AR Fighter: Using HMDs to create Vertigo Play Experiences

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ABSTRACT
Game designers working with Head-Mounted Displays (HMDs) are usually advised to avoid causing disorientation in players. However, we argue that disorientation is a key element of what makes "vertigo play" (such as spinning in circles until dizzy, balancing on high beams, or riding theme park rides) engaging experiences. We therefore propose that designers can take advantage of the disorientation afforded by HMDs to create novel vertigo play experiences. To demonstrate this idea, we created a two-player game called "AR Fighter", in which two HMD-wearing players attempt to affect each other's balance. A study of AR Fighter (N=21) revealed three recurring vertigo-experience themes for researchers to analyse and associated design tactics for practitioners to create digital vertigo play experiences. With this work we aim to guide others in using disorientation as intriguing game element to create novel digital vertigo play experiences, broadening the range of games we play.

CCS CONCEPTS
• **Human-centered computing** → **Mixed / augmented reality** • Human-centered computing → Ubiquitous and mobile devices**;**

Author Keywords
Vertigo; augmented reality; sensory confusion; mixed reality; HMD; perception.

INTRODUCTION
According to games sociologist Caillois, vertigo is one of 4 key game types; he describes vertigo games as an "attempt to momentarily destroy the stability of perception, and inflict a voluptuous panic upon an otherwise lucid mind" [9]. Examples – according to Caillois – are spinning in circles until dizzy, balancing on high beams, riding theme-park rides or racing fast cars. Recently, researchers have begun to explore ways of affecting the "stability of perception" in digital games. For example, we have previously shown that games can use galvanic vestibular stimulation (GVS) – an electronic system that affects the inner ear and hence one's vestibular sense – in order to confuse players' sense of balance, and thus destroy the stability of their perception, in order to create engaging gameplay experiences [6,7]. We extend this prior work by proposing that we do not need to send electronic currents through people's heads, but could rather use HMDs, in particular their ability to cause disorientation, as a way to affect the stability of perception in order to create engaging digital vertigo experiences.

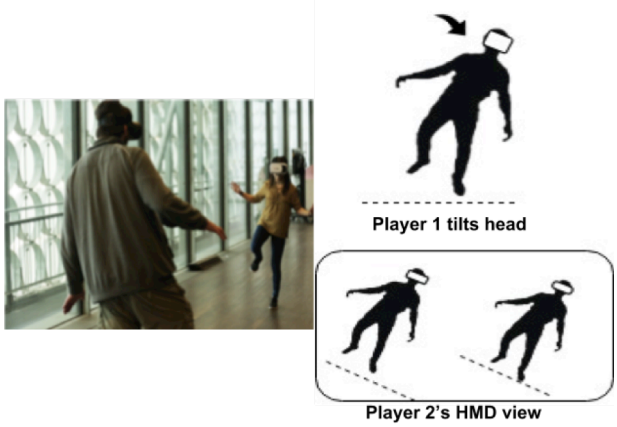

Figure 1: Left - *AR Fighter*. Right – as player 1 tilts head, player 2's HMD exaggerates how much player 1 is leaning.

Usually, game designers working with HMDs are advised to avoid causing disorientation in players [40]. This is often because viewing an augmented or virtual reality world through an HMD which is not synchronised to real world motion can cause a confusion between the visual sense and other bodily senses [24,40], facilitating an instability of perception that is often experienced as disorientation or nausea. We argue that the potential of HMDs to cause a mismatch in perception – which is usually seen as a technology limitation [40] – can actually be regarded as a design opportunity, and one that can be deliberately exploited by designers as a way to facilitate novel digital vertigo play experiences. These digital vertigo play experiences purposefully destroy a player's stability of

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perception through inducing sensory confusion in players. The contributions of this work are:

- An extension of the notion of vertigo play into the digital realm by using HMDs to create instability of perception, introducing their inherent technical limitations as an opportunity for game design.
- A novel vertigo game, *AR Fighter,* which uses HMDs to demonstrate the feasibility of our idea.
- A study of participants playing *AR Fighter* that revealed three recurring design themes, which researchers can use to analyse digital vertigo games.
- Four tactics for designers interested in creating digital vertigo experiences.

Motivation

Games of vertigo can be fun, but in AR games designers usually try to limit disorientation. Yet we believe through understanding how to design digital vertigo experiences can lead to the creation of engaging play experiences with a variety of benefits, for example:

- Facilitating a wider range of different bodily play experiences [33].
- Balance training games for athletes.
- Rehabilitation to help improve balance strength.
- Improving one's sense of body intelligence [14].

Before discussing the design, study, and resultant findings of *AR Fighter*, we first begin with a discussion of related work.

RELATED WORK

Here we describe many of the prior works which inspired and guided our research.

Vertigo Experiences

Caillois describes that players of vertigo games are "surrendering to a […] shock […] which destroys reality" [9]. In surrendering to this *shock* players have a chance to lose themselves, resulting in "intoxicating physical sensations of instability and distorted perception" [43]. Altering perception can be achieved in a variety of ways, and thus, in vertigo games, one might not be merely affected by vertigo in the common sense (through a disorder of the inner ear) but also through scale, speed and traction [43]. Perception is dependant on the correct stimulation of the senses [38], and vertigo games often require the use of large, specialised equipment, (such as rollercoasters) to over-stimulate the senses, thus altering one's perception. We propose that digital technology can enable novel ways of engaging vertigo without the need for expensive infrastructure.

Medically, vertigo has been described as "a sensation of motion [...] in which the individual or the individual's surroundings seem to whirl dizzily" [29]. 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 enjoyable bodily play experiences. For example, many people enjoying dizzying bodily experiences, like "Zorbing" (being pushed down a hill in an inflatable ball), to challenge their bodily limits.

