to be within one of the four risk areas: more daring, more comfortable, more overwhelming, and more confusing. For instance Zorbing is designed to, for a time, create intense sensory confusion and remove as much agency as possible, so it appears in the top right of the graph.

With regards to the extent of facilitated sensory confusion, designers can choose to build this "extent" over time, as with Benford et al.'s trajectory examples [2008], or deliver a large amount of confusion (e.g., a high pull to the right from a GVS system) immediately. Further, digital vertigo experiences could move around this space throughout the duration of gameplay, allowing players to experience many different types of digital vertigo games, e.g., some may be short, some long and gradual, some full of moments of intense confusion and surrendered agency, and then periods of little stimulation. We encourage designers to choose an area they wish their experience to mainly be in, and consider only moving into or through other areas as a matter of necessity (e.g., when introducing players to the game in the "predictable" area), or as infrequently as possible to avoid overwhelming the player.

9 TACTICS FOR DESIGNING DIGITAL VERTIGO EXPERIENCES

Throughout this article, we have presented four different case studies, each of which have examined the design of different types of digital vertigo experiences. Each study uncovered recurring themes and associated design tactics for the design of digital vertigo experiences based on the studies that preceded them. Below, and in Table 1, we provide a summary and overview of the

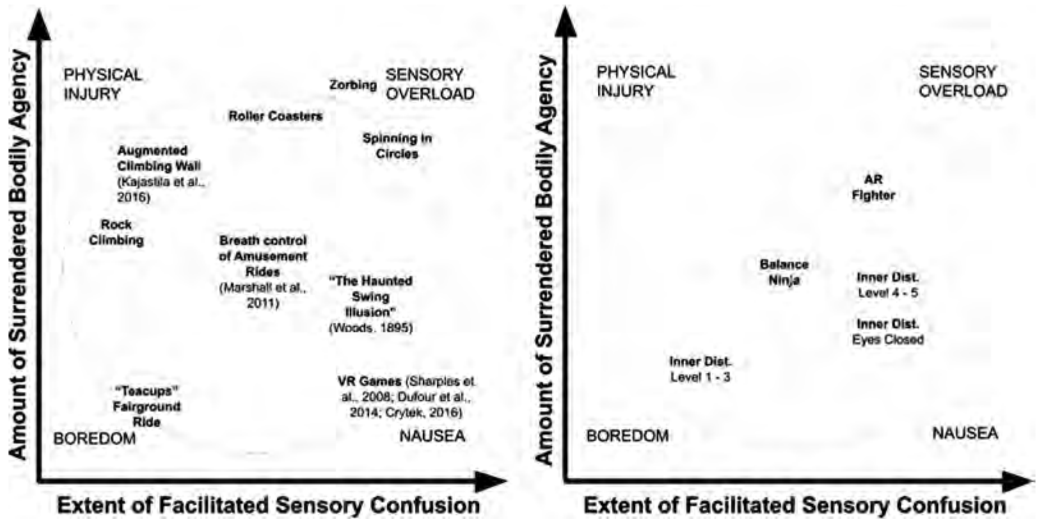

Fig. 9. An example of where within the design space relevant related work (left) and our vertigo experiences (right) would appear within the Digital Vertigo Experience Framework.

Table 1. A Summary of the Tactics from Each of the Digital Vertigo Experiences Presented in Case Study 1-4

Group Name	Inner Disturbance	Balance Ninja	AR Fighter
Engaging vertigo	Alter a player's sense of bodily control to keep the experience from being too challenging or too boring through the level of stimulation applied	Design game environment to enforce the facilitation of sensory confusion	Discourage players from regaining bodily control through ignoring facilitated sensory confusion
Narrative acts	Incorporate the use of an unfamiliar interface to create sensory confusion into the gameplay	Use a narrative arc to prepare the players for the different vertigo sensations	Ease players into experiencing sensory confusion and surrendering bodily control
Limiting familiarity	Work with or against a player's expectation of vertigo	Use vertigo interfaces unpredictably to avoid players becoming desensitised	Dynamically adjust sensory confusion based on a player's surrendered bodily control
Player ability		Support players of different abilities through altering the amount of removed bodily control, or the level of stimulation applied	Allow players to recover from repeated or extreme periods of facilitated sensory confusion by allowing the regaining of bodily control
Subtlety of stimulation		Design for the subtlety of the stimulation technology	

tactics presented in this work grouped by their common principles. We view these tactics as our recommendations for designing digital vertigo experiences, and encourage designers to read the more in-depth presentations of the tactics as discussed in related work [Byrne et al. 2016b, 2016a, 2016c, 2018].

9.1 Engaging Vertigo

Tactics grouped under this heading relate to creating an engaging digital vertigo experience. Players commented in the case studies how at times they were able to overcome the sensations they were experiencing and even cheat the game. These tactics provide examples that designers can use to help avoid that from happening in their own experiences. For instance in visual-based digital vertigo experiences (e.g., HMDs) designers can track whether players' eyes are open or closed and penalise players if they close their eyes. Alternatively, in GVS experiences, designers need to design an aspect of the game to distract the player so they can not employ, for example, the strategy of concentrating on a point on the floor (reported in *Balance Ninja*).

