Balance Ninja: Towards the Design of Digital Vertigo Games via Galvanic Vestibular Stimulation

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ABSTRACT

Vertigo – the momentary disruption of the stability of perception – is an intriguing game element that underlies many unique play experiences, such as spinning in circles as children to rock climbing as adults, yet vertigo is relatively unexplored when it comes to digital play. In this paper we explore the potential of Galvanic Vestibular Stimulation (GVS) as a game design tool for digital vertigo games. We detail the design and evaluation of a novel two player GVS game, Balance Ninja. From study observations and analysis of Balance Ninja (N=20), we present three design themes and six design strategies that can be used to aid game designers of future digital vertigo games. With this work we aim to highlight that vertigo can be a valuable digital game element that helps to expand the range of games we play.

Author Keywords

Vertigo; play; ilinx; movement-based games; exertion games; vestibular stimulation.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

INTRODUCTION

Caillois [6] highlights that vertigo is one of the four key categories of games and play, explaining that activities such as spinning around, rock-climbing, skiing and dancing are positive play experiences that arise through the encouragement of disorientating and confusing the players' senses. Digital games have mostly considered vertigo as a negative side effect of bodily play experiences, and should therefore be avoided.

Figure 1. *Balance Ninja.*

However, some game designers *have* considered vertigo in their designs. In these explorations, visual stimulation is often used in the form of Virtual Reality (VR) to create virtual vertigo experiences, such as rock climbing games [9,13] or to create the illusion that the player is walking over precipices [21]. Non-visual stimulation has also been used such as using physical force feedback to move the players' body through the use of special ride machinery [31], or through combining both visual and physical stimulation to create, for example, an immersive VR skydiving experience [14]. In each of these above examples, vertigo is created as a second-order response to an external stimulation (altered vision, or the physical and forceful movement of the body) to create novel and fun experiences, yet in digital games, designers appear to consider vertigo as a negative effect, and something that has the potential to make players feel nauseous, for example in the case of VR 'simulator sickness'.

In contrast, we believe vertigo could have a role to play in digital games, and in particular, believe that digital technology offers novel opportunities to facilitate unique and engaging play experiences not previously possible. Unfortunately, little has been written concerning the design of digital games that use vertigo as a core design element. Yet, whilst designing for digital vertigo games has not generally been considered in a structured way, recent advances in areas such as VR have led to a resurgence in the development of game designs involving vertigo elements, such as VR flying experiences [8,22]. As such, we believe that now is a good time to explore vertigo within digital games in greater detail.

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In order to facilitate this, in this paper, we describe a novel vertigo game system called *Balance Ninja,* which directly stimulates the body's balance organs in order to confuse and disorientate players' senses. We achieve this through the use of Galvanic Vestibular Stimulation (GVS). In *Balance Ninja*, players must battle to keep their balance whilst under GVS stimulation triggered by an opposing player. GVS is a simple and safe way of affecting one's balance by applying a small current (+/-2.5mA) to one's vestibular system [16]. Electrodes placed behind each ear deliver the current and the user feels a *pull* towards the anode, and also feels a loss of balance in that direction. We see GVS as having the potential to take a pivotal role in digital vertigo games and therefore begin our investigation here.

In the following sections we first explore background work on vertigo games and GVS before describing our GVS prototype. The design and implementation of *Balance Ninja* and a description of our user study follows. We employed a thematic analysis of interview and video data captured during the study in order to provide insight into the gameplay experience of *Balance Ninja*. Studying participants' experience of the game allowed us to address our research question: *"how should we design digital vertigo games?"*

With this work we aim to encourage game designers to consider vertigo in their games through making the following contributions:

- A proof of concept design of a vertigo game system.
- Three themes derived from analysis of the player experience of *Balance Ninja*.
- Six design strategies for designers of digital vertigo games, useful for practitioners who want to utilize vertigo in their game design practice.

BACKGROUND

To design digital vertigo games, we must first understand how vertigo has been considered in game design and what it is about vertigo games that people find compelling.

Vertigo can be medically defined as "a sensation of motion <…> in which the individual or the individual's surroundings seem to whirl dizzily" [33]. Intuitively, it would seem that such sensations should be avoided in digital game design. However, we note that these sensations can be the basis for a range of popular non-digital play activities such as skiing, racing fast cars and ballroom dancing [6]. Similarly, sports psychologists highlight that "the pursuit of vertigo" [1] is the main attraction behind certain gameful experiences such as rock climbing [1,25]. We therefore believe that vertigo might also be valuable in digital game design, especially bearing in mind that the role of the body is increasingly considered in digital play experiences. Caillois calls activities that draw on such sensations ilinx or vertigo games [6] and describes them as consisting of "an attempt to momentarily destroy the stability of perception and inflict a kind of voluptuous panic on an otherwise lucid mind" [6](p23). In this work, we lean on Caillois' definition of vertigo games and extend it to include digital games, defining digital vertigo games as: digital games that digitally alter the stability of player perception, creating a pleasurable panic for the player.