In the HCI community, play experiences have emerged to explicitly challenge the body [27,34]. For instance, uncomfortable interactions [4] specifically induce sensory confusion in players through causing discomfort. Several play experiences have also investigated using discomfort to create engaging experiences, such as requiring strangers to tightly embrace in order to control a videogame character [17], and thus changing the way in which they normally control such characters. We suggest that digital vertigo experiences fall within the similar area of purposefully challenging how players normally interact with games, and are therefore worth exploring in the HCI community.

Adapting and simulating bodily experiences with HMDs

Sports psychologists have argued that "the pursuit of vertigo" is the main attraction behind many popular vertigo sports, such as rock climbing, or skiing [1,25]. Digital facsimiles of such sports have been made possible through the ubiquitous nature of digital technologies, including HMDs, sensors [51], and projectors [22,49]. For example, several digital games allow players to traverse climbing routes within a virtual space by wearing an HMD [10,11]. Research has even suggested that players can potentially experience vertigo within the virtual space due to the inherent sensory confusion afforded by these HMDs, i.e. the player moving in the virtual world but being stationary in the real, physical, world [30,40].

Whereas sensory confusion of this kind can be considered to be the cause of motion sickness or a way of inducing nausea in players [23,40], recent work contests that embracing this confusion can lead to more immersive vertigo experience simulations, such as simulating death-defying tightrope walks [41]. The design studio *Inition*, for example, challenged players to walk across a real world plank whilst wearing an HMD which depicted the plank as being suspended high above the ground between two buildings [18]. Players described how real the experience felt, calling it "stomach churning" and "adrenaline pumping" [18], highlighting how powerful digital technologies can be in creating vertigo experiences.

Designers have also explored combining HMDs with large scale equipment in order to create more intense simulations, such as simulating the feeling of wingsuit flying [19], or skydiving [12]. Recently theme parks have looked towards creating experiences entirely based around riders wearing HMDs, and also looked towards the possibilities of HMDs updating existing rides to breath new life into the experience of riding them. On the *Galactica* rollercoaster [31], for example, riders wear HMDs to experience a virtual spaceflight which moves in response to the real rollercoaster. Similarly researchers have also postulated adapting waterslides in waterparks to allow riders to wear HMDs to alter the experience while sliding down the slides [37]. With researchers increasingly exploring tracking in

AR [51] and VR [15] games, creating immersive, sensory confusion causing experiences becomes easier, and we see now as a great opportunity to explore the development of digital vertigo experiences.

Altering the environment to enhance vertigo experiences

In HCI, investigating the design of body-based games is extremely popular [33,36], and designers are investigating different ways of adapting the environment around players to create engaging bodily play experiences. Mueller et al. [35], for example, presented a game where a player hangs by their arms over a projected river, attempting not to let go unless there is a virtual plank beneath them. In JoggAR, Tan et al. [44] used a heads-up display to alter a runner's visual perception in order to create a more gameful running experience. Although these experiences do not consider creating vertigo directly, they do serve to highlight how digital technology can be used to alter player perception.

Similarly, the work of Hämäläinen et al. [16] collates several body-based gravity games, such as a trampoline training game that makes jumpers feel as though they are jumping higher than they are [21]. Kajastila et al. investigated digitally altering the player environment with their augmented climbing wall [20,22], where climbers can follow projected routes, and even play games to improve their movements. These works serve as examples of how to digitally affect a player's visual perception, and we see extending this to induce sensory confusion in players as an opportunity to explore.

Inducing Sensory Confusion

Creating vertigo-type experiences is achieved through the confusion of two or more bodily senses, and fair grounds, which actively design for such experiences, have been entertaining people in this way since the Eighteenth Century. The Haunted Swing Illusion (1895) [50], for instance, 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 swing. In actual fact, the riders are near stationary and the room the swing is placed in rotates around them. Riders experience "vertigo" due to the confusion of their visual sense and sense of balance, and thus their confused senses alter their perception. Inspired by this work Tennant et al. investigated purposefully developing HMD experiences where the visuals were not synchronised to the body's real world movement [45]. In their work, their version of the swing amplified a riders swinging motion, and lead to players feeling as though they were swinging further than they really were, and is another interesting example of altering the senses to change rider's perception.

Research Opportunity and Research Question

Caillois alludes in his work that if sufficiently advanced technology existed, "powerful machines", such as the fairground rides he believed were needed to help experience vertigo, would no longer be necessary [9] (p26). We believe that with today's advances in digital technology it may be possible to achieve similar vertigo sensations to the haunted swing, without complicated ride infrastructure (as was also needed with Tennent et al.'s version [45]), to develop novel and engaging vertigo experiences. In particular we consider using HMDs powered by the ubiquitous mobile phone.

Most closely related to our work is that of Byrne et al. [6–8] who have considered the design of vertigo games through the use of Galvanic Vestibular Stimulation (GVS). The authors use GVS to stimulate the vestibular system of the inner ear, creating a form of sensory confusion between a player's sense of balance (affected by GVS) and their visual sense. This work inspired us to create our game *AR Fighter*, where we considered whether you could confuse a player's visual sense with his/her sense of balance.

