HCI Lessons From PlayStation VR

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Abstract
PlayStation VR has quickly built up a significant user-base of over a million headsets and its own ecosystem of games across a variety of genres. These games form part of a rapidly evolving testing ground for design solutions which can usefully inform HCI design for virtual reality. This paper reviews every PlayStation VR title released in the first three months of its lifecycle in order to identify emerging themes for locomotion. These themes are discussed with respect to the lessons learned as part of the on-going development of an Environmental Narrative game for PlayStation VR as part of the Horizon 2020 REVEAL project.

Author Keywords
PlayStation VR; virtual reality; locomotion; motion-sickness; Horizon 2020; REVEAL.

ACM Classification Keywords
H.5.1 Multimedia Information Systems: Artificial, augmented and virtual realities.

Background
This paper reports on work by the *Steel Minions* game studio at Sheffield Hallam University which is a licensed PlayStation developer, and receives support from Sony Interactive Entertainment under the PlayStation First Programme. This scheme provides the studio with access to PlayStation development hardware and tools, and the studio has already designed, developed and

(a)

(b)

Figure 1: The PlayStation VR headset (a) external view (b) internal view. © Sony Interactive Entertainment Inc.

The REVEAL consortium partners are Sheffield Hallam University, Utrecht University, CNR ITABC, VRTRON, UTC Sheffield and The Jenner Trust.

published several commercial products on the PlayStation Store. The studio has been working with PlayStation VR (PSVR) for over a year and has two commercial titles currently in development.

The REVEAL Project

This research was conducted within the context of the Horizon 2020 REVEAL project: a collaborative Innovation Action involving games industry partners, museums, schools and universities. The project is developing frameworks to facilitate the rapid development of VR-based Educational Environmental Narrative games (EENs) for PlayStation 4. The problem of motion sickness in player locomotion is well documented [1, 7, 11]. However, first-person perspective player locomotion is essential to Environmental Narrative games (e.g. *Dear Esther* and *Gone Home*) which are sometimes even referred to as "walking simulators". REVEAL aims to develop an inclusive VR locomotion system which is accessible to novice users in museums and school contexts as well as typical PlayStation users in the home. Therefore, the final game must be both simple to use and free from the most extreme effects of motion sickness.

As demonstrator for the REVEAL technologies, the Steel Minions studio is creating an EEN game based around the life of Edward Jenner, the Edwardian country doctor credited with the invention of vaccination [3]. The game is set within a reconstruction of his family home in Gloucestershire, England (now a museum) and explores the controversial aspects of Jenner's discovery (such as experimentation on children) as well as the classic story of smallpox, milkmaids and cowpox [16]. The final game will be published on the PlayStation Store as a digital product.

Figure 2: An EEN game set in the home of Edward Jenner.

PlayStation VR

The PSVR headset (figure 1) is comparable to the Oculus, and is designed for use in a sitting or standing position without walking. PSVR supports rotational and positional tracking in 3D space, and all players have access to at least one Dual Shock 4 controller (figure 3a). These track 3D position and orientation, and are designed for use with two hands. Optional PlayStation Move controllers are available which track position and orientation separately for each hand (figure 3c).

SYSTEMATIC REVIEW OF PSVR TITLES

There is a significant body of academic literature on the topic of virtual reality locomotion which can be used to inform good design [1, 4, 7, 11, 14]. However, a body of commercial work also has the potential to inform good design. While it is rare for commercial works to be the subject of rigorous empirical evaluations [15], market forces often have a similar effect in highlighting successful design solutions. The effect of 'natural selection' on game design has fed academic theorizing in the field of educational games, for example [2].

(a)

(b)

(c)

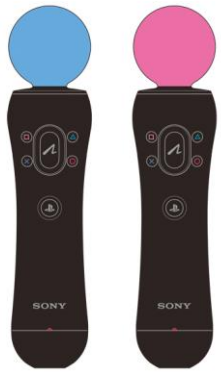

Figure 3: PlayStation Controllers. Dual Shock 4, from above (a) and front (b). PlayStation Move controllers (c). © Sony Interactive Entertainment Inc.

Virtual reality gaming may still be at a nascent stage where dominant solutions have yet to emerge, but they provide a rich gene pool from which to distil promising ideas and approaches. To this end a systematic review of existing locomotion solutions for PlayStation VR was undertaken to inform the design and development of potential movement mechanics for REVEAL.

