The Challenges of Visual-Kinaesthetic Experience

Paul Tennent, Joe Marshall, Brendan Walker, Patrick Brundell, Steve Benford
Mixed Reality Laboratory, School of Computing Science, University of Nottingham
Nottingham, UK
firstname.lastname @ nottingham.ac.uk

ABSTRACT
Virtual reality experiences typically isolate the user from the real world. Notions of immersion are conventionally associated with the idea of convincing users that they are in another place, disassociated from physical reality. Given the user is however situated in that physical reality, kinesthetic bodily sensations often conflict with the virtual reality. In this paper we seek to elucidate the challenges associated with developing *Visual-Kinaesthetic Experiences* - experiences which provide related visual and kinaesthetic spectacle. Rather than use complex motion platforms, we submit here that physical reality is replete with interesting kinaesthetic experiences, which may be repurposed by the application of new visuals to create engaging hybrid experiences. We approach this by describing the development and deployment of *Oscillate* - a virtual reality experience that takes place on a swing, using it as an example to draw out what makes such experiences intrinsically interesting, and to construct three design challenges for this space.

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INTRODUCTION
Virtual Reality (VR) is gaining increased traction as a topic both within academia and in the wider public consciousness. With the release of mass market systems such as the Playstation VR, being built on the success of the Oculus Rift and more recently the HTC Vive, this is an appropriate time to consider a fundamental problem with VR in most settings. Virtual reality experiences typically isolate the user from the real world. Notions of immersion are conventionally associated with the idea of convincing users that they are in another place, disassociated from physical reality. Given the user is however situated in that physical reality, kinesthetic bodily sensations often conflict with the intended virtual reality. Beyond simply loss of immersion, this lack of consistency between visual and vestibular systems is known to cause simulator sickness [21].

One solution would appear to be to correct the relationship between motion and visuals. Indeed this has been the principal selling point of the HTC Vive, which uses one-to-one tracking and translation of the user's head and controller positions to allow for *room-scale* experiences, and for many users this does appear to reduce instances of simulator sickness and improve immersion e.g. [27]. However, this approach can only work for certain types of experiences - the user must be standing and moving in ways a human can move, and the trackable space is currently limited to five meters squared.

At the other end of the scale, motion platforms can be used to provide corrected kinaesthetic sensations for a user. This approach forms the basis of many professional-level simulators[1] , commercial VR treadmills[2], and software actuated racing car seats[3]. However, the following quote from an interview with a former Formula 3 racing driver conducted as part of our research in this area: *"No matter how good they are, simulators don't feel quite right"*, suggests that such a perfect one-to-one mapping of kinaesthetic sensation may be some way from feasible; it is certainly prohibitively expensive in many contexts. While technologies for immersing people in visual and audio content – ranging from high resolution projection systems to a new generation of head-mounted displays – are relatively well advanced and affordable, those for stimulating our more physical senses – especially our kinaesthetic sense of bodily movement through space – are far less so. In spite of impressive developments in motion platforms, separation of what the user sees from movement that they feel remains a fundamental constraint on achieving deep immersion in future content.

In this paper, we suggest that rather than use motion platforms which aim to create generic forms of movement experience, we rather make use of existing exciting kinaesthetic experiences, and create thrilling experiences which overlay them. One example of such an approach is virtual reality rollercoaster rides such as Alton Towers' *Galactica* (2016) or Six Flags' *Dare Devil Dive* (2016), both of which take an existing coaster and overlay virtual experiences to the ride. Rather than using technology to separate users from the external world, such experiences are in fact made more exciting by the rider's

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[1]http://www.cruden.com/
[2]Virtuix Omni http://www.virtuix.com/
[3]RacingCube http://fasetech.com/?v=dd65ef9a5579

knowledge that the physical sensations occuring to them are a real part of the world, that they are really flying through the air. A second, contrasting example is the game Taphobos [8], in which the player is buried alive. Taphobos uses a real coffin to create physical sensations of constriction; the game is made more thrilling by the knowledge that physical coffin sensations are 100% real, as opposed to the result of haptic stimulation systems or other computer generated simulation.

We call systems which use this approach of highlighting and using exciting kinaesthetic experiences *Visual-Kinaesthetic Experiences* (VKE). In this paper, we describe the design of a VKE called *Oscillate* which overlays exciting virtual stimulation on top of a conventional playground swing. Oscillate was installed at Sheffield International Documentary Film Festival (Docfest) and London's Victoria and Albert Museum (The V&A) to significant critical acclaim and national media attention. Key to the design of Oscillate is the manipulation of the movement in the virtual world so that it is deliberately different to that in the real world; we believe that manipulation of *congruence* between real and virtual worlds is a key challenge for VKE design. In our discussion section, we describe how VKEs pose challenges in three key ways: firstly they create unique practical challenges for those building and deploying them; secondly, they require new ways of evaluating experience, and finally the use of new physical experiences creates new design challenges for builders of experiences.

The key contributions of this paper are:

1. The concept of visual-kinaesthetic experiences (VKEs).
2. The presentation of Oscillate, an example VKE.
3. Discussion of three key challenges of VKEs.

BACKGROUND

Kinaesthetic sensation as entertainment is established in human culture from childhood games of spinning, to playground equipment and fairground rides, enabling what Caillois calls *vertigo play* [11]. The pursuit of vertigo is described by Caillois as one of the four key forms of play. Such activities aim to *'momentarily destroy the stability of perception and inflict a kind of voluptuous panic on an otherwise lucid mind'* [11], such as in childhood games which involve spinning to the point of dizziness. Caillois argues that the industrial revolution enabled the creation of powerful machines such as fairground rides and racing cars, which allowed this kind of play to reach levels of intensity that made it popular amongst adults. It is therefore perhaps no surprise that researchers have been exploring technologies for delivering kinaesthetic experiences for many years, most notably via robotic motion-platforms. In turn, the wider entertainment industry have adopted motion platforms to deliver VR simulation rides while also seeking ways of introducing greater freedom of movement and even interactivity into traditional 'fixed' rollercoaster rides, for example the robotic rides developed by robocoaster.com.