Unfortunately, prior work has suggested that Caillois' thinking is not easy to incorporate into digital games. For example, Salen and Zimmerman highlight that Caillois' vertigo definition "falls outside the boundaries of games" and that the vertigo classification goes "beyond a description of <digital> games" [43]. Conversely, Bateman [2] has discussed the "joy of ilinx", describing how vertigo can actually be a potent force in digital games, suggesting that high speed racing and snowboard simulation games, for example, can heighten the player's enjoyment of the game through artificially inducing a state of vertigo in the players. He notes that the vertigo of digital games is not the nausea-inducing kind, but echoes Caillois' sentiment that it is a "vertiginous" experience. Bateman reflects that "very little has been written about the ilinx of videogames", which further suggests that Caillois' vertigo understanding may have previously proved difficult to translate into digital game design.

We propose that this shortage of literature about drawing on vertigo in digital games is perhaps why designers of body-based physical games have not considered designing games with vertigo as a central design element. For example, designers of exertion games [39] have looked to traditional videogame design whilst moving focus more and more toward the human body, yet do not consider vertigo explicitly. Similarly, Hämäläinen et al. [19] collate several body-based games that consider the use of gravity as a design resource, involving apparatus such as trampolines and gymnastics rings that could indirectly create a feeling of vertigo in players, yet knowledge about vertigo is still limited when it comes to designing body-based games that explicitly draw upon vertigo.

Prior work suggests that current play experiences that facilitate the emergence of vertigo do so as a second-order effect to the body being moved, in other words, an external force moves the player's body to create instability in players' perception that then can result in feelings of vertigo. For example, Cheng et al.'s *Haptic Turk* requires a group of players to physically move another player whilst they 'fly' through a VR world [8]. More commonly, however, players are moved through the use of specialised machines in order to facilitate feelings of vertigo, for example through rollercoasters and other amusement park rides [14,31].

In VR, early experiments identified that people could experience vertigo within a virtual world [34] and more recently there has been interest in creating entertainment and commercial experiences of vertigo through the use of VR. For example the design studio *Inition* presented a virtual vertigo experience [21] requiring participants wearing a 3D headset to walk across a real-world plank that appeared in the VR world to be suspended between two tall buildings. A series of fans were also used to simulate high altitude winds, further enhancing the experience. Similarly, based on the idea of exploring heights in VR, Dufour et al. [13] created a mountain climbing game where players can see a generated mountain terrain via a 3D headset and climb the mountain through controller input. Likewise, *The Climb* [9] also allows players to traverse mountain trails within a VR world. These works exploit acrophobia - a fear of heights - to create a vertigo experience. Exploiting a fear of heights could be one potential way of designing vertigo games, however, Caillois describes vertigo games as causing a *voluptuous* (pleasurable) panic for the player, which suggests to us that there are other opportunities to facilitate vertigo in digital games beyond drawing on uncomfortable interactions [4].

Despite these initial explorations around vertigo experiences, designing for vertigo as a direct part of digital games has not been readily explored. With our work we see an opportunity to address this gap in design knowledge by providing game designers with an understanding of how to design digital vertigo games. As such, we address the research question: "*how should we design digital vertigo games?*"

Galvanic Vestibular Stimulation

Our review of related work highlighted that most existing related games use indirect methods of creating vertigo, i.e. they move the player's body through external forces, provide visual stimulation or draw upon a fear of heights. In this section, we describe an additional technique: Galvanic Vestibular Stimulation (GVS). GVS is a technology that directly affects the player's vestibular system by inducing sensations of vertigo within the inner ear. GVS has the advantage that it is a simple and mobile system that can easily be digitally controlled, and therefore lends itself to being connected with other sensing and game elements.

Traditionally used in physiology [17] and psychology [44], GVS is a digital system that is described by Fitzpatrick and Day as a simple and *safe* way to elicit vestibular reflexes [16]. GVS affects a person's vestibular system and hence their balance through the electrical stimulation of the vestibular system via electrodes placed on the mastoid bones behind each ear. The resulting effect is that wearers feel a *pull* or *sway* towards the positive electrode and thus the system affects one's sense of balance in that direction. Repeated use of GVS results in no deterioration to global function [47], and only minor itching from electrode placement [45].

Designers have considered the possible applications of GVS, for example Nagaya et al. [38] investigated altering a person's visual perception and balance based on the playback of music tuned to the GVS stimulation, whilst Maeda et al. [29] adapted a GVS system to allow one person to affect another's balance via remote control. Maeda et al. [30] have also investigated GVS in VR environments, finding that in a VR setting, GVS can increase one's sense of self-motion. GVS has also been explored as a practical training tool, for example, Moore et al. [35] used GVS as a training tool for astronauts to simulate post-flight effects. Such applications highlight the versatility of GVS and also the control one may have over the stimulation applied in order to achieve specific effects. Using such a technology in game design could allow designers of body-based games to have control over how the player's body internally reacts to gameplay.

GVS, we propose, could be adapted and used to realise the design of vertigo games. Caillois even suggests that as we get older we seek more exotic and extreme measures to experience the feeling of vertigo he defines - from simply spinning playfully in circles as a child, to needing what he calls "powerful machines" (e.g. spinning fair ground rides), to experience the same feeling as adults [6](p25). Interestingly, Caillois suggests that if a system existed such that it could affect the balance organs of the inner ear (which is what GVS does), such powerful machines may not be necessary anymore [6](p26). With GVS, we have a technology that can facilitate feelings of vertigo and can be digitally controlled. Furthermore, GVS can be mobile and cheap to build (as we demonstrate in the next section), and therefore lends itself to be used in digital games.