Inclusion Criteria

Our inclusion criteria encompassed all PSVR titles (digital and physical products) released in PlayStation's European publishing region, during the first three months following the headset's launch (on October 13th 2016). Examination of the PlayStation Stores for the other two publishing regions indicated that almost identical PSVR products were available in North America, while a number of unique titles were only available in Japan. As it would be difficult for the research team to obtain and understand Japanese products, this region was excluded from our analysis. Initially, only PlayStation 4 tiles badged as "PlayStation VR required" were included, and only if they weren't also badged as "Apps" (rather than games). However, these initial criteria only yielded 37 results and so the range of release dates was expanded up to 24th January 2016, when 14 new PSVR products were released on the same day. Some titles previously excluded for only being badged as PlayStation VR "compatible" rather than "required" were now included if they contained locomotion as a core element of the game. This produced 51 games (38 digital and 13 physical) which was deemed an appropriate sample for the review. Publicly available gameplay videos and/or free demos were then used to establish which of the games included 'player-controlled locomotion'. Our definition only included games which provided the player with direct control of the camera position as viewed by the principal game avatar, and excluded games where the camera follows a pre-defined path for most of the game (i.e. "on rails"). This produced a list of 28 games which were all obtained and played to explore the emerging themes for player locomotion in PlayStation VR titles.

Locomotion Themes in PlayStation VR

The following section describes the different locomotion techniques used in our sample, grouped according to themes and ordered by frequency.

None

It is important to note that 23 of the PSVR games in our sample (45%) contained no independent camera movements of any kind. Although no comparable data was recorded for 'non-VR' games, fixed camera positions are far less common in 3D games which aren't designed for virtual reality. This suggests that game designers are conscious of the potential issues with motion sickness and player locomotion, and many choose to avoid it completely by designing VR games which provide VR head-tracking, but no locomotion.

Flight

Seven games were classified as using flight-based locomotion in our sample, as they allowed continuous independent movement in three dimensions (including in the ocean). In the real-world, the perception of motion in flight is often dependant on the relative moment of other objects around you. It's not surprising then that flying close to ground level in VR (e.g. *Eagle Flight*) tends to introduce more problems with motion sickness than in outer space (e.g. *EVE: Valkyrie*). Many flight-based games incorporate the additional complication of requiring continuous movement and

rotation in three dimensions. While research suggests that there isn't a dominant axis around which virtual scene movement is more tolerable, it does suggest that more axes of rotation will induce higher levels of motion sickness [6]. In games employing space flight the player is usually provided with the ability to come to a complete standstill, but this isn't plausible in less high-tech scenarios. This combination of low flight and continuous movement in *Eagle Flight* has caused the designers to go to great lengths to try and reduce motion sickness. This game incorporates an (avian) nose superimposed on the player's head to provide a fixed reference point [17] and dynamic systems to reduce the player's field of view based on speed [10]. While this did appear to reduce motion sickness, some members of the research team found it very distracting as a technique. Furthermore, the reduction of field of view seemed to turn the game back into a screen-based experience which was happening in front of the player rather than something the payer is immersed in—making it less engaging as a result.

Free Movement

Six of the games provided *free* movement mechanics comparable to control methods seen in most first-person 3D games not designed for VR. On the PlayStation this typically involves continuous movement with one analogue control stick and continuous rotation with the other. Notably, none of the free movement games in our sample included continuous *rotation* as a default control method. Instead, they all implemented a segmented rotation mechanic, either snapping instantly or turning very quickly in 20-45 degree increments. Where continuous, non-segmented turning was available as an option, it appeared to induce the strongest feelings of motion sickness in the research team—particularly when moving and rotating at the same time. Some of the games included a degree of automatic turning based on the relative direction of the head with respect to the direction of travel (i.e. looking right in the real-world while moving forwards in the virtual world gradually turns the player to the right). Interestingly this didn't seem to provide the same level of motion sickness as turning and rotating at the same time with the head in a fixed real-world orientation. Presumably this is an example of matching physical movements to stimulate the vestibular system in line with the player's visual experience.

Most of these games also didn't seem to include the same level of acceleration and inertia which are typically applied to character movement in equivalent non-VR games. One game which did include obvious acceleration and inertia (*Windlands*) certainly seemed to induce additional levels of motion sickness. The designers of this game appear to have fully embraced the concept of free movement in VR, allowing the player to leap around under moon-like gravity, and swing on a grappling hook, with all the associated continuous physical locomotion. Nonetheless, the game also contains one of the most extreme optional 'comfort modes' seen in any of the games, including a mode which fixes a large, cage-like ball directly in front of the player's view to provide a stationary reference point.