Rollercoasters and theme park rides have been the subject of much HCI research in and of themselves e.g. [5, 38, 28, 32], however much of this research has focused on the psychological or psychophysiological sensation (e.g. in [32] rather than the kinaesthetic. Similarly, rollercoasters have also served as an introduction to virtual reality for many people with *Rift-coaster* being one of the most popular demos for the Oculus Rift DK1, and even now, a search in the Oculus or Steam store for 'rollercoaster' delivers results in double figures.

The combination of a physical rollercoaster and VR is a recent occurrence, initially done in guerrilla fashion such as [44] then more recently the parks themselves have developed rides which use VR visuals to refresh existing experiences - for example, the Alton Towers rollercoaster previously known as *Air* was repurposed in 2016 to become *Galactica*. *VR Coaster* (www.vrcoaster.com) who specialise in developing these rides currently cite twenty one installations around the world.

Of course, motion platforms and rollercoasters are not the only sources of kinaesthetic sensation. The everyday world is replete with them - every time we travel in a car, or a lift, or one of any number of other situations we experience bodily sensations of motion. Other bodily sensations may also prove to be interesting to explore. Research has tapped into these sensations to create a plethora of interesting experiences playing with, for example, sensations of vertigo [9, 10], claustrophobia [8, 24], hyperventilation [42] or interpersonal touch [18, 17] amongst many more. Similarly haptic interaction is a field unto itself covering interaction with virtual objects [36] and environments [1]. One particularly interesting source of kinaesthetic sensation which resonates strongly with Callois' discussion of vertigo play is the playground. Egglestone et al. [13] consider possibilities for interaction and sensation afforded by playgrounds and equipment such as swings, slides, roundabouts and see-saws (teeter-totters). One of Benford et al's "uncomfortable" experiences [4] uses a large, motor actuated swing, coupled with visual limitations caused by wearing a gas mask. Uncomfortable interaction is often a component of kinaesthetic experiences as seen in e.g. [9, 8, 18].

If these interactions can be seen as psychologically uncomfortable, there are also sensations of physical discomfort to consider. First we must include the conventional notion of *motion sickness* as described in e.g. [14], and caused by certain types of bodily motion, which may be an issue for kinaesthetic experiences which move our body. Particularly relevant is *simulator sickness*, a form of motion sickness caused by disconnect between visual and vestibular stimulation [21].

Conventionally, experience of VR is understood to be influenced by equipment, content, use circumstances and individual characteristics [26]. A great deal of previous research into evaluating VR has focused on task performance, sickness, and presence (broadly defined to be the sense of "being there"). In entertainment experiences such as we study here, some of this work may create tension with the nature of the entertainment. For example, VR researchers have argued that lack of control has negative impact on both presence [45] and sickness [40, 39]. However, in the wider literature on HCI and games, we see arguments that voluntary surrender of control [23, 25] and associated experiences of psychological discomfort [4] are key to the design of thrilling and meaningful entertainment experiences. Similarly, entertainment makes use of suspense and suggestion to create unknown or negative expectations of future experiences, something which traditional VR research would again relate to adverse symptoms [30]. One of the earliest examples of a visual-kinaesthetic experience was built in the 1890s at Atlantic City Boardwalk. Amariah Lake's *haunted swing* [46] is a swing inside an enclosed room. While the swing moves a small amount, the whole room is mechanically rotated around the swing to give the impression of very extreme swinging. The experience is very effective and has led to implementations of the illusion being used as amusements for over a century. One such installation is the popular ride *Hex - The Legend of the Towers* at Alton Towers theme park. One consistent feature of the haunted swing illusion is the huge and expensive mechanism required for it to function. Indeed Hex, one of the biggest examples, which simultaneously sits 78 riders reportedly cost approximately four million pounds to build [43]. The haunted swing illusion forms part of the inspiration for our driver project *Oscillate*.

OSCILLATE

To explore how visual-kinaesthetic experiences might work in the real world, we have taken a performance-led, 'in the wild' approach [3] in which artists drive the creation of performances in collaboration with interdisciplinary teams of researchers who help build technology, study deployment in artistic venues, and build theories based on this. This section describes the artwork *Oscillate* by Brendan Walker, two versions of which were installed at Sheffield International Documentary Film Festival (Docfest) and London's Victoria and Albert Museum (The V&A) to significant critical acclaim.

Overview

Oscillate is a visual-kinaesthetic experience designed by artist Brendan Walker. It takes the form of a playground swing on which a rider sits and puts on a virtual realty headset and a pair of ear defenders. In the VR world, the gallery in which they are sitting is recreated correctly to scale but empty of other exhibits and inhabitants. As the rider begins to swing, the correct motion occurs in the VR experience. Over the course of ninety seconds, the apparent maximum angle of the swing is increased to more than double the real swing angle causing the rider to seem to be swinging much higher than they actually are. In the following ninety seconds this multiplier decreases back to one. In the same cycle the distance between the rider and the floor is also increased, giving the vertiginous sensation of being very high up.

Artistic Vision

Oscillate is an immersive interactive artwork based on two popular entertainment technologies: the multi millennia-old rope swing and 21st century virtual reality - the former designed to excite the vestibular system, the latter designed to excite the visual cortex. The title *Oscillate* was chosen to reference the physical oscillations used to excite the vestibular system; oscillations between immersion in real and virtual worlds; oscillations between private and public spaces and interactions; oscillations between extreme and sedate ride encounters.

The Artist adopted the simple motion of a swing for Oscillate in part because activation of a swing is a technique learned by most in childhood. Swinging is naturally self-limiting, that is, people choose to swing as high as they wish or dare. Riders perceive themselves to be in control of their experience. The artist coupled the physicality of the swing with the design language of the playground, where the practical act of queuing also acts as a reason for spectating. The installation would need no instructions to be ridden, or watched.