GVS PROTOTYPE

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 study can be seen in figure 2a.

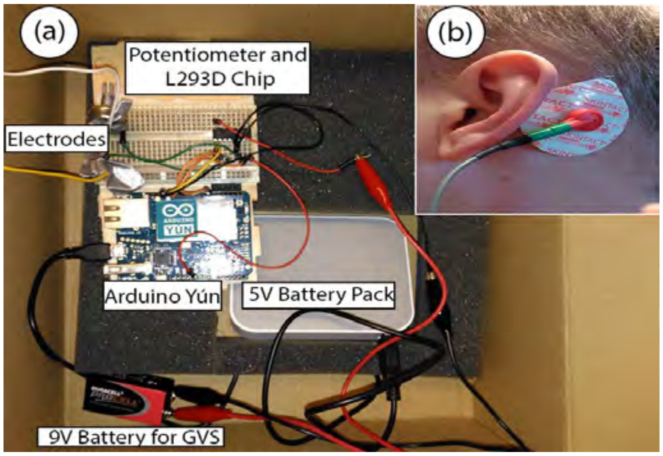

Figure 2. (a) The GVS system used in the study, (b) GVS electrode placement.

For our study we made two identical systems. The circuit of each system consists of one L293D full bridge motor driver chip, which acts as an H-Bridge, allowing us to change which electrode (left or right) is positive. An isolated 9V battery powers the actual GVS circuit, whilst 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 as explained below. Two 2.5 meter low resistance insulated wires complete the circuit and are attached to the electrodes (see figure 2b).

Safety Considerations

The system was designed for safety reasons such that the maximum current of the GVS system could not go above 2.5 mA. We chose this number since related work indicates good performance from 1 mA - 2.5 mA [17,37], and it is far less than the recommended maximum of 5 mA [10].

Although the GVS circuit is relatively simple (essentially a small current of no more than 2.5 mA alternating via an H-bridge), we made sure that the system would be as safe as possible to use in our study. Also, due to the effect of GVS causing an individual to lose their balance, we took the following precautions when using the system:

- We designed our system to be modular, and thus come apart under physical stress. If a participant were to stumble excessively (which did not happen during our study) we made sure that the cables easily detached from the breadboard. We also used snap-style electrode connectors, which could "pop" off under stress.
- We made sure that no physical obstacles that could cause harm during play were near participants. This included the deliberate choice not to use soft mattresses or crash mats next to the game. As the balance boards are only a few inches from the ground, players recover very quickly by stepping onto solid ground. A soft surface may have caused players to actually stumble and trip when recovering.
- The system was controlled remotely from the researchers laptop (players could not activate it, but could deactivate by detaching themselves), and we ensured a stop button was available to the researcher that would immediately end the game and any stimulation, should a participant feel uncomfortable or in the case of any excessive stumble.
- Two researchers were present during the studies to assist participants if needed.

The above were assumed precautions, and during the study the stop button did not need to be pressed, nor did anyone lose his or her balance in a dangerous way.

BALANCE NINJA

Balance Ninja is a balance game for two players. Both players stand on their own wooden board (which we call a balance board) resting on a shared wooden beam (see figure 1) and both players are attached to their own GVS system. Players also wear a pouch containing a tight-fitting Android mobile phone, and the accelerometer readings taken from the phone affect the other player's GVS system. For example, if player 1 leans to the left, the GVS of player 2 creates a pull to the right for player 2 (and vice versa). The more player 1 leans, the greater the level of stimulation applied to player 2. The maximum stimulation is applied when players are leaning around seven degrees from the vertical, which, although a noticeable lean, is not enough that a player would lose their balance without the extra stimulation being applied.

Figure 3. Player 1 (left) smiles as he wins the round when player 2 touches his balance board to the floor.

The object of the game is to cause the opposing player to lose their balance and either step off their board, or touch their board to the floor (see figure 3). The game is not turn-based and thus players are free to "attack" at any time. A point is awarded to the winner of the round and the first player to reach five points wins the game. Each round has music playing in the background, the end of which signals that the round is over and a voiceover indicates that, for example, player 1 lost the round and player 2 was awarded the point. Points are displayed on a scoreboard from a laptop visible to both players and spectators.

STUDY PROCEDURE

Before playing *Balance Ninja*, players had to prepare by first attaching the phone pouches around their chests. The electrodes were then attached to the mastoid bones of each participant by either the lead researcher or participants themselves, in which case the lead researcher checked the connection and placement. Next, the GVS systems were calibrated.

As individuals can have a different level of skin impedance it is necessary to calibrate the GVS system. In other words, one player could be affected at a much lower current than another player. To calibrate the system, participants were asked to stand on their balance board one at a time and their GVS system was turned on and the current slowly increased by the researcher until the player lost their balance (by touching their board to the floor). We stopped increasing the current and the maximum setting for that player was derived. Calibrating the system was also a necessary safety precaution since it ensured that players would not experience stimulation higher than their comfort level. This process was then repeated for the second player.

Players were given a one minute practice round to familiarise themselves with balancing on the boards and the GVS sensation. After this practice round the game started properly. Each game session was started and stopped from the researcher's laptop, with music signalling the start of each round and that the GVS systems were activated.

When a point was awarded (i.e. a player won a round) gameplay paused and the systems were deactivated between rounds. Following the game, participants were detached from the GVS system before they were asked to remove the phone pouches and electrodes. They were then invited to take part in a post-game interview with the lead researcher.