Therefore, the aforementioned related work appears to highlight a gap in understanding of how visually induced sensory confusion could be viewed as a design opportunity. In this paper we contribute to addressing this gap through asking the research question: *how can we use the sensory confusion afforded by HMDs to facilitate engaging digital vertigo play experiences?*

AR FIGHTER

AR Fighter is a two-player game where both players, wearing HMDs, face each other and stand on one leg. A player's head movements affect the view of the opposing player's HMD, and thus players must wrestle with their own sense of balance, and choose when to attempt to affect the opposing player's sense of balance. To win, players must attempt to remain balanced, and the first player to place their raised foot back on the floor loses the game round, and the winning player (who is still balancing) scores a point. The first player to earn a total of five points wins the game.

The HMDs consist of low-cost cases (around AUD$20) and each houses a Google Nexus 5x mobile phone, with the phone initially displaying the feed from the phone's back camera, allowing players to view the world around them. This view is slightly offset due to the camera placement on the phones, but is sufficiently close to the user's normal view to enable them to balance easily.

When players first wear the HMDs, or whenever the game is reset after a round, they see the direct view of the camera, so that the horizon in the view is at the same angle as the real horizon. However, during gameplay, as one player tilts their head, the display of the other player is rotated in the same direction. This means that the affected player perceives visually that they are tilting from side to side, even if they are not. This mapping is symmetrical, so that player 1's head tilt controls the view of player 2, and player 2 controls the view of player 1 at the same time.

As such, players experience sensory confusion since their vestibular sense reports that they are orientated one way, whilst their visual sense reports something different. Players need to fight the urge to correct this confusion in order to inflict further confusion on the opposing player

through moving their head (and thus their body) more, until one player eventually gets so out of balance that she/he needs to place their raised foot back to the floor.

Gameplay

A game of *AR Fighter* consists of multiple rounds. Each round starts with a countdown from five to one, at which point the game music starts, and players must raise one leg and begin to balance. We asked players to raise one leg based on prior work [6–8] which suggested that vertigo can be enhanced if a player is already off-balance.

During the round, players' head movements are mapped to the opposing player's HMD as explained above. When a player places their foot on the floor the other player receives a point and the system enforces a rest period (where players can rest their legs and remove the HMDs) before the start of the next round. We chose a rest period of 1 minute also based on the findings of our prior work [6–8], which suggest using rest periods in order to allow players to recover from the effects of vertigo and standing on one leg.

Furthermore, we also wanted to prevent players becoming too disorientated as continual sensory confusion from wearing HMDs can result in a feeling of nausea [36]. A full session of gameplay lasted on average five minutes per pair.

Technical implementation

The main game program was written in Unity 3D, and a python based server running on a laptop controlled the game by communicating to two Android phones (running Kit Kat) over a dedicated WiFi network. The tilt value of each phone was sent to the server via UDP messages (reliably < 50ms), which then forwarded the tilt value to the opposing player's phone. A human observer performed the foot touch detection.

We did not render parts outside of the camera source image, this was a practical design choice as we were not investigating game realism, but how it would affect the player's experience of vertigo. Players did not comment on these areas in the interviews suggesting that not rendering them did not affect the gameplay.

Safety precautions

We received ethics approval from the university before conducting the study. The HMDs were fitted to player's heads via easy-to-adjust straps, and the devices were cleaned (before new players took part) and checked to make sure that they were secure before playing. All players were instructed that they were permitted to remove the HMDs if they felt uncomfortable. Before playing we also made sure that there were no obstacles in the immediate area.

We invited participants to play the game in pairs. The game does not require any special calibration stage, so once ready participants were invited to stand in the play area (roped off for the safety of both the participants and spectators) and to face each other. Players then donned the HMDs and were invited to get used to looking around with them. Players were then asked to prepare to balance on one leg before the countdown started.

We closely observed the players to 1) make sure that players did not stumble dangerously (helpers were also on hand in case players stumbled, although this did not happen during the study), and 2) to monitor when a player placed their foot back on the floor. When a player placed their raised foot back on the floor, we awarded the point to the winner and paused the game (which also paused the visuals on the HMDs) and invited the players to remove the HMDs as they rested after the round. We could have also implemented a sensor that detects when a raised foot is placed on the floor, but did not see the need and we liked the simplicity and reliability of the current implementation.

The process was repeated until a player reached five points. We chose five since we assumed this is a large enough number to get multiple rounds of gameplay (all pairs shared winning rounds to some degree), but not too many that it would overly fatigue the participants. Once the game was over, participants were invited to take part in a semi-structured interview, where we asked each pair about their experience of playing *AR Fighter*.

Participants

21 players in total (10 pairs, 8 female) played *AR Fighter*. One player played against a previous participant as their opponent was no longer available (otherwise there would have been 22 participants total). The participants were aged between 19 and 42 (M=26, SD=5). Participants were recruited primarily via the university mailing list and word of mouth, although some volunteered after observing others playing the game.

Data Collection

We collected data through the use of audio and video recording of all gameplay sessions and interviews. We followed a semi-structured interview schedule to allow participants to discuss the experience in detail, with follow up questions and little prompting from us. We asked players about their experience, how they found the gameplay, the best and worst parts of the experience, and what the sensory confusion felt like when playing. We also invited participants to individually complete a 5-point Likert scale questionnaire (1 = strongly disagree, 5 = strongly agree), about their play experience (fig. 3).

Data Analysis

Although questionnaires such as PENS and IMI could be useful in evaluating *AR Fighter* as a game, we were more interested in the vertigo aspect of the experience at this stage. So, in order to investigate how *AR Fighter* was perceived, we employed an inductive thematic analysis approach to the data, as described by Braun and Clarke [5].