The element of physical jeopardy designed by the artist in Oscillate is similar to that of an historical mechanical amusement park ride called the Haunted Swing (figure 1), which gives one's body the illusion of radical movement, although it may not be moving at all [46]. The artist proposed making a virtual facsimile of the gallery physical space. The rider would be seated in exactly the same place in the virtual and real worlds. Once seated, the rider would be able to visually examine the virtual and real worlds in the same way. When they started to swing, the rider's trajectories in both worlds would be the same. However, over the first ninety seconds of the ride, the rider's swing amplitude in the virtual world would become amplified up to a climax. Over the final ninety seconds the amplification factor would gradually return to neutral. This cycle would repeat, or reset if no rider was detected. To accompany this experience, the virtual floor would lower and rise in harmony with the swinging motion, and also increase and decrease in intensity. The amplified swing illusion was designed to make the rider believe that they were swinging higher than they actually were, the floor dropping illusion sought to replicate the camera zooming technique employed by Hitchock in his movie Vertigo, in an attempt to replicate the dizzying effects of vertigo.

A motivation and reward for swinging higher was required to counterbalance an increasing sense of physical jeopardy.

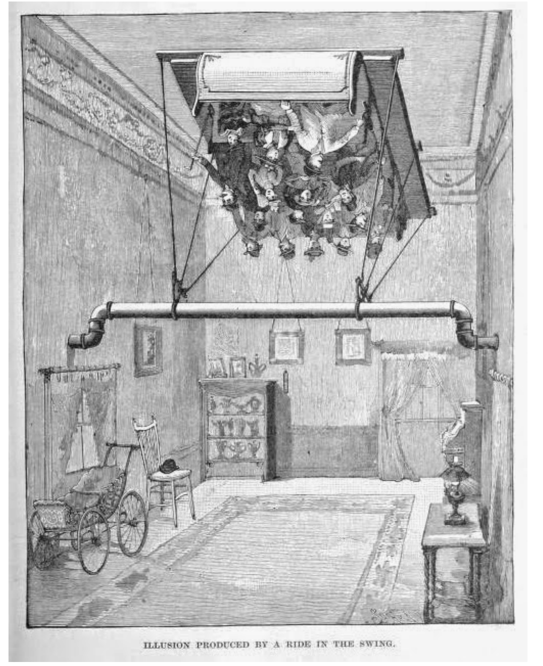

Figure 1. An illustration from an 1897 book *Stage Illusions and Scientific Diversions, including Trick Photography.* - Public Domain

Figure 2. Oscillate installation at Docfest 2015

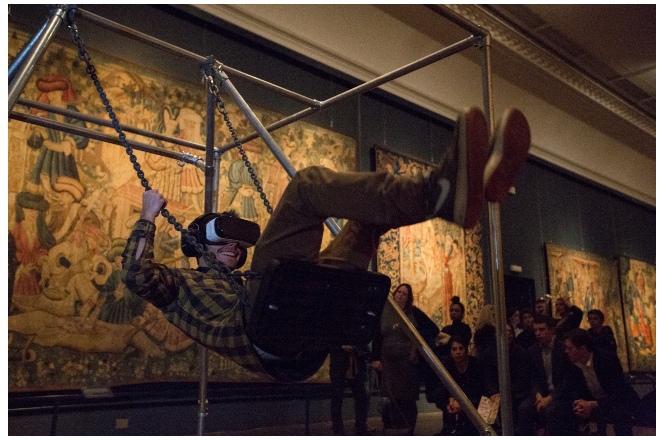

Figure 3. Oscillate installation at The V&A 2016

To answer this need, the artist placed the virtual facsimile of the gallery in outer space. Galaxies could be seen through skylights and doors, which were designed to entice the rider to swing higher, to peer into the cosmos beyond. Finally, the virtual world was designed to be completely empty of other exhibits and audience. He coated the walls of the virtual gallery in acoustic foam, easily recognisable from the design language of sound booths and equipped the rider with a pair of real ear defenders. The desired effect was to distance the rider from a watching public, and create an insular experience, but still to leave them with a muffled trace of real life. This trace was designed to help transport riders' consciousness back to the real world, but subtle enough to allow the sound to be subsumed into the VR world should they choose to ignore it.

Versions

Oscillate has been deployed in two different galleries, first in 2015 at Sheffield International Documentary Film Festival (Docfest) (version 1 - see figure 2), where it ran for two weeks, then in 2016 in London's Victoria and Albert Museum (the V&A) (version 2 - see figure 3) for just one night. As a part of the artwork is that the virtual world is a to-scale representation of the room in which the swing is situated, this was recreated for each installation. Similarly the physical characteristics of the room at the V&A, specifically the very high ceiling, required the physical swing to be redesigned. Finally, with the rapid advancement in headset technology, the hardware was also updated to be wireless for version 2.

Physical Swings

Version 1 of the swing was designed to hang from a frame attached to the ceiling, and created from steel scaffolding to evoke memories of playground swings, albeit distorted by being upside down. Figure 2 shows the design of this mounting. Conversely, version 2 of the swing was designed to be freestanding and more abstract in its cubic form. Figure 3 shows this clearly. In both cases the swing itself is chain mounted and hung from a crossbar with the seat being fifty centimetres from the floor. This accommodates most sizes of rider. In version 1 cabling for the headset and sensor were run down the left chain.

Hardware

Both versions of oscillate used the same two elements, a sensor mounted on the base of the seat of the swing to detect its motion, and a VR headset for the rider.

In version 1, the sensor on the swing was a Phidget Spatial (phidgets.com), a nine degree of freedom USB-connected motion sensor comprising a tri-axis accelerometer, gyroscope and magnetometer sampling at 256Hz. Only the gyroscope and accelerometer are used. In version 2, this sensor was replaced with a Samsung Galaxy S7 phone, connected with both Wifi and Bluetooth for redundancy, calculating the swing angle internally (see next section) and sending that to the headset at 100Hz.

Version 1 used an Oculus Rift DK1 headset. This was selected over the also available DK2 for its lightness and the form and positioning of its cables. It was decided that the sacrifice of resolution was acceptable when weighed against these practical concerns. This was connected along with the seat sensor to a Windows PC a short distance away which ran the software. For version 2, the PC was dispensed with and the headset replaced with a Samsung Gear VR, containing a second Samsung Galaxy S7 which was able to run the software locally. This had the distinct benefit of fewer cables - and thus fewer mechanical points of failure, traded against the need to monitor battery state. This was deemed acceptable risk as Version 2 was constantly invigilated.