Participants

We recruited 20 participants to play *Balance Ninja*, (17 Male, 3 Female), aged between 23 and 51 (*M*=29, *SD*=7.4). Participants, on average, played videogames at least 4 hours per week. Only one participant said that they did not play videogames at all. Participants were recruited via the university mailing list, word of mouth, and interest generated from watching the game being played.

Ethical Approval

Ethical approval was obtained prior to the study and precautions were taken to ensure safety to the participants. Each participant was thoroughly briefed and asked to provide informed consent prior to playing the game and taking part in the study. Play sessions occurred in the open atrium of the computer science department of the university, during the working day when first aid personnel were also available.

Data Collection

Data was collected through the use of video and audio recordings of all gameplay sessions, pre and post game setup, and participant interviews. We used both video and audio due to the open nature of the study venue and wanted to ensure responses could later be transcribed correctly. Audio and video was taken with participants' consent and in total around two hours of video and audio were recorded.

After each play session, which lasted typically no more than five minutes, participants were interviewed in pairs using a semi-structured interview schedule, which lasted an average of six minutes. Following the interview, participants were also invited to fill in a short 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) questionnaire about the game to elicit a quantitative understanding of their experience.

Data Analysis

We employed an inductive thematic analysis approach to the data, as described by Braun and Clarke [5]. Participant interviews were transcribed from the audio and video recordings of the interview sessions and the completed transcripts were exported for qualitative analysis. Two researchers independently consulted their own copy of these transcripts. We consider each turn of speech in the transcripts to be 'Units', and thus, excluding interviewer questions, there were a total of 206 Units to consult, each of varying length (short answers and longer responses). In order to garner meaning from these Units, both researchers designated their own codes and description of the codes to the Units as they deemed fit. Following this process, a meeting was held where the researchers consulted and refined their codes until a final agreement resulted in a total of 10 codes. These codes were then further examined and referenced with the transcripts to search for overarching themes, which were again reviewed by both researchers in another meeting. This approach resulted in three overarching themes in total.

RESULTS

In this section we detail the responses to the participant questionnaire and also describe the three overarching themes that we derived from our analysis of the data: Game and GVS Feelings, Balance Ninja Gameplay, and finally, Balance Ninja Technology.

Questionnaire Responses

Likert responses are illustrated in figure 4. Participants generally found the game fun, citing positive responses with a Median (*M*) of 4 and Median Absolute Deviation (*MAD*) of 0.5, with participants also agreeing that they would play the game again (*M* = 4, *MAD*=0). Participants had mostly neutral responses to the GVS sensation being uncomfortable (*M*=2.5, *MAD*=0.5), however, participants mostly agreed that the GVS sensation was subtle (*M*=4, *MAD*=1). We received mostly neutral responses to participants being in control of their body and also feeling disorientated (*M*=3, *MAD*=1), and finally, participants mostly found the game difficult to play (*M*=4, *MAD*=0.5).

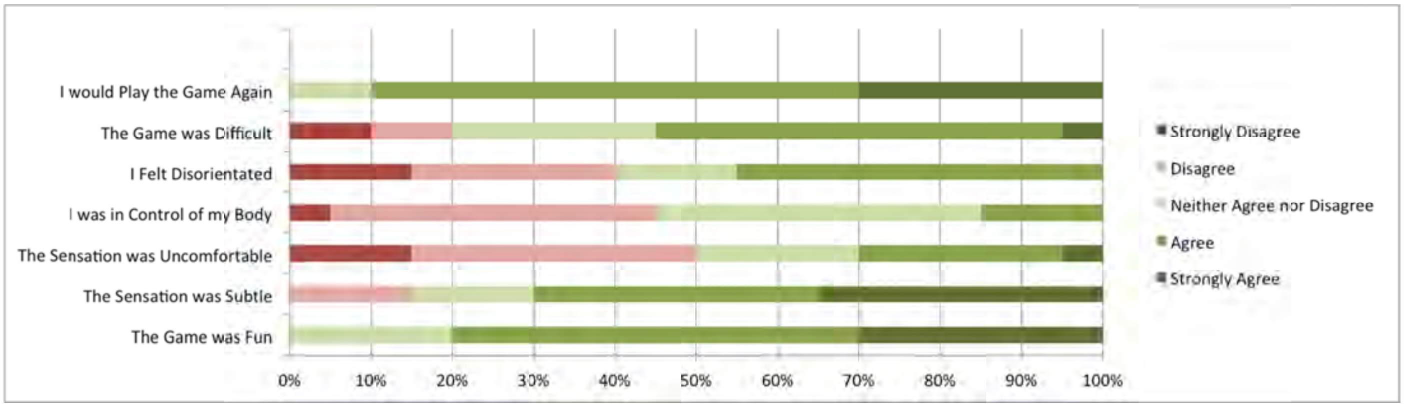

Figure 4. Participant (N=20) responses to *Balance Ninja's* Likert questionnaire.

Theme 1: Game and GVS Feelings

This theme describes 112 of the 206 Units and is divided into four categories: Feeling of GVS (82), After-Effects (9), Vertigo (6) and finally Game Enjoyment (15). We had expected to receive a high number of Units describing GVS as we asked participants how it felt playing the game. However, we did find that participants were eager to discuss the feeling, and often required little prompting to describe their experience of the game and of using GVS.