Following the approach outlined by [5], we first transcribed the audio data of all of the participant interviews. We consider each turn of speech, or statement, to be a "Unit", and, not including interviewer comments, there were a total of 222 Units to consider when coding the data. The coding

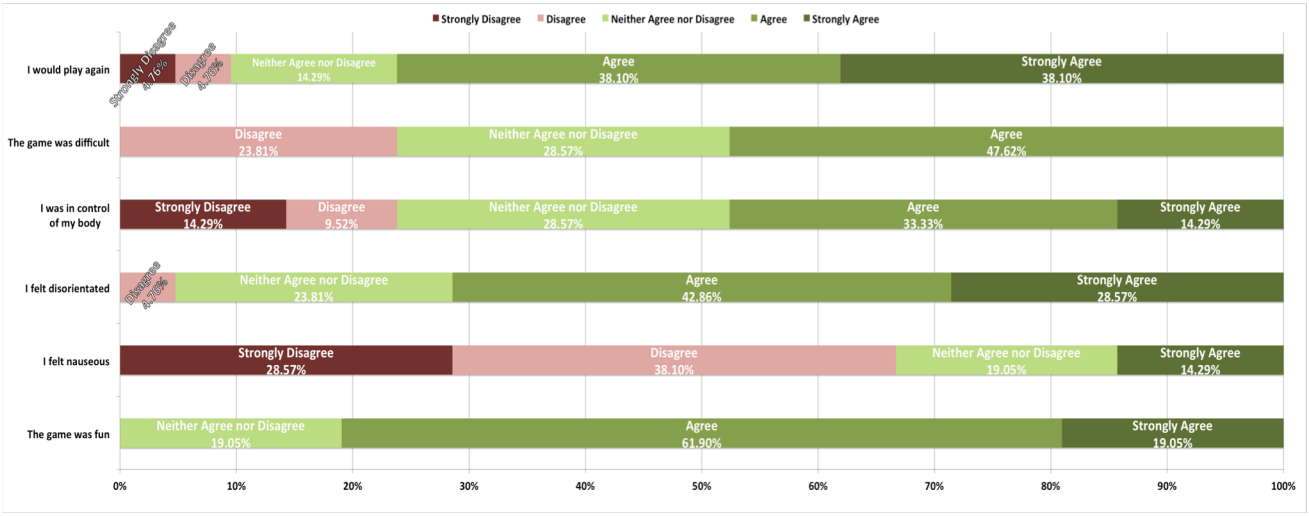

Figure 2. Likert responses to participant questionnaire (N=21)

process involved two researchers independently considering these transcripts before assigning their own codes to each unit. After both researchers had completed this process a meeting was held where the researchers, for the first time, considered the codes together and refined them to create 8 codes total. Each unit was then considered with these codes to derive recurring design themes, which were again agreed upon and refined by both researchers, resulting in a total of three overarching themes derived from the data. These themes are explained further in the next section.

RESULTS

In this section we report on the results of the participant questionnaires, before explaining in detail each of the three overarching themes we derived from our analysis of the interview data: Bodily control, gameplay and enjoyment, and finally, vertigo feelings and effects.

Questionnaire responses

Figure 2 illustrates that most participants found the game fun (Median (*M)*=4 and Standard Deviation (*SD*)=0.63), and that participants generally did not feel nauseous (*M*=2, *SD*=1.32). When describing a feeling of disorientation and whether they felt in control of their body participants stated that they did feel disorientated (*M*=4, *SD*=0.86) yet they were in control of their body (*M*=3, *SD*=1.26). Participants were split on whether they found the game difficult (*M*=3, *SD*=0.83) but mostly agreed that they would play the game again (*M*=4, *SD*=1.10). Additionally we asked whether participants had played AR games before (11 had) how often they played video games on average (once per week) and how long for (7 hours per week).

Theme 1: Bodily control

Below we describe the findings concerning the single code category of bodily control (43 Units) in *AR Fighter*.

Players described how they lost and recovered bodily control during the gameplay: *"I was in control because I could do some action to recover from whatever disturbance was brought to my visual system. So I think yea, I'd say yes. Although it was difficult to recover from that disturbance."* Players appeared to find keeping their own sense of bodily control whilst trying to affect the other player's to be challenging: *"Yes and no. It's only when I start doing the 'attack move' and then I don't know where I am now (laugh) once you lose the person, you're just like 'where is he?'"*. This loss of orientation sometimes caused players to lose the round: *"I was trying to find you [player 1] and that's when I lost my balance, tilting my head and I lose control of my leg (laugh)"*.

Players used figures to describe their feeling of being in control: *"I would say 60% in control, but 40% sometimes."* They explained that they were able to remain in control until they attempted to move: *"It's like a fifty-fifty thing when I was trying to concentrate very hard, trying not to make the view move fast, I think I was in control. But once I moved just the slightest bit, it was all haywire."* For other players, the feeling of control was not very strong: *"I was not feeling in control at all. I was like a free bird, you know? 'I have to fly!' I was feeling, like, I'm high or something, you know?"*

Players were surprised at how easily they lost bodily control when playing, particularly when they were proficient and experienced with balancing techniques: *"Having spent years of pretty much my entire life doing martial arts which is all about spatial awareness and body balance, being able to have that taken away from me so easily, that is what I enjoyed." "It was cool. It was interesting, I didn't think it would be that hard to control my body."* Another player, when asked if they had felt in control of their body responded: "*definitely not! That was the biggest conflict of the game - just when you think you have control, just when you think you've got [the other player] on their last leg, all of a sudden you realise your whole body is starting to tilt and you can just feel yourself falling.*"