Capturing and Correcting Motion

The most significant technical challenge of Oscillate was the need to correctly calculate the *real* angle of the swing from incoming accelerometer and gyroscope data. We elected to limit our interest to a single axis (Y), reasoning that the swing primarily moves in a single axis. We were able to accurately read angular Y velocity from the gyroscope, and integrate this to provide an angle, however gyroscopes tend to drift so this needed to be corrected. Fortunately, the pendulum-motion of the swing creates a maximum z-axis acceleration as it passes through the origin, so we were able to use this to correct the gyroscope drift with every half swing. With a period of 2-3 seconds, this still allowed for a small amount of drift, however

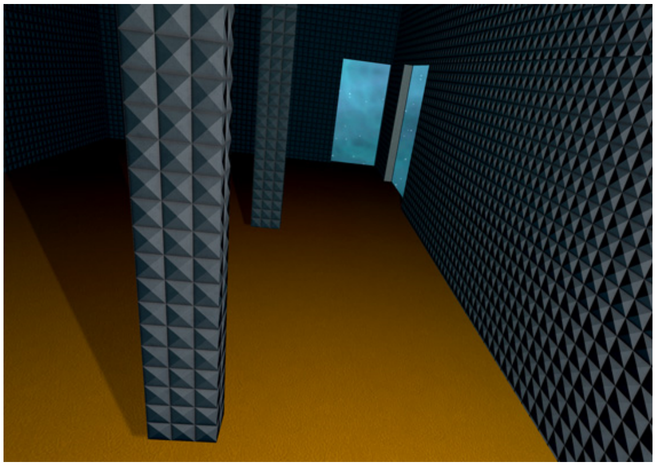

Figure 4. The virtual room representation at Docfest 2015

we accepted this as minimal error. The fact that the rider was effectively blindfolded, and the fact that we were also perturbing this angle over time allowed us a certain amount of undetectable error margin. We note that whilst we did consider more complex models, a swing with a person on it does not behave as a perfect pendulum, due to a combination of body position changes and flex in the chains connecting the seat to the swing bar. Measuring *seat angle* also means that our measurement is very slightly different to *swing angle* due to seat angle changes when body position changes, but while actively swinging, this alters angle by <5 degrees on very extreme swings. In version 1 the raw data was collected by the PC and the angle was calculated there. In version 2 this work was offloaded to the phone which hosted the sensors, freeing up resources for rendering, and allowing data to be transmitted wirelessly at a lower rate (100Hz instead of 256Hz).

Headset orientation was detected using the on-board sensors of the headsets. In version 2, the magnetometers of both devices were used to determine the angle at which the software started ensuring that a good mapping was maintained for the orientation of the device, avoiding problems caused because the device normally resets direction when the headset is put on - potentially causing misalignment. Unlike the Gear VR, the Oculus Rift DK1 did not do this orientation reset, so instead the rider was asked to look straight forward for two seconds after putting on the headset but before starting to swing to correct the drift in headset orientation. This drift was a known issue with the Rift DK1 and has been subsequently corrected by future versions which use cameras to track the position and orientation in coordination with the fast on-board sensors.

Virtual Worlds

The primary visual conceit of Oscillate is that the gallery in which it is situated is represented in perfect one-to-one scale in the VR world, albeit with some texturing changes, and that the rider is isolated from other pieces and people in the same gallery first by their not being included in the virtual world and secondly by the application of physical ear defenders. To extend this idea of isolation, the gallery is then taken out of

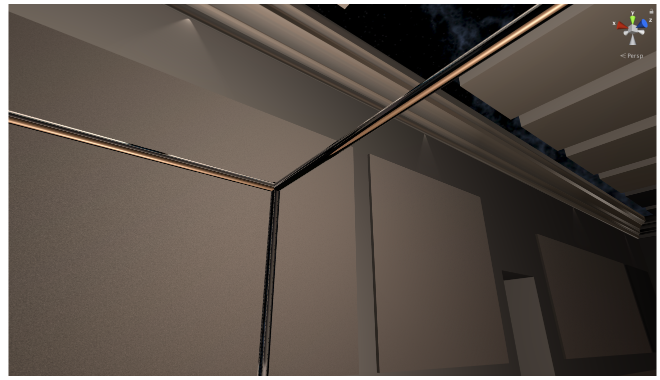

Figure 5. The virtual room representation at The V&A 2016

context and apparently suspended in outer space. This also gives the rider something unusual to look at, and through the skylight, an incentive to swing higher.

The worlds were built using the *Unity* game engine (unity.com), in each case from detailed millimetre correct plans of the rooms. A 3D painted flat skybox was used to create the feeling of being in outer space. For Docfest, the walls were textured to look like anechoic foam (figure 4). For version 2, the gallery contained a number of very large tapestries. In conversation with the curator, the artist drew inspiration from the reported acoustic properties of tapestries, and chose to isolate and represent these artefacts as pieces of anechoic foam instead of covering the full walls (figure 5).

Oscillate does not provide a representation of the swing or the rider, though version 2 does include the swing's outer structure as a reflective surface. In both cases the position of the rider's head is represented by a moving light source which helps to add dynamism to the scene. In the case of the V&A, a much larger room, additional lighting was provided as spotlights above the 'tapestries'.