Feeling of GVS

Participants explained how the GVS sensation was new: *"the feeling itself was really, like new to me, except for when I was drunk!"* "*The best bits were just how weird it was, it was just, like, different"*, *"I've never known <anything> like that before!"* Participants did not appear to find the GVS sensation uncomfortable or unpleasant: *"I wouldn't say uncomfortable in a bad sense. If there was any discomfort it was in the playful sense, so all good"*, *"it didn't hurt, it was very comfortable"*, *"I think it wasn't any feeling of un-comfortableness"*. In fact, participants were often not aware that there was any stimulation being applied: *"I didn't feel anything <laugh> actually. I felt the sensation of not being balanced"*, finding any sense of the stimulation to be subtle in nature: *"mine felt subtle, I didn't know I was falling over until I fell over!*" This is important for us, since we did not want to make an uncomfortable gameplay experience, although some research has shown that uncomfortable interactions can be an attractive design element in games [4,20]. However, it is important to stress that there is obviously a difference between *uncomfortable* and *painful*, and no participants reported the game or the GVS as being painful. The main discomfort reported by the participants was interestingly not the GVS sensation or the gameplay but the process of removing the electrodes.

Feelings of vertigo

When asked if they had experienced vertigo whilst playing, participants generally agreed that they had experienced vertigo: "a*fter a bit I could definitely feel it as a dizzy-ness, like a vertigo feeling that really made me sway"*, *"I think it's a pretty good approximation <of vertigo>." "Vertigo? Yeah it did feel relatively similar actually, the stronger sensations there definitely equate to that kind of feeling"*. Some participants were unsure if they experienced vertigo at first, asking if we actually meant acrophobia: *"vertigo is the fear of heights right?"* However, in such instances we reiterated our definition, which often led participants to agree that they did actually experience vertigo: *"um, I think under your definition for me I did achieve a degree of 'vertigo', yes. That's true, there was disorientation and a definite unusual state about it"*.

After-effects

Although participants did not report any pain or discomfort, some reported on interesting after-effects they experienced, saying that they felt: *"just a bit weird after, yeah"*, *"I kind of, like, almost had to sit down just for a little bit to almost relax for a little bit, but I don't know if that's because we were trying to balance for ages and just standing on firm ground was not a balance thing*", *"I just felt slightly less control, I felt a little bit wobbly"*. Participants likened the effects to those felt post-exertion, such as: *"<it felt> like coming off a trampoline"*, *"yeah, when you're not on the trampoline <anymore> you feel really weird",* which could have been due to the nature of using one's legs to keep the board balanced, resulting in muscle fatigue from doing so. To note is that although participants indicated that they experienced some post-game feelings, the feelings did not last very long *"uh afterward you feel a bit of a hangover just for like 10 seconds maybe, 5 or 10 seconds"*. *"When I first stepped off I felt quite awkward, <and> not sure whether to move or stay still for a second, but that cleared quite quickly"*. By the end of the interviews none of the participants showed any sign that they were still experiencing adverse post-game effects, explaining that in the case that they had felt anything after the game, it had subsided quickly as they regained their sense of balance. We also note that a vertigo game such as spinning around in circles leaves the player feeling dizzy for a while afterwards, which is actually the desired result. For our players, playing *Balance Ninja* seems to have resulted in a similar experience.

Game enjoyment

The feelings of vertigo also led to participants expressing how they had enjoyed playing the game "*the best thing was the two occasions I got where it was really clear that the game was actually affecting my sense of balance"*, *"the best bit was when I did feel it, the kind of visceral feeling almost when you actually go: 'actually this thing has made me unbalanced'"*. Participants described the game as cool and fun, *"it was good I enjoyed it"*, *"I think it is really cool"*, *"yeah, it's a cool kind of game, definitely", "that was really good and fun"*. This was really important as we purposefully designed the game to be difficult and physically challenging to play through affecting players' sense of balance, but more importantly we wanted the game to be fun to play.

As well as participants enjoying the sense of their own balance being affected through GVS, participants also expressed that their sense of fun came from their ability to control other players, *"it was fun, as a game perspective trying to make the other person feel what I was feeling"*, *"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"*. The post-game questionnaire responses support these findings, showing that participants positively agreed that the game was fun to play.

Figure 5. Player 2 (right) loses the first round, and concentrates on their breathing technique to remain balanced in the next round.

A concern of ours when we decided to use GVS to affect player balance in a digital vertigo game was that players could have found the effect uncomfortable, and, due to the disorientating nature of the game, unpleasant. However, in our game this did not appear to be the case and participants enjoyed playing. Participants offered suggestions for future games, such as a GVS controlled vertigo horror game: *"in a horror game, if you got that feeling at a crucial moment, that would make it a lot more fun, and, like, seem more real"*, suggesting that they would be eager to not only play *Balance Ninja* again, but future digital vertigo games. We also observed a sense of playful engagement emerging between players with participants regularly laughing when they lost and joking with each other at the attempts of another player to cause them to lose their balance. None of the participants wished to stop playing during the study and, as the questionnaire responses suggest, 90% of the participants would play the game again, with the remaining 10% neutral about replaying.