9.2 Narrative Acts

Each of the vertigo experiences presented followed a three stage process: (1) a calibration stage where the HMDs were fitted or the GVS systems attached and calibrated for each player; (2) the gameplay; and (3) the removal of the systems and after-effects. The tactics within this grouping provide designers with ideas of how to incorporate each of these stages such that it supports an engaging digital vertigo experience. For example, leaning on the work of Benford et al. [2012] who describe Freytag's narrative pyramid structure [Freytag 1863] as a way of promoting an engaging gameplay experience, we encourage designers to see stage (1) as the rising action, (2) as the climax of the experience, and (3) as the falling action.

Designers can use the calibration stage as a way of easing players into the experience, allowing them to gain trust in the stimulation system such that they are prepared to surrender bodily agency in the next stage of gameplay (this could even be achieved by incorporating a tutorial level into the game). Game designers could consider the after-effects stage as a way of creating a desired after effect (e.g., fatigue in players [Mueller et al. 2012a]), and design their digital vertigo experience to result in players feeling a certain way (e.g., did they feel or thought they had a "daring" or "overwhelming" experience?).

Moving through these narrative acts also provides designers with a method of understanding when to apply digital stimulation, and hence facilitate sensory confusion in players, and also when to remove or return bodily agency to players. Therefore designers of digital vertigo experiences can lean on this narrative acts as a way to structure their experiences.

9.3 Limiting Familiarity

An issue observed in *Inner Disturbance* was that players quickly became used to the repetitive nature of the stimulation being applied. The predictability of this pattern can be advantageous in early game rounds or tutorial stages but through prolonged gameplay sessions could lead to a "boring" experience.

Designers could choose to start games in the predictable area in order to encourage players to open up to the experience to come, allowing them to understand how the sensory confusion will be administered and in turn encouraging them to surrender greater bodily agency. Similarly, familiarity could be used to help players re-orientate themselves after a period of intense sensory confusion (e.g., after an experience situated in the "overwhelming" area). However, designers should try to facilitate sensory confusion at key points of the gameplay such that players do not get used to the experience through repeated play sessions. For example, in *Balance Ninja* and *AR Fighter*, the predictability of the stimulation is limited as the sensory confusion is based on the movements of an opposing player.

9.4 Player Ability

These two tactics detail how to support players of different physical abilities. As digital vertigo experiences affect the vestibular system, a player's adeptness at balancing is a factor in the experience they may have. Designers can choose to purposefully create a difficult experience if they desire, but should allow players the ability to assess the risk in playing, such that they do not injure themselves with playing.

When playing against an opponent, designers could choose to *balance* the game [Altimira et al. 2013] such that the more experienced player is penalised in some way, and the less-experienced player supported in order to allow the players to play with each other in an engaging way.

9.5 Subtlety of Stimulation

Designers are free to experiment with different types of digital technology to facilitate sensory confusion in players of their own digital vertigo experiences. In our experiences, we used HMDs and GVS systems to achieve this. GVS was slightly problematic for some players of *Balance Ninja* who were unsure of if the system was affecting their opposing player. This was also referenced in *AR Fighter* where players explained that due to the disorientating nature and limited field of view afforded to them, they found it on occasion difficult to locate the other player or see if their movements were affecting the opponent.

Designers should consider how to display feedback to the players (or spectators) about what is happening with the systems. Some examples of achieving this are described earlier and in our prior case studies [Byrne et al. 2016a, 2016c, 2018]. On the other hand, designers may wish to embrace the ambiguity afforded by sensory confusion systems like GVS so that players are surprised by what happens in the game. In these cases, consideration would also need to be given as to how to ease players into the experience such that they are open to surrendering bodily agency and do not fight the induced sensory confusion when they start to experience it.

10 FRAMEWORK SUMMARY

The Digital Vertigo Experience Framework is the result of all four case studies described throughout this article. Through the knowledge gained from the iterative development of three different digital vertigo experiences, and the design workshop, we identified the core parts of the framework. Namely, for digital vertigo experiences, the relationship between the extent of facilitated sensory confusion vs. the amount of surrendered bodily agency of players is paramount to the different types of user experience that designers could create.

We presented four types of user experiences in total: more daring, more overwhelming, more comfortable, and more confusing. We have also highlighted that designers are free to move within these different user experiences. In fact, it is highly likely that through the duration of gameplay players will move, from one area to the next (such as from more comfortable at the start to one of the other areas as sensory confusion or surrendered bodily agency increases). Moving through each axis can be achieved in different ways, for example, it is easier to surrender bodily agency through manipulating the environment (e.g., have players balance on balance boards or stand on one leg), whereas moving through sensory confusion (x-axis) is achievable by increasing the amount of stimulation applied (e.g., stronger GVS or increased visual disorientation). Exploring how to traverse the design space in interesting ways, we see as an exciting area and opportunity for future work.

Additionally, the framework describes four different risks that designers need to consider when developing digital vertigo experiences, and we have suggested designers avoid designing games within these areas by keeping within an "engaging space."