Despite losing control, some players suggested that they were not sure whether their loss of control was affecting the other players, and that more visual feedback would have been useful: *"so you know you may sit there and strategically hold steady and let them attack and once they sort of settle down - like you could have a double bar graph, one that says how much they are affecting yours, and how much theirs is actually unstable. How much they are swaying, because then you can look at it, because if they are really attacking you - and steady - bad time to attack. You need to cop [bear the brunt of] the attack, sort of thing. Then attack back when they are unsteady and quickly 'shake the head, shake the head, shake the head! Or lean, lean, lean!'"*

Rest and Recovery

Players seemed to appreciate that the HMDs could be removed during the rest periods, or if they felt uncomfortable when playing suggesting that knowing they were able to stop playing and maintain an aspect of control over their actions meant a greater level of enjoyment for that player: *"Well, the thing is, I know at any point I can do this [lifts HMD off] and the disorientation is going to stop, I re-orientate. When I think about the unpleasantness of nausea connected to vertigo it is more because, well, some of the scuba divers I dive with get vertigo and they just hate it because when you are underwater, and everything's spinning, it's just a nightmare and you know it can't stop. The other thing is you can't just bail [escape] because you are thirty meters underwater and you'd just kill yourself; so here at least we always know that at any point we can escape, so there's sort of an escape from the vertigo element. But that is sort of what makes it fun"*.

In some vertigo experiences, such as being strapped in a roller coaster, players can not remove themselves until the ride stops, but as another player also said: "*knowing that as soon as you take the headset off, 'everything is fine', - it makes perfect sense*" This finding is in line with vertigo games requiring players to make "calculated risks of limited duration" in order to play [9,43]. *AR Fighter* appears to have supported this by having a very simple and quick method of removing oneself from the gameplay and accompanying sensory confusion.

The game can be quite physically demanding: "*it's a physical activity kind of game so it's very enjoyable, in that way. You are tired at the end, not really exhausted but yea certainly trying to get your breath back*"; and the rest periods allowed players to recover from this physical strain, and also appeared to stop players from feeling nauseous: "*I think if I played longer I may have started to feel a bit sick*", with many players stating that they did not feel nauseous at all at the end of the game, despite being disorientated when playing.

Theme 2: Gameplay and Enjoyment

This theme was derived from 120 of the 222 Units, and four code categories: Enjoyment, Difficulty and Game Design, Gameplay Analogies, and Gameplay Strategies.

Enjoyment

Participants found the game enjoyable (*"I really enjoyed [it]")*, and compared the activity to other enjoyable vertigo experiences: *"You go to enjoy those rides to experience the unpleasant, which I was able to experience here, so that was good, yeah!"* They also expressed that even when losing they found it fun to play: *"I laughed, I smiled, so I guess that's a thumbs up from me, even though I did lose"*, and *"the experience was fun. So I would try it again, but I don't think I would win [laughs]."* Players even had what they described as an adrenaline rush: *"it was exhilarating, there was a real adrenaline rush."* The game was: *"something really new",* and players expressed how they had: *"never done anything like it"*, and stated *"I've never played this kind of game before"*.

One player commented that, with theme park rides: *"you go to enjoy those rides and to experience the unpleasant, which I was able to experience here, so that was good"*. Participants suggested that the social aspect of the game contributed tot their enjoyment, explaining the game was *"very fun, I liked it because I was not the only one playing, it was with a friend,"* and the *"best bit was the team - not team, but playing with someone."* This social aspect added an element of competitiveness for some players: *"It was fun, but, I guess it helped that [other player] and I have a little bit of a rivalry sometimes"*, with the other player responding: *"Yeah! So I have totally walked away ashamed!"*

Difficulty and Game Design

Players found the game difficult to play, *"Yeah, it was hard"*, but although: *"it was a challenge, it was fun"*. Some players used the challenge to their advantage: *"I just had to wait for [the other player] to lose, right? Because I wasn't able to do anything that would challenge them - I never got to that point. I had to just hang on and wait for them"*. This suggests that some players had a more difficult time battling the sensory confusion, and relied on the other player making a mistake, rather than actively trying to induce further sensory confusion in the opposing player. Others found the game hard, but still enjoyed playing: "*the game was a lot harder than I expected, but it was a good experience - it was really fun trying to make my balance work when I was being thrown off so much*".

The difficulty may have also been a result of players not being able to keep track of their orientation, or losing their bearings when playing: *"Most of the time, it was not player 2 that I was seeing, but something else that I was seeing, even though I think I was looking straight, you have to tell me if I was looking straight or not!"*

The game was setup in the same way for all players, and although some found it difficult, some players appeared to

rely on their own previous balance experience to help them in playing, for instance two players found the gameplay quite easy, explaining that *"because we Longboard"*, they had gained a very good grasp of battling the environment and their sense of balance. Another player also found a way to overcome their disorientation, explaining that they: *"found it easier balancing by disregarding the opponent, [since I am] both a dancer and someone who regularly does yoga, balance is something I am very used to"*.

Importantly to us was that all players appeared to enjoy playing the game, with many suggesting that they would play again (76%), and zero players stating outright that they did not find the game fun. This could have been because although players had different balancing abilities, the game appeared to be very accessible and simple to understand: *"[it was] easy to play, just put [the HMD] on and play it. So that was quite nice"*. One player commented on how the game: "*was easy, because it didn't have many rules. Just look and try to keep yourself balanced and try to knock the other player [over]"*. Another player expressed that they: "*love[d] the simplicity of it all, like something at a party, you can pull it out and yea - just the one-up-man-ship is just great. The way you can play it anytime of day, anywhere. Very easy!"* These were important remarks for us, as we wanted this game to be more accessible, quick to experience, and less invasive than related vertigo play work [6].