The game also appeared to invoke other gameful states, such as competition, with participants commenting when asked about the best bit: *"winning was the best bit-" "-and losing was the worst!" "The best bit was that I won! I don't win anything so I'm going to take this one and enjoy it." "<The best bit was> winning! <Laughs>"*. These comments about wining and an eagerness to play *Balance Ninja* again suggest to us that participants did view *Balance Ninja* as a game, which further suggests that digital vertigo games could be adopted and appreciated by players and not seen just as novelty experiences. In *Balance Ninja*, participants played in pairs so generally played against their friends or colleagues, which may have also facilitated the sense of competition amongst the participants. However, for vertigo games of more than one player we predict that the co-located nature of these multiplayer vertigo games would likely result in friends playing primarily together, so believe that the sense of competition arose from the gameplay as well as playing with friends. Participants even suggested games that they would like to play with their opposing player in the future, for example that they: *"like<d> the idea there's cerebral gladiators out there <who> don't need sticks to knock people over"*, which refers to a game where players traditionally knock each other off podiums with padded sticks.

Theme 2: Balance Ninja Gameplay

This theme was present in 78 of the 206 Units and we have divided it into four categories: Game Strategies (21), Game Feedback and Difficulty (42) and Game Fairness (15).

Game Strategies

Participants displayed varying tactics to win the game, such as trying to stand still, *"there were definitely times where I felt the best strategy for me was to try and stand as still as possible"* and using their own breathing techniques to remain balanced, *"yeah I did Pilates, <laughs>"*. This particular tactic can be seen in figure 5, where player 2 loses a round, but employs breathing techniques to avoid losing in the next round. Alternatively, for some, the best strategy was not to remain still, but to move in order to put the other player off balance, *"little quick twitches were good"*, *"Yeah that's how he got me!"*

Participants also found that if they distracted themselves and readjusted their focus they could remain balanced, *"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"*. Participants also expressed how finding the right amount of movement was part of the fun of the experience *"you're trying to knock over the opponent but at the same time you have to be a bit cautious - so it is <a> fun experience"*, also explaining that the learning curve and finding the optimal strategy was important to the gameplay: *"figuring it <the game> out <...>, once you've got a strategy off you go. It definitely was a game, at the end"*, "*if I do this <quick side to side movements>, too much body movement would be costing me to lose"*.

Game Feedback and Difficulty

Despite finding winning tactics, participants did express difficulty in playing the game due to being required to balance, *"so I found balancing on the board quite hard anyway, but it's probably not my naturally good skill set"*, *"if I just stood still I could see the other person swaying and go back and forth, as soon as I tried to do it as well then I* *just couldn't!"* Some of the perceived difficulty could be due to the game not providing much feedback to players, *"what's difficult is the fact that I did something in it that affected <the other player>, but I couldn't obviously see that"*, *"yeah sometimes I find it, I'm not sure I'm controlling the other player, am I really controlling him, or <is> he just losing <balance> by himself?"* We did explain to participants that it was leaning the upper body that would affect the opposing player's GVS system, but it apparently seemed more intuitive and a more natural body movement to move the balance board instead: *"also, I wasn't sure if it was tilting the board that got the effect. I knew, because you told me in the beginning, that the phone was the actual tilt sensor, but the natural feeling for me was that I should try tilting the board"*.

This confusion over what player actions controlled the GVS stimulation led to participants suggesting to include visual or audio feedback to confirm the system was working: *"I would have liked some feedback, so I could see what part of my movement was having an effect. Apart from the effect on the other person I wasn't sure if it was actually working"*. With *Balance Ninja* we assumed that seeing the opposing player moving would be feedback enough, but perhaps in some digital vertigo games additional visual feedback may be required, particularly if designers are aiming to alter perception in a non-intuitive way.

Game fairness

Finally participants suggested further improvements. such as ensuring both players started the rounds fairly: *"often when the rounds started, you <player one> were already leaning!"* The GVS systems were activated at the start of each round, so if one player was already leaning then the opposing player would receive a higher level of stimulation than the leaning player from the very start of the game until that player stopped leaning. Interestingly participants also offered ways of making the game harder to play, such as including sensors in the balance board itself: *"so you'd make it harder as* you'd *have to rock the board without touching the ground"*. This suggested to us that game fairness is subjective, i.e. there were participants who enjoyed the challenge and wanted more, whereas there were other participants who found it too difficult playing against players who had better control over their balance, indicating that for vertigo games, like other body-based games, matching player abilities is something that could be considered.

Theme 3: Balance Ninja Technology

This theme relates to participant discussions concerning the digital and physical technology we used to implement the game. 24 of the 206 Units were described by this theme, which we derived from one category code: Game Technology (24).

Balance Board Setup

In *Balance Ninja* the balance boards were not attached to the beam but placed on top, which led to difficulty for some players in maintaining their balance: *"the balance board itself I thought, perhaps, was not very well designed"*, *"I didn't like the wooden thing, it was too easy to fall off and it was too difficult to kind of, reset"*, and suggested that the boards should have allowed players the ability to lean further: *"I should have been able to lean more before I fell off"*. We observed that at first participants seemed to prefer moving the board whilst keeping their body vertical, but quickly learned that they needed to lean their upper body and try not to move the boards to experience the game and the GVS effect properly. We designed *Balance Ninja* purposefully to encourage this upper body movement and lean, but did not anticipate that participants would find it difficult to grasp at first. Although, participants did offer that they quite liked the way the balance boards facilitated the balance aspect of the gameplay: *"I didn't mind it I thought it was good actually, I thought it was a good balance board for this"*. However, for multiplayer digital vertigo games perhaps consideration needs to be given towards supporting players of different balance abilities, and how the game environment can facilitate this support.