Physical-Virtual decoupling

The main component of the Oscillate experience is the changing relationship between how far the user is physically swinging and how far they *appear* to be swinging. The virtual angle is a function of both the physical angle and the time within a session. The point in the session is used to generate a value between 0 and 1 where 0 is the start of the session, 1 is the peak (90 seconds) and 0 is the end of the session. if we use t to represent this value and θr to represent the physical angle, with a constant α to represent our target maximum angle multiplication then we can calculate the virtual angle θv as:

$$\theta v = \theta r + \alpha t \theta r$$

We did not want the apparent angle to exceed 175 degrees, believing that the illusion would break (based on the theory of *quarantining* [7]) if the rider appeared to be "swinging over the crossbar", so the value was clamped in the range -175 to 175 degrees and we selected a value of 2.5 for α. This meant that a rider swinging out to 50 degrees would reach an apparent maximum swing angle in the virtual representation of 125

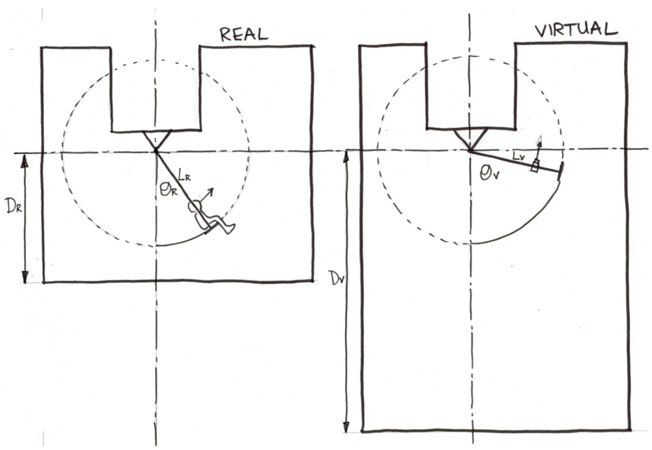

Figure 6. The original design sketch for the swing's virtual motion

degrees. This maximum virtual angle meant we expected a physical swing limit of 75 degrees (175/2.5). Part way through the session of version 1 we increased α to 3.5, based on our observations of swinging in practice, where riders very rarely exceeded 50 degrees. Indeed in version 2 of the swing, the angle was mechanically limited to 50 degrees to ensure the stability of the free standing structure.

The second aspect of the Oscillate experience is the vertiginous dropping away of the floor. Using the same cycling value (t) as in the angle multiplication, the floor was dropped away congruently with the swinging action. Maximum deflection here (*m*) was arbitrarily selected as 20 metres. With each swing forward or back, the floor would drop away and return to normal as the rider's physical angle approached zero. Artifacts such as doorways would travel with the floor. This means that when one is at the back of the swing looking down, the floor looks terrifyingly far below, and rushes back towards you as you swing down. The apparent distance to the floor for a given frame *Dv* was calculated from it's real distance *Dr* as follows:

$$Dv = Dr + mt\theta r$$

Reception

At both venues Oscillate was very well received. In particular, during its time installed at Docfest it was the most tweeted artwork at the festival and was positively reviewed across a variety of national and international media. This serves only as anecdotal evidence of its success without a formal evaluation, however informal interviews with a range of riders have indicated that the effects worked as intended and have led us to consider certain themes in the next section. At Docfest in excess of 200 people tried it. At the V&A we ran it constantly for four hours, with a turnaround time of five minutes per rider, giving us a throughput of approximately 48 riders.

DISCUSSION

Here we discuss some key themes to come out of our observations on both building the artwork and discussing it informally with riders. We follow this with a discussion of more general challenges associated with developing and deploying visual-kinaesthetic experiences.

Sickness

One area in which Oscillate appears to fly in the face of conventional wisdom is sickness. Oscillate did not cause riders to feel sick. As we advised the artist on initially seeing the designs, the design of Oscillate on the face of it appears likely to cause nausea in participants for four reasons:

Firstly, on describing the experience to two world experts on motion sickness and simulator sickness respectively, both suggested that they would expect high levels of sickness. Similarly, when given a description, riders also mentioned that they expected to feel sick. As noted in [30], we would expect these negative expectations to be strongly correlated with experience of adverse symptoms.

Secondly, Oscillate deliberately plays with notions of vertigo by increasing both the apparent height of the swinging, and by having the floor drop away to further extend the apparent height. Feelings of vertigo often create symptoms of dizziness and sickness [9], and several riders reported feeling scared by apparent height, however this did not appear to cause undue feelings of sickness.

Thirdly, the pendulous motion of a swing is one of the classic causes of conventional motion sickness [14]. Given most riders have experience of swings dating back to childhood, we felt it would be acceptable to discount this - assuming that any riders who know themselves to be subject to that degree of motion sickness would choose not to ride the swing, but on top of other factors, we expected a high risk of sickness.

Finally, the mapping between real and virtual movement is not one-to-one. The core ride experience is this discrepancy of rotation angles. Following the research from works such as [21], we would expect this incongruence to lead to simulator sickness, however this does not appear to be the case. It appears that the fact that the physical motion is similar enough to the virtual motion - traveling in the same direction and accelerating in the same way relatve to body position (despite amplification), that this is enough information for the brain to 'sort it out'. Similar effects have been shown with very small, subtle and slow incongruences, as in 'redirected walking'[29], but that technique deliberately aims for small and imperceptible levels [41]; we would not expect this result in such extreme and blatant manipulation of senses.

This is perhaps the most unexpected and challenging finding from oscillate, and warrants further study to understand more completely. Some pilot work in which we had headset wearers stand still while another rider actually operates the swing, along with development experience testing the environment with pre-recorded swing data convinced us that no physical motion coupled with virtual swing motion was extremely sickness inducing. A similar test in which the virtual motion was inverted (i.e. swinging backward on the real swing, resulted in forward virtual motion) yielded similar results. This points strongly to the idea that motion does not have to be one-to-one to compensate for simulator sickness, but that physical motion does needs to suggest motion occurring in the visuals at least in direction.

One factor that may play into many of these outcomes is control. A swing is a mechanical device that most people have learned how to control from childhood. We understand how to increase and decrease our speed, and we also know that we can put our feet down at any time to stop. The control is somewhat limited by the nature of the pendulum - it can only move in a specific fashion (swinging back and forward), but we can influence that movement. Lack of control is known to have a negative impact on feelings of sickness [40, 39]. It is possible that the amount of control afforded by the swing is sufficient to compensate for other nausea inducing factors. We did note in some users a reluctance to put their feet down (one of the key methods for controlling the swing) reportedly as a result of both apparent distance to the floor, and feelings of traveling faster than they were in reality.