The four risk areas are: risk of nausea, sensory overload, physical injury, and boredom. They occur at the extremes of each experience area and suggest designers reduce facilitated sensory confusion or increase bodily agency if the system detects players are in these risk areas for too long. The exception to this is "risk of boredom," which may occur if the game is too safe as a result of limited surrendering of bodily agency, and little facilitated sensory confusion. In this case, we have suggested designers stay in this space only during tutorial stages or at the start and end of gameplay to ease players into the experience, or return them enough agency that their senses are not too overwhelmed after a long play session.

Finally, we revisited the recommended design tactics, which are described in-depth throughout the case studies, providing a summary here to serve as a convenient reference for designers.

11 CONCLUSION

With this work, we set out to explore the research question:

> *How do we approach the design of digital vertigo experiences?*

The Digital Vertigo Experience Framework is our contribution to this discussion. With the presentation of our framework, we aim to inspire and encourage both designers and developers to explicitly design for digital vertigo experiences. It is possible that designers may deviate from our recommendations, and still create enjoyable vertigo experiences; however, we offer our own practical examples and design tactics as initial inspiration to assist such designers in the development of their own novel digital vertigo play experiences.

The framework was derived from the findings and analysis of four case studies (A design workshop [Byrne et al. 2016c], *Inner Disturbance* [Byrne et al. 2016a], *Balance Ninja* [Byrne et al. 2016c], and *AR Fighter* [Byrne et al. 2018]), each of which contributed recurring design themes, as uncovered from a qualitative analysis of the user experience of playing the games. In addition to serving as inspiration for future work, and to encourage designers to think of not only designing digital vertigo experiences explicitly, we have also offered our advice on possible user experiences that could be derived from different types of digital vertigo experiences.

We encourage designers to not only use this framework as inspiration, but also to use it in validating their own digital vertigo experiences, and to help guide them in the design of different types of vertigo user experience. In the future, we look forward to seeing our framework being enhanced and adapted through more user experiences as designers continue to explore and create new, novel, and exciting methods of inducing vertigo in players.

We believe that the discussion into how to design digital vertigo experiences is only just beginning, and we look forward to seeing how our work encourages the design of future vertigo games, and what types of exciting experiences designers come up with.

11.1 Future Work

Below we suggest some possible future work for designers inspired by the framework presented in this article.

11.1.1 Combine Different Stimulation Methods. In this work, we explored GVS and HMDs as the main ways of facilitating sensory confusion in players. However, we never combined them to see what an experience would be like for a player wearing both a HMD and a GVS system. Our work identified that in order to overcome the GVS sensation, players could focus their vision on a point in the distance, and that closing their eyes when wearing a HMD allowed them to take a break from the visually induced sensory confusion. It would be very interesting to combine both stimulation methods such that closing one's eyes when wearing a HMD and GVS system would result in the GVS sensation becoming too extreme, or trying to focus on a point in the distance would be interrupted by some on-screen event. Additionally it would be of interest to explore and identify other digital technologies that could be used to facilitate sensory confusion in players.

11.1.2 Validate Different Game Ideas and User Experiences with the Framework. The design space within the framework serves as initial inspiration and encouragement for the development of

Digital Vertigo Experiences. Yet designers may wish to use the framework to help them validate their own use cases and methods of creating digital vertigo experiences. Designers could, for instance, use the framework to help them situate their existing games, and then look to see how they want to adapt the games to make them more overwhelming through facilitating greater sensory confusion, or perhaps dampen the experience by reducing this and moving players more towards the predictable area of the design space. Doing so would further help to foster what we believe is an exciting field for designers and developers.

11.1.3 Validate the Framework Through a Design Workshop. We note that a limitation of this work is that the framework has not been fully validated. As we present this work as inspiration and initial recommendations for designers, we acknowledge that the next logical step would be to validate the framework in practice. We plan to achieve this through a design workshop, where designers of body-based games will be presented with the framework and tasked with creating digital vertigo experiences.

11.1.4 Identify Different Ways of Inducing Sensory Confusion. GVS and HMDs are only two ways of inducing sensory confusion in players, and as future work, we plan to look at other existing ways of creating non-digital vertigo games, and seeing how we could appropriate them in to the digital realm.

11.2 Final Remarks

We believe that vertigo games are fun to play and experience. They challenge the body in ways that allow the player to experience sensations that are uncanny and exciting. As children we often enjoy the discovery of these exciting experiences, and as adults we look to thrilling and evermore exotic methods to achieve the same feelings, such as going to theme parks, or racing fast cars. Yet with digital technology, we have the opportunity to create exciting and thrilling digital vertigo experiences at home, without the need for expensive ride infrastructure.

As a group of people who enjoy the pursuit of vertigo, understanding how to translate the design of such experiences to the digital realm was the biggest challenge of this work. However, with the design tactics and Digital Vertigo Experience Framework to serve as inspiration and guidance, we expand our understanding of designing digital vertigo experiences, and in doing so, help to expand the range of exciting body-based games we play.

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