For example, our GVS vertigo game required players to be off-balance to exaggerate the GVS sensation. Simply applying the stimulation is not enough to easily achieve this off-balance sensation. In our experience the affect is exaggerated when in motion (i.e. either off balance or walking). Therefore, in supporting players of different abilities designers would need to consider the best way to make the gameplay environment adaptable to facilitate the off-balance sensation.

Electrodes

Finally, participants described the 'worst' part of the game to be the removal of the electrodes, usually because of their hair getting stuck to the electrode adhesive: *"yeah the worst was trying to get rid of the <electrodes>, <because of> my hair"*, *"it was a bit sore, to be honest but that was partly because I got some hair caught"*. What we found interesting with our study was that participants described only the electrodes as being uncomfortable to remove or the worst part of the game, suggesting that both *Balance Ninja* and the actual GVS sensations were not unpleasant to experience. Unfortunately GVS requires electrodes or some other conductive material to use, in much the same way as similar technology like Electric Muscle Stimulation (EMS) does so. However, we see an opportunity for incorporating this necessary step into the gameplay by encompassing the main game within a compelling narrative that enforces an intro (calibration and setup) phase, and an outro (removal of electrodes) phase to the gameplay.

DISCUSSION: STRATEGIES FOR DESIGNING DIGITAL VERTIGO GAMES

Here we articulate six design strategies that we derived from our data analysis, informed by the recurring themes and participant feedback that we have previously described. These strategies are for designers of future digital vertigo games to guide the development and design of these games, based on our experience and study of *Balance Ninja*.

Design Physical Game Setting to Support Vertigo Stimulation

Some of our participants were able to win repeated rounds of the game by employing tactics that helped them limit the GVS effects. They uncovered these tactics during the course of playing the game, with one player, for example, focusing their vision so that they could concentrate on not losing their balance. With GVS, the effect is weakened when people focus hard on visual balance cues [11], so designers could dampen this tactic by considering visual elements which distract the player, for example by using head mounted displays or blindfolds to remove any visual cues.

Another popular technique was to try and remain as still as possible and focus on not moving. The balance boards were designed specifically to make it so players had to constantly balance. We could make this more pronounced by actuating the surface on which the person is standing, so it occasionally shakes or wobbles, to require the players to respond. Marshall et al.'s breath controlled bucking bronco ride [31] employs a similar tactic, by deliberately jolting riders in an attempt to cause them to fall off once they reach the final difficulty level. In response to our findings we suggest designers of vertigo games would need to consider how to design the game settings to enforce the vertigo effects.

Create an Appropriate Narrative for Digital Vertigo Game Acts

In our game, there were essentially three acts: setup, gameplay and post-game. Setup involved calibration before use, and post-game involved removing the electrodes and the after-effects of GVS stimulation. Considering this, designers could lean on the work of trajectories [3] and videogame narrative [23] to creatively explain why their players must wear a system and engage in a calibration process. For example, a mind control game could involve players trying to gain control over another, requiring them to wear a futuristic helmet with the GVS inside which, in turn, would affect another player. Or, in a supernatural horror game, players could wear mobile GVS systems that activate when an imposing presence is near by, causing them to momentarily lose balance when trying to run away. Designers could also employ the use of trained actors to perform the setup stage, in a role appropriate for the particular digital vertigo game. For example, Yule et al. [48] investigated the role of using docents in mixed-reality games, finding that the role of the docents improved the player experience. These docents were trained in the use of the system and acted as guides who also helped to explain *why* players were performing their particular tasks, all whilst remaining in character. As such, we recommend to designers to consider an appropriate narrative for digital vertigo game acts, and how to support the different acts.

Consider the Type of Feedback Provided to Players due to the Subtlety of Vertigo Sensations

As confirmed in our interviews, GVS is a subtle and nuanced sensation that also suffers from an inherent latency of approximately 200mS [17]. This resulted in a delay in players feeling an effect, which at times could have led to some of our players questioning whether the system was working. Providing simple visual or audio feedback of when the GVS system was working, and what intensity of stimulation was being applied, could have helped to alleviate concerns that the system was not working. However, in other game genres, such as horror games, the subtlety of the sensation and the ambiguity of how the system is affecting players could in fact become the core strength of the game design. Designers of vertigo games who want to create this type of experience could consider ambiguity as a design resource [18] to decide the level of feedback that is most appropriate for their vertigo game. As such, we recommend designers consider if highlighting the subtlety of vertigo through additional feedback in their games is the appropriate choice for the type of digital vertigo game experience that they are trying to create.

Design Digital Vertigo Games for Players of Different Abilities

Some participants discussed that they found balancing on the balance board to be difficult, whereas others found balancing quite easy. Those who found balancing straight forward often said during the interviews that they usually had quite a good understanding of their balance due to sports or meditation activities they frequently pursued, such as Pilates. In multiplayer videogame design balancing players of varying abilities is often achieved by limiting the abilities of experienced players, whilst providing a greater advantage to weaker players [7]. Similarly, exertion games have adapted the effort required from individual players based on the players' level of fitness [36].