Permission to play

Play is an integral part of human development [11]. In many parts of the world, "the playground" is synonymous with childhood experience of outdoor play and is generally centred on a small set of traditional elements: swings, slides, roundabouts etc. Of these, perhaps the most universal is the swing. As adults, much of our play is centred around games and sports - play to which strict rules are applied [35], and elements and apparatus of play that do not have an associated rules or competitive structure tend to fall out of favour as we grow up. Similarly, as we get older we become more cautious, both in terms of inhibition [20] - we don't want to publicly make fools of ourselves, and physically - we are either unable to physically perform, or unwilling to risk physical injury in the same way as children. While there may be many physically exerting experiences such as sports in which adults engage, these mostly focus on rules and competition rather than 'play'.

Part of the artistic motivation in the design of oscillate was an aim to hark back to feelings of pure play. It is not a game: it has no rules and there is no way to win or lose. It is simply an experience. However it delivers to its rider an amplification of effort designed to evoke feelings of childhood freedom. We may not feel able to try and swing over the crossbar as we did in childhood, but Oscillate gives us the illusion that we can.

Specifically the structure of Oscillate - using the design language of a playground swing, coupled with the environment in which it is set - an art gallery, provides the rider with what Rogerson describes as *permission to play* [34]. Rogerson draws attention to the *"growing recognition of the economic value of play by adults"*; noting several authors who have identified a relationship between play and creative thinking, invention and entrepeneurship, and argue for the importance of life-long play [33, 15, 6].

It is questionable whether all visual-kinaesthetic experiences would have the same degree of playfulness and permission to play afforded by Oscillate, given the specific playground connotations it creates, however, the playground is a rich source of kinaethetic sensation, being largely built on the premise of Calois' *vertigo play*. If we consider VKEs to be built around notions of motion, control and sensation then this sense of playfulness is likely to pervade future works in this area.

VR as performance

In the artistic vision for Oscillate, the artist specifically notes how riders are expected to be watched. Indeed in most cases a rider will be a spectator first, since queueing to take one's turn on the ride is generally a necessity. This process does not occur by accident. The design of Oscillate draws on the designed-in experience trajectories as described by Benford in [2]. Oscillate can not and should not be considered a ride in isolation, but part of a wider experience. Excluding for reasons of scale the surrounding festival environment where it was situated, the whole experience was designed to be much more than the three minute ride itself.

Drawing on theme-park designs, the rider trajectory begins when they see it first as a spectator - a time at which the virtual world is unseen. The rider then begins the process of kitting up - getting onto the swing and putting on a headset and ear defenders. In many cases this may be the rider's first experience of virtual reality - and in even more cases it will be their first experience of virtual reality combined with physical motion. They then have what is for the rider a very personal and seemingly isolated experience – emerging from the VR at the end to see an audience – perhaps containing friends who have just in some way shared their experience and with a different perspective as they become once more a spectator, albeit one with new perspective on what they are spectating.

This runs counter to conventional expectations of virtual reality. Leaving aside *social* VR experiences like multiplayer games, VR is by nature a solitary experience. The user is essentially blindfolded. In Oscillate, we also block out external audio with ear defenders. A user is quite literally "in their own world". But of course they are not. The rider is fully aware of where they are in the real world - the trajectory of the experience has seen them first as spectator, and they are conscious that people (perhaps friends or family) are watching them. This puts them in the odd position of performing without being able to see themselves or their audience. The artist mentions the name Oscillate as referring (amongst other things) to oscillations between public and private spaces, and this is observably in many riders' thoughts. e.g. some riders play up their fear for the audience or narrate their experience.

This blending of public and private, of experience and performance is very much part of how we experience many types of rides. In [37], the authors note the screaming of thrill riders who are aware they are being recorded. Emotional contagion [16] is a well travelled thread of research: when we all scream on a thrill ride it makes us all scream more; when we all laugh at a comedy show it makes us enjoy it all the more. What is interesting about performance in VR is that we are simultaneously aware of, but unable to assess the responses of our watching peers. More research will be necessary to determine the effect this might have on our performance. Certainly the viewing of people experiencing VR, especially for the first time, is engaging - thousands of such reaction videos are available on youtube.com. The expectation is then that the same should be true - perhaps even more so - for VKEs, since the user's body may well be being actuated as part of the experience forming part of the spectacle.

CHALLENGES FOR VKES

In this section we lay out some challenges associated with creating visual-kinaesthetic experiences in three key areas: *practical* considerations, *evaluation* considerations and finally *design* considerations.

Practical Challenges of VKEs

Based on our experience developing and delivering Oscillate, we offer the following practical considerations for building visual-kinaesthetic experiences.

Sensing State of Physical Experiences

For experiences where a person is moved by or within an underlying physical motion system, a key challenge for VKEs is to know the current state of the motion system. Even with a classic motion platform, where the system is sent a position or orientation and moves to that position, due to time taken to move, feedback as to the actual current position of the system is important in order to tightly synchronise the state of the VR system with the motion of the system. When we begin to integrate with more complex and less controllable physical experiences such as Oscillate's swing, sensing the physical state of the motion system becomes a real challenge. Even with relatively pre-set experiences such as rollercoasters, mechanical factors such as heat, rain and wind can cause significant differences in timing and speed of motions. Our current approach and that used on VR rollercoasters, is to apply an extra sensor on the motion platform. However, this adds extra infrastructure and complexity to systems. One alternative is to consider the constraints of the motion system and infer the state based on the motion sensors already in the headset - for example we have an early prototype of Oscillate which analyses headset movement in conjunction with a physical model of swinging motion, which enables it to be used on any playground swing without extra hardware. Another alternative is to use external components for sensing such as with the HTC Vive, where trackable objects can know their position based on a pair of external beacons.

How Close is Good Enough?

In Oscillate, tracking is never 100% perfect, plus it is deliberately distorted by significant amounts. In this situation, we have scope for both error and deliberate manipulation, as users cannot see the environment, and only have to interact with physical things (the swing) which they are sitting on and holding onto already. However, if people have to interact with real physical objects from within the VR environment which are not physically attached to their motion in some way, we may be under much tighter constraints as to displaying the relative position of those objects.