Gameplay analogies

When trying to describe the experience of playing *AR Fighter,* players often relied on analogies of similar experiences in relation to how they felt when playing, such as comparing the game to fast theme park rides: *"A little bit like a mini rollercoaster but not like the turn ones, just the really fast ones"*. Similarly, one player compared *AR Fighter* to a disorientating tunnel ride: *"There was a tunnel with a bridge through the middle of it, and you have to walk through the tunnel and the whole tunnel spins, so the visuals, everything you see is rotating around, and everyone on the bridge just can't help but fall. It's just absurd to watch that. So I found this similar to that as well"*. This type of ride aims to overload players' senses in order to result in them falling over, and for players to compare *AR Fighter* to similar ride experiences seems to suggest that *AR Fighter* did help to induce sensory confusion in players. Further, players reported the game as fun, so the sensory conflict created a pleasurable and enjoyable experience, and could therefore be said to have been a digital vertigo play experience.

Players also articulated how the experience reminded them of childhood games such as "hopscotch" due to players jumping around on one leg. Another player was reminded of games they used to make up as a child to challenge their sense of balance: *"As a kid you'd make games up on the spot and sometimes when you are walking on the street, you would find a line or a path that you would try and stick to, and you would try to balance yourself and make sure that you're staying on that path. Whether it is like some concrete edge or something like that, it kind of reminded me of that even though it wasn't walking or anything. It felt like the same or similar type of experience of trying to balance myself."*

Another participant recalled an experiment they had seen in a TV documentary: *"I saw this silly experiment that they do on a documentary where they have three walls and some pattern on the wall and they stand on this block and they have to hold this platter with a glass of water. Then they move the walls, but they don't tell them that they are going to move the walls and when they, as soon as they move the walls then they drop it. Even though they haven't moved."* Playing *AR Fighter* reminded this player of something they had once seen where sensory confusion was caused in people standing still, simply be manipulating their visual perception through rotating the walls of the room. Such an illusion is the basis of several popular rides, and most notably the *Haunted Swing* [50] illusion.

Strategies to overcome sensory confusion

Players were inventive in attempting to score points and win the game, employing different bodily strategies to overcome the sensory confusion facilitated by the game. For example, one player commented that: *"I was trying to mess [the other player] up, so I just shook my head, [laugh]"*. The player chose not to move the rest of their body, but just the head, so that the opposing player would become disorientated through their own movements and the visual sensory confusion induced by the player's rapid head movements. This appeared to be a popular strategy, with players trying to ignore the visual stimulation: *"For me, I more focused on my body, rather than on the visual."* Another player went so far as to overcome the sensory confusion by closing their eyes: *"You know what, I felt like, I don't know, if you say it was cheating, but I could stabilize only when I closed my eyes. But when I was looking forward I could not balance myself."* Closing one's eyes appears to be a strategy employed to allow players to re-orientate themselves and regain an aspect of bodily control to strategically beat the opposing player: "*I was stressing so much like 'no! I am losing all the points!' so I closed my eyes and then I could stabilise myself*". Although for some players closing their eyes wasn't entirely easy: "*I noticed the challenge of people being able to close their eyes, I noticed in one round it still a little difficult you still have to balance and what not, but yea there is that 'cheat' against your opponent*".

Theme 3: Vertigo feelings and effects

The final theme contains two categories, detailing 59 of the 222 Units: Vertigo and Disorientation, and Nausea and Vision.

Vertigo and Disorientation

Players found playing *AR Fighter* made them question what they knew about their own bodies: *"I've become very reliant on my balance, you know, especially doing a lot of sports where spatial awareness doesn't matter, where you*

always have a sort of knowledge of where you are. To then have that, completely taken away - it's almost to my detriment that I rely on that sense so much now. [The other player] would tilt the head and I would feel like going, my body, I just - cognitively I know it is an aspect of [the other player] changing my perspective but the internal mechanics of my brain are already wired to go 'Whoa, oh, you're falling!' So that is why there was sort of, a lot of skipping." The skipping referred to here was a result of the player hopping around when playing, instead of staying completely still on one leg, in their attempt to remain in control of their balance.

Nausea and Vision

Inherently, it could be that this sort of gameplay could lead to players feeling nauseous, but this did not appear to be the case for any of the players. The reason for this is likely that the players still had some control over their bodies, they were able to choose to move and therefore the movement did not affect them in the same way as in traditional HMD simulators, which can easily result in motion sickness [24,40] As one player explains: *"I think that potentially some of the reason that I didn't feel nauseous was that the movement of the screen was not being changed against my own will. Like I was influencing the movement. Even though [the other player] had some impact on it as well, because I was also moving along I didn't feel that sense of nausea. Whereas in the past, with Oculus Rift games, when you are not moving but the Oculus Rift is moving against your own will, that gives you like a disconnect between what is happening on the screen and what is happening to your body, or what is not happening to your body."*

DISCUSSION

Below we present a discussion on designing digital vertigo experiences that use HMDs as the main way of affecting player perception, and thus inducing sensory confusion, as derived from the analysis of *AR Fighter*. Playing HMD games can cause disorientation, and we have shown with *AR Fighter* that this facilitated sensory confusion can actually be quite fun to experience. In this section we describe four design tactics derived from our work, aimed at designers of future HMD-based digital vertigo play experiences, or designers interested in introducing vertigo into existing HMD based games.

Tactic 1: Dynamically adjust sensory confusion based on a player's surrendered bodily control

Players of vertigo experiences will have different abilities, and some will lose control faster than others at different levels of facilitated sensory confusion. Theme 1 and theme 3 highlighted that at times players could rely on their own experience of balance activities to help them overcome the disorientation, or at other times found it surprising at how easily their bodily control was lost, despite being proficient at balancing activities. For players less experienced with balancing, however, the game was found to be often difficult, especially when paired with an experienced player. This is not a surprising finding, but in the same way that not all rollercoasters are suited to all riders, designers of digital vertigo experiences, which require confusing two or more senses, need to consider whether the game should appeal to all players, or a specific type of player, (e.g. for "extreme" or "novice" players).