However, for multiplayer-digital vertigo games, designers need to consider how the player is affected by two factors: 1) the environment, 2) the stimulation. For example, in *Balance Ninja* simply helping the weaker player to balance by making the board stationary (the environment) would not help if they were also affected strongly by the GVS stimulation. Conversely if a player is good at balancing, giving them a higher level of stimulation than the weaker player may also be unfair as they may be particularly sensitive to the stimulation applied.

For single player digital vertigo games, designers do not need to consider how to match players of different abilities, however, they could perhaps use the game as a training tool such as, for example, helping players learn to ride a unicycle. In exertion games Kajastila et al. [24] found that combining trampoline training with a platform video game improved players trampoline abilities, and perhaps the same could be true for digital vertigo games aimed at improving player balance. Designers would therefore need to consider what type of multiplayer game they want to create and in particular if they want to cater to players of different abilities, similar abilities, or design the game so that it has flexibility to support both ability types.

Design for the Invasive Nature of Digital Vertigo Technology that Affects the Body

Sensing people can often be achieved in a non-invasive manner. For example, the Kinect can be used to detect people's state of balance from a distance [26]. However, technologies such as GVS, EMS [27] or haptics often require some form of direct attachment to the body, such as the gel-electrodes used in *Balance Ninja*. We can see two potential ways designers can respond when using these technologies: the most obvious is to attempt to minimise the invasiveness of the technology, for example by using headbands with embedded conductive foam for GVS; alternatively, we could take the approach of Marshall et al.'s [32] breathing sensor gas masks, where they embrace the discomfort of the sensing method, and make it part of the experience. We suggest designers consider how to design for the invasive nature of balance altering technology for digital vertigo games, and how such technology affects the body.

Use Vertigo Interfaces Sparingly to Avoid Players Becoming Desensitised

Vertigo can be subject to desensitisation effects. These effects are different to simply learning or gaining competence in playing the game, but are more related to players becoming used to and expecting the stimulation. For example, repeated long term exposure to GVS can cause familiarity and an ability to overcome the effects [12]. This means that if vertigo-inducing stimulation is overused, digital vertigo games may no longer be exciting to play. To reduce chances of players becoming overly familiar with the sensation, designers should be mindful of using the vertigo interfaces too excessively. For example, in *Balance Ninja* the intensity of the effect felt by a player was determined by the lean of another player (up to their maximum setting). This added unpredictability to the effect, which prevented players from becoming familiarised with a set pattern, since the effect was related to the movement of the opposing player. Using these interfaces sparingly helps to overcome this effect and reduce chances of desensitisation. For example, stimulation could be used to exaggerate or punctuate specific game moments, and not be continually applied or repeated. As such, we recommend designers use the vertigo interfaces sparingly and at key moments, to avoid players becoming desensitised and familiar with repeated play sessions.

LIMITATIONS

In this paper we have shown that digital vertigo games using GVS can be an exciting and positive gameplay experience. As far as we know, GVS is not currently available as off-the-shelf hardware that can be plugged directly into digital games, however, some researchers have considered patenting the technology for entertainment purposes [15]. It is possible that GVS has perhaps not been made commercially available for entertainment purposes yet as it may be seen as an unpleasant gameplay accessory. However, similar experimental interaction technologies from recent HCI work, such as EMS interaction [28,40] make use of off-the-shelf EMS systems. These systems often come with a warning that medical advice should be sought before using, yet have been adapted into game design and used for entertainment purposes. There also exists commercially available entertainment games centred on the use of electricity to stimulate players, such as *Lightning Reaction* [49], an electric shock party game for 2 – 4 players where the last player to press a button when a light flashes receives a small electric shock.

Additionally, there is also recent interest in developing vertigo experiences through the use of head mounted displays. For example, researchers have investigated novel ways of using VR in waterparks [41,42] and theme park designers in the UK have built the first virtual reality rollercoaster, called *Galactica* [46,50]. These developments suggest to us that it is now an exciting time to consider the development of digital vertigo games, whether that is through the use of GVS or other stimulation technologies.

With this work we have explored the artificial stimulation of the senses through only one method of stimulation: GVS. Alternative ways of facilitating vertigo in players, such as through visual or physical means, are also of interest to us, and we are currently exploring games that use these methods of stimulation towards the design of a digital vertigo game design space.

CONCLUSION

In this paper we reported on the development of a vertigo game, *Balance Ninja*, which used GVS as its main gameplay interface. Through a thematic analysis of a study with 20 participants we identified three overarching design themes, and articulated these along with six accompanying design strategies for designers of digital vertigo games. We challenge designers to use our findings and strategies to develop their own digital vertigo games, and encourage them to think of how they can use other technologies to explore this newly articulated design space.

We also highlight a gap in research concerning games of vertigo. Whereas vertigo has appeared in games, it has often been a second-order effect and not the intended core game play mechanic. We hypothesised that this was due to a lack of consideration regarding the design of vertigo games. Similarly we highlighted that both vertigo and interfaces such as GVS have not generally been considered from a game design perspective.

With this work, we therefore encourage challenging negative preconceptions, such as vertigo being an unwanted game sensation, and using digital technology to transform the negative effects into positive user experiences. Designers are encouraged to explore the body's limitations and transform them into novel user experience opportunities.

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