Safety, Sickness and Sensor Failure

Combining extreme physical motion with a headset which removes your vision of what is around you creates obvious safety concerns. In Oscillate, we deal with safety primarily by ensuring people only wear the headset whilst on the seat, constraining them to a relatively safe place. However, there are still some potential safety concerns - for example, we drop the virtual floor, creating a space where you might think you could lower feet into, but can't. Conversely, people who wish to stop can find it hard for two reasons, firstly it is hard to touch feet down while the floor is dropped, and secondly, the increasing amplification of the swinging can make it hard to know when you are really slowing the swing down ready to stop. We must also consider the dangers inherent in physical experiences and decide whether and how to deal with them, for example in our swing, people could at any point jump off, putting themselves in real danger.

A major element of safety in any use of a VR headset is sickness induced by VR motion which is inconsistent with real motion. Our work on Oscillate suggests that there is scope for altering the mapping between VR and real motion sensations without causing sickness. More research is required to explore what the range of this flexibility is. One thing we do know from Oscillate however, is that complete non-motion in VR while the real world is moving, such as if the sensor on our swing seat fails, is extremely nausea inducing. This means that position sensing algorithms become very much a safety critical element of our system, and we must design graceful failure modes, either by falling back to other sensing, or removing the visual stimulation and stopping the experience in order to avoid motion inconsistencies resulting in queasiness or worse!

Challenges of Evaluating VKEs

Here we consider what it means to effectively evaluate a visual-kinaesthetic experience. Astute readers will note that this paper does not include a formal evaluation of Oscillate, merely a series of informal discussions and anecdotal experience. This is because we submit that there is a need to develop new evaluation approaches to deal with this type of experience. While there is much to be said for taking the kind of ethnographic approach often associated with studies 'in the wild' as discussed in [3], these types of studies may be difficult for certain types of experience which are not directly observable [12] - of which VR is one example. There is also a case to be made for more formally understanding how these experiences work and affect riders under lab conditions.

Understanding what we want to evaluate

A great deal of previous research into evaluating VR has focused on task performance, sickness, and presence. A focus on experiences for entertainment's sake and the systematic relaxing of the coupling between the visual and the kinaesthetic casts these familiar issues in a new light. There is a need to revisit conventional approaches to usability in VR. In general terms, it is questionable whether engaging with cultural experiences is best understood as a *task*. It may be necessary to extend conventional notions of task performance to address more entertainment-oriented outcomes such as *thrill* and *pleasure* while also broadening the notion of *satisfaction* to accommodate personal interpretation and meaning-making. Such models have been applied to understanding theme park rides in e.g. [13], and similar psychophysiological approaches to measuring the complex emotional states of thrill and pleasure may be appropriate for understanding the success of VKEs.

Are existing measures appropriate?

We believe it is also necessary to revisit conventional thinking around virtual experiences. For example, considering 'immersion'[19], often considered a gold standard of VR experiences, a commonly used immersion measurement tool asks:

> "To what extent did you feel as though you were separated from your real-world environment?"[19]

If we consider this question in relation to VR enhanced rollercoaster Galactica, the success of the ride relies both on people experiencing an exciting space flight, but also on the ongoing knowledge of what is happening in the real world, that the ride is taking them to a real height and really dropping them down. Similarly, with Oscillate, the awareness that you are on a real swing is key to enjoyment of the ride. VKEs like Oscillate also function in ways that are counter to current understandings of effects such as presence and sickness. For example, sensory conflict is conventionally considered to negatively affect both presence and sickness; However, our experience with Oscillate suggests that this may not necessarily be the case, or that other factors such as thrill may counter-balance these effects in terms of overall pleasure.

A second issue that is also considered to negatively impact both presence [45] and sickness [40, 39] is a lack of control. Building VKEs from physical experiences other than thrill rides (as with those developed by VRCoaster and Robocoaster) affords the opportunity to add both control and agency to the users' experience of the ride - as shown with oscillate - a manually powered swing. However, others have argued that some people may enjoy relinquishing control and psychological comfort [23] which would appear to be especially apposite for rides. Finally, unknown and negative expectations have also been related to adverse symptoms [30], although again, entertainment experiences such as rides routinely trade on these as part of suspense. We have observed riders of oscillate finding it did not meet their negative expectations in terms of sickness, providing further challenge to convention. We must therefore reassess conventional wisdom about the role of sensory conflict, control and prior expectations in VR in the light of these more complex visual-kinaesthetic relationships and explore how these may positively and negatively affect entertainment experiences.

How do Effects Change Over Time and Between Individuals?

Beyond simply measuring the overall effects of experiences, it may be interesting to consider how these various factors may vary over time and between individuals. Do sensory conflicts, for example, need to be introduced and/or resolved gradually, as they were in oscillate in order to have the optimum effect with minimum adverse consequences? And how might they vary between riders? Might it be possible to profile individuals and so recommend or even adapt their experience on the fly?

Design Challenges for VKEs

Here we put forward what we consider to be a number of key factors to consider when designing Visual-Kinaesthetic experiences. We consider first how to go about selecting apropriate physical experiences to augment, then consider the wider trajectories around the experience as well as how it might be feasible to both spectate and document such experiences.

What Kind of Physical Experiences Are Suitable For VKEs

Oscillate stands as one example of a VKE, alongside Lake's original haunted swing and it's spiritual successors such as Hex - The legend of the towers, and the new generation of VR-augmented rollercoasters. This is a very limited subset of potential kinaesthetic experiences to have been treated. Questions immediately arise about what other kinds of experiences might work well with augmentation. We have mentioned that the playground as a good source of physical experiences based on Caillois' vertigo play [11] and one we intend to pursue, however it is appropriate here to consider what characteristics of a physical experience would make it suitable for augmentation as a VKE. We would propose that any experience which meets the following criteria might be suitable:

- *It creates physical sensation without relying on vision.* While sensations of motion are certainly one option, as suggested earlier other types of visceral sensation may also be appropriate for consideration. Experiences which induce dizziness, vertigo, claustrophobia, touch, a sense of being pushed/pulled in a direction or other engaging physical sensations might be considered. However as we shall see, kinaesthetic sensations may be heightened or induced by application of visuals to a more everyday physical sensation.
- *It can be markedly changed by the application of different visuals.* One excellent example set to consider here are the plethora of VR 'walk the plank' experiences e.g. [22]. In these we have a physical sensation of a plank under our feet - which is actually lying on the ground so we know we are completely safe, however visuals make us think we are at the top of a skyscraper, over a roiling ocean or atop an active volcano. This combination of the simple haptic feedback of the plank under our feet (which has defined edges) and the visual suggestion of danger of falling makes for a very engaging experience. We saw the same effect with Oscillate where the visuals induced feelings of being high and traveling fast. The point here is that sensations can be created from very simple physical physical experiences.
- *Is is safe to operate without vision.* This is a critical if practical consideration - it is necessary that there be no 'real' danger which does rule out a number of potentially interesting physical experiences.
- *It allows for some degree of control.* While companies such as VRCoaster are developing VKEs based on massive physical infrastructure (e.g. rollercoasters), we suggest that at a smaller scale, physical experiences over which the user can exercise some control may be equally or even more interesting to work with. Considering the known effects of a sense of control on both sickness and presence [40, 39, 45] we postulate that control may be an important factor, especially when we begin to perturb the relationship between *real* movement and *apparent* movement.

How Might We Design Experience Trajectories for VKEs?

In the section of VR as performance we mentioned that oscillate had been designed in consideration of an entire experience trajectory (as described in [2]) rather than as an experience in isolation. This leads us to consider the general trajectories of

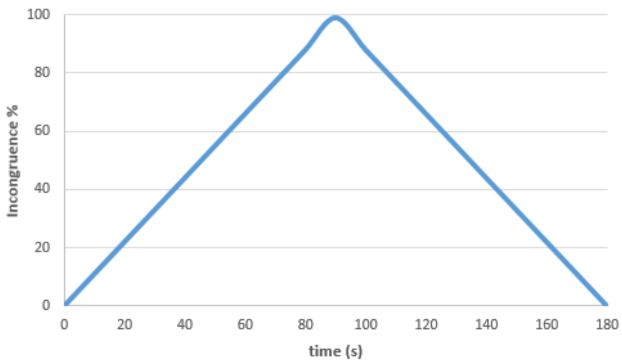

Figure 7. Oscillate's congruence envelope

VKEs. From a design standpoint, the first consideration might be whether such an experience would be:

- *Fully private* - In an entirely private setting, for example at home, a designer need only focus on core experience. The expectation is that there is no external visibility of a user as they engage with an experience. This may be most appropriate for certain types of very personal experience.
- *Small scale publicly visible* - An example here would be a version of Oscillate that a user can run themselves at a local playground. In these cases the user is in a public space. The designer must consider characteristics of possible spaces that might be used such as who might be there and what the user might *appear* to be doing. These examples are likely to be unmoderated and as such perhaps most sensitive.
- *Large scale publicly visible* - In these cases we might look to the VR rollercoaster example. We are considering public spaces in which users are likely to queue to take a turn. In these cases they are likely spectator first, then rider, then experienced spectator. Such spectacles (like theme parks) are often visited with friends or family, so a designer must also consider the local social context as well as the wider context of the setting. This is the context that would cover most 'built experiences' and perhaps the most likely to be in a commercial setting.
- *Deliberately performative* - Here we consider examples of an experience in which the user is put 'on stage', that is they are as an individual the centre of attention as they experience the VKE. This is very much the space in which Oscillate resides. In these cases the rider is almost expected to deliver a performance to spectators while riding. This was covered more in the section on VR as performance.

Beyond external factors of the ride, it is necessary for designers to consider the internal trajectory of the experience. Oscillate does not start with disconnect between *real* and *apparent* swing angle - the perturbation is introduced slowly. We suspect that the slow introduction of this incongruence might be a reason for riders not feeling a strong disconnect. As such we present the possibility for designers of using a *congruence envelope* see figure 7, in which the experience at least begins with a one-to-one mapping of sensation then decouples and/or recouples that over time. Playing with this envelope may be one way of delivering interesting VKEs

Spectating and Documenting VKEs

Virtual reality headsets are by default what Reeves [31] describes as a 'suspenseful' user interface, where the actions of the person using the headset are highly visible, yet the effects of those actions on the virtual world are invisible to the viewer. In Oscillate, we embrace this, with the rider's virtual experience only conveyed to the audience by excited shouts and laughing as they swing. This is designed to attract further riders to the experience. Whilst this is a valid approach for spectator experience design at the time of running Oscillate, documentation of the experience presents further challenges; without description, a video of Oscillate is simply a video of someone swinging on a playground swing with a VR headset on. Without access to a motion platform, it is inherently difficult to replay experiences which rely on a combination of visual and physical sensations. For example, the conventional way of documenting VR, by combining external video with the view from inside the headset does not necessarily convey the full experience; It is hard to see that the swinging is being visually exaggerated without feeling the kinaesthetic sensations of swinging as a rider would. There are several possible alternative ways of documenting such experiences, for example by overlaying external footage with 3D renderings from other viewpoints (e.g. in Oscillate, showing the real swing overlaid with rendering of the virtual exaggerated swinging). However, these create new challenges such as having to alter 3D models to show additional external viewpoints. We could also consider using physiological data to present information on riders' internal state, for example to expose 'thrill' [37].

CONCLUSION

Virtual reality is a technology which has found consumer traction recently. We suggest here however that some of the core issues with VR - simulator sickness, lack of presence etc. caused by an incongruence between visual experience and bodily sensation may be addressed by making use of existing physical stimulation. While there have been some commercial ventures in this area, for example rollercoasters in which the visuals have been replaced with VR, we suggest that this is a something that can be done on a smaller scale. We also submit that by decoupling the visual from the kinaesthetic, it is possible to create new and interesting types of experience. We have used the example of one such experience: *Oscillate*, a VR augmentation of a playground swing, to demonstrate this principle, and to highlight a series of challenges in terms of *practicality*, *evaluation* and *design*. More research is needed to fully answer the challenges defined here, but Oscillate, along with other similar experiences demonstrates that *Visual-Kinaesthetic Experiences* represent a field worth exploring.

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