Digital vertigo experiences benefit from being able to finely administer stimulation to one or more senses to facilitate sensory confusion, but could be further extended to also sense the bodily control surrendered by players as a result of the facilitated sensory confusion administered. For example, if players appeared to be getting too quickly out of control, the system could detect this and reduce how much disorientation was being administered to the player. Similarly, if the players were not responding very well to the facilitated confusion, the systems could automatically increase the extent of the stimulation.

Designers should also be aware that external factors could contribute to the facilitated sensory confusion in unwanted ways, which may negatively affect the experience. In theme 2, for instance, we described how players found it difficult to "find" their opponent after they had turned around too much in the real world and were no longer facing one another. This was an unexpected outcome of the gameplay for us. Furthermore, players noted how easy it was to lose control due to the visual confusion they experienced, especially when they lost the relative position of the opposing player (theme 1). At times, this caused certain players to become too disorientated.

Providing feedback to the players could also assist in keeping the players immersed and in control. For instance, in mixed reality games based on rock climbing, the absence of haptic or passive feedback is noticeable when traversing the terrain [26], and including such could improve the immersive experience. In *AR Fighter*, players suggested visual feedback could have helped them to get them back on track to face their opponent. Designers could opt to incorporate feedback to help the player, and then choose to remove or reduce the feedback throughout the duration of gameplay, continually reducing and then increasing the sensory confusion experienced by the player.

We therefore encourage designers to detect how much bodily control is being surrendered in their digital vertigo experiences, and allow the system to dynamically alter the facilitated sensory confusion based on if this is too much or too little at the present game play time. If too little, designers are encouraged to design the system to increase the facilitated sensory confusion, and likewise reduce it when players appear to be too greatly out of control in order to ensure players have the "optimal" experience. That is to say, to keep players in what we consider to be a "sweet spot", where players are neither too disorientated (and at risk of nausea), or too under-stimulated and at risk of a boring gameplay experience. Dynamically altering the facilitated sensory confusion by detecting the surrendered bodily control will allow players to remain in the "sweet

spot" of gameplay, and will also help to limit unwanted sensory confusion from diminishing the experience as the system will react when players get too out of bodily control.

Tactic 2: Allow players to recover from repeated, or extreme periods, of facilitated sensory confusion, by regaining bodily control

Players of *AR Fighter* noted in theme 1 that the game was physically demanding, and that the rest periods allowed them to avoid becoming nauseous from prolonged gameplay or from experiencing too much disorientation, such as described in theme 2. We see rest periods as a valid method of prolonging the vertigo experience, as vertigo moments in games, Caillois states, should last for limited periods of time [9]. Therefore, by extension, HMD vertigo experiences should also limit the duration of facilitated sensory confusion if designers want players to enjoy their experience.

Other vertigo experiences can also be prolonged with frequent breaks, such as in rock climbing, where climbers often rest to recover from muscle fatigue, or to plan their next moves. More intense vertigo experiences, however, need to be extremely limited in duration to avoid overly stimulating players or removing too much bodily control too quickly. For example, in the activity of Zorbing, the amount of time spent in the inflatable ball is extremely limited. Riders are able to climb back to the top of the hill and have another go, but the hill they are pushed down allows the ball to only travel for a short distance. The rider inside experiences intense sensory confusion due to an overloaded vestibular sense that then conflicts with the other non-overloaded senses, as they continually roll over and over. If this were to last a long time, riders would be at risk of nausea or physical discomfort.

In HCI, Benford et al. have suggested the use of trajectories [2,3] as one method of controlling the user experience through the rising and falling actions of Freytag's narrative. Similarly, HMD vertigo experiences could follow similar trajectories, starting with a limited amount of sensory confusion, rising to a climactic moment of high sensory confusion, before tailing off and allowing the players to recover bodily control. Depending on the desired outcome of the experience, designers can choose to have a single intense experience, following a single Freytag trajectory (such as Zorbing), or several smaller ones to create many vertigo moments (as with *AR Fighter*).

We recommend that designers of vertigo experiences take advantage of introducing rest periods into their games, as enforcing rest periods is one easy to implement way of ensuring players regain enough bodily control to make them susceptible to experiencing sensory confusion.

Tactic 3: Discourage players from regaining bodily control by ignoring HMD's facilitated sensory confusion

Our results suggest that HMD-based vertigo experiences can be very accessible to players (theme 2) as they allow players to place the HMD on their heads and immediately start playing. There is a limited setup required compared to other vertigo experiences that often require custom-made hardware and a calibration procedure [6,7,28], and although this is a strength, it can also be a weakness that designers need to be aware of.

As described in theme 2, one of the strategies employed by players to overcome an induced sensory confusion was to shut their eyes. Manipulating players' sense of vision, however, is obviously the primary way in which HMD digital vertigo experiences would be able to induce sensory confusion in players. However, it appears that closing one's eyes allows enough of a break from the induced sensory confusion in order to overcome the effects, essentially breaking the game in a way that we had not anticipated. This is specific to visual methods of creating vertigo; for example in previous work directly affecting the sense of balance [7], or on rollercoaster rides, it is usually impossible to opt out of the vertigo in this way until either the stimulation method is stopped, or the ride comes to an end.

In related work, Marshall et al. [28] witnessed a similar occurrence when they observed riders trying to beat their Bucking Bronco ride, which was controlled by the riders' own breathing patterns, by actually holding their breath. This work parallels ours since with the Bucking Bronco game, players would eventually have to breath, and after holding their breath they would most likely breath heavily which would cause the ride to spin quicker. In our game, players who closed their eyes may have temporarily overcome the facilitated sensory confusion, but if they did not win shortly after doing so, opening their eyes may reveal that they are in a completely different position, having rotated around their axis through any balancing movements (such as hopping), and this confusion could also lead to the player becoming even more disorientated.

A solution to players holding their breath on the Bucking Bronco ride was to make subsequent levels more difficult for that player as a direct result of them attempting to "cheat" the game [46]. This creates an interesting challenge for designers of HMD-based vertigo experiences and poses the question of whether or not to penalise players and discourage them from closing their eyes? Designers of HMD based vertigo experiences could choose, similarly, to penalise players who close their eyes (by detecting this through sensors embedded in the HMDs), or simply create visually important gameplay aesthetics that encourage the player to keep their eyes open (and thus stay susceptible to the facilitated sensory confusion) such as needing players to look at virtual targets to score additional points.

Tactic 4: Ease players into experiencing sensory confusion and surrendering bodily control

HMDs can greatly affect a player's field of view, and not being able to see accurately could create a certain amount of anticipation concerning tripping, falling, or injuring oneself when playing. This is an obvious shortcoming of using HMDs, and is something that is also referenced by

leading HMD manufacturers. The guidelines for the HTC Vive, for example, explicitly state that players need to remove any obstacles or hazards before playing [48]. In addition to making the gameplay area inviting and obviously free of any obstacles, we see several additional ways in which designers can ease players into surrendering bodily control, and hence be open to experiencing the facilitated sensory confusion.

The power of HMDs is that they allow players to become absorbed into another world, or have the world around them appear to be changed. Game designers allude to the "Magic Circle" [32] as a way of referring to the physical space and its challenges vs. the conceptual space for players to play in (i.e. the real, physical world game area, vs. what players observe through the HMDs). The challenge for HMD-based digital vertigo experiences is how to allow players to asses the risk (as required per Caillois' vertigo description [9]) in playing a body-based game whilst wearing an HMD, and thus be open to experiencing the sensory confusion and surrendering bodily control.

One possible method is simply to allow players to observe the game being played – either through a live demonstration or introduction video that would outline the gameplay rules and mechanics, with an emphasis on how safe the environment is to play in, and how safe players feel when playing. Another way of easing players in has been previously considered [7], where the technology we used to facilitate sensory confusion required a calibration phase for each player, which subsequently acted as a method of easing players into experiencing their game. Once players had succumbed to the effect of the induced sensory confusion for the first time they enjoyed playing the game, and any apprehensiveness was reduced through this easing-in stage.

Our findings support related work, which also suggests that slowly introducing players to an altered environment through an HMD can improve their experience and ability to measure distance within the environment [42,47].

Playing HMD games within a safe space with untethered technologies can also help to keep players within the "Magic Circle" [39], and we followed this procedure through using portable HMDs and ensuring the space was free of any obstacles for the player.

We did not need a calibration stage for *AR Fighter,* but we observed players becoming more comfortable with the experience, (with players even hopping around the game area (theme 2) or skipping (theme 3)), as they became more open to the facilitated sensory confusion and reducing their own bodily control as the game went on, and especially after they had played one round.

Therefore, in addition to obviously creating a low-risk gameplay area, we encourage designers to create a calibration stage or gameplay tutorial that acts in the capacity of easing players into surrendering bodily control and opening up to the facilitated sensory confusion to fully embrace the vertigo experience.

LIMITATIONS & FUTURE WORK

In this paper we acknowledge that we have only considered AR induced vertigo via HMDs, however we believe our findings could equally apply to VR-based vertigo experiences. Additionally, we have not considered in this work whether a certain type of player was attracted to playing the game (just as not everyone enjoys riding rollercoasters), nor how adding vertigo elements to existing AR games could alter the gameplay. Further, we only considered 2-players in this study, whereas we believe our insights may have relevance for 1-player or even 3-player vertigo experiences, which could reveal similar insights to the themes we described above.

Further, we aim to explore different methods of inducing vertigo in players, such as combining HMDs with GVS [6,7], or moving the virtual or physical environment while the player is stationary [13,50]. We see the above as an exciting opportunity for future work as we believe there is a lot more to uncover concerning the design of digital vertigo experiences, and we are excited to pursue this research.

CONCLUSION

Digital vertigo games are an area of research that we were intrigued to explore as researchers had suggested that deliberately inducing sensory confusion in players does not necessarily have to be avoided [4,6,7]. In their experiments, the authors made use of GVS, which induces sensory confusion in players in an internal way. With our work, we have shown that it is also possible to create digital vertigo experiences with a non-invasive technology: HMDs.

To illustrate this we introduced *AR Fighter* – a novel two-player HMD game that uses the natural disorientation afforded by HMDs as an intriguing game element to facilitate an engaging digital vertigo play experience. Through our study of the player experience of *AR Fighter* we derived three recurring themes, useful for researchers interested in articulating and analysing the digital vertigo player experience. Derived from our own design experience, we use the language of the themes to also present a discussion of how to design digital vertigo play experiences through the presentation of four design tactics. These tactics are aimed at game and play designers who are interested in creating their own HMD-based digital vertigo experiences, or interested in introducing vertigo elements into their existing HMD experiences.

With this work we aim to guide designers in using disorientation as an intriguing game element to create novel digital vertigo play experiences, ultimately expanding the range of games we play.

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