Vehicular Movement

Five games were based around ground-based vehicles, and provided continuous movement and rotation in line with expectations of driving control mechanisms outside of VR. The acceleration and deceleration of vehicles induced the greatest feelings of motion sickness in the research team. All these games

provided default 'cockpit' environments (or helmets) which obscured a notably large proportion of the player's view, presumably to reduce motion sickness in line with research on reduced fields of view [1]. Some of these games could be played without the cockpit, and feelings of motion sickness were more pronounced once it was removed. All of the vehicular games were designed to be played in a seated position and incorporated virtual seats. Some opted to include virtual arms and torsos as well, although there was no obvious effect of these on feelings of motion sickness to the research team.

Node-Based

Four of the games provide *node-based* movement mechanics along the lines of those commonly seen for the default configuration of the Oculus headset. The player looks towards a node (often represented by an icon or glowing shape) and presses a button to teleport to the node's position. These teleportation sequences often transport the player over long distances and are consequently accompanied by a fade to avoid player disorientation. However, one game (*Batman: Arkham VR*) provides nodes at more regular intervals and uses very fast continuous motion to move between them. Contrary to expectations, but in line with observations by [9] this very fast movement induces a much weaker feeling of motion sickness than free movement mechanics. By avoiding teleportation, it also appears to be less disorientating in terms of maintaining a continuous sense of presence in the environment. *Batman: Arkham VR* was also designed to be played standing up and contained no controls for rotation, relying instead on the player physically turning (in the real world) to change their direction in game.

Climbing

Two of the games in the sample (*Robinson: The Journey* and *Carnival Games: VR*) provided climbing locomotion mechanics. PlayStation Move controllers are required for this technique, where the player must reach for new grasping points with one hand, while holding on with the other. Trigger buttons were used to control the player's grip separately for each hand and locomotion is produced by moving a grasping controller towards the player's body. The way in which the player's physical body movements naturally match their visual experience, seems to reduce the potential for motion sickness in line with previous studies with treadmills [12].

Arc-Based Teleportation

Surprisingly only one game in our sample (*Tomb Raider: Blood Ties*) included a pointing-based interface comparable to those very commonly used for the Vive and Oculus (with Touch controllers). This game is designed to be played standing up and achieves locomotion using a parabolic arc which is positioned in the virtual world by pointing the Dual Shock controller with both hands. A semi-transparent representation of Lara Croft (the game's famous protagonist) is projected onto the end of the arc to show where the player will move to. If it is not possible to move to the position (because of an obstruction) then the arc turns from blue to red and the representation of Lara disappears. The arc appears when they player holds down one of the trigger buttons, and movement is activated by pressing a second trigger button at the same time. The player can also change the orientation of Lara at the end of the arc using one of the analogue control sticks. Teleportation to the new position is accompanied by a very short (barely noticeable) fade. Like its Vive and

Oculus equivalents this technique appears to successfully circumvent any potential for motion-sickness, but sacrifices some level of presence and immersion by doing so.

Ghost

One game (*Weeping Doll*) implements an approach which combines elements of the Arc and Free techniques above. Like the Tomb Raider approach, the player's new position is indicated by a projected 'ghost' image of the player's avatar. However, instead of controlling its position by pointing a controller, the player directly controls the ghost avatar from a third person perspective, and then teleports inside the ghost again when they have moved it to the desired position. This is an interesting locomotion mechanic, which avoids motion sickness, and fits with the ghostly setting of the game, but the research team found it quite disorientating to control.

Grid

Crystal Rift implements an approach in which locomotion is only possible between points on a regular grid structure. Movement between grid squares is continuous and at a slower pace than *Batman: Arkham VR*, providing increased feelings of motion sickness in line with [9]. The player can only control rotation in 90-degree increments, but these snap through 30 degree intervals along the way.

Camera

Hatsune Miku: VR Future Live implements a very simple locomotion mechanic which teleports the player to a different predefined camera position in a concert stadium. Movement is controlled by various button presses and is accompanied by a fade transition.

Blink

The default locomotion technique in *The Assembly* provides a blink-based locomotion which is analogous to the idea of closing your eyes to move a short distance and opening them again when you have stopped. This was universally considered to be a very disorientating approach by the research team, and it was difficult to tell if it really did limit any effects of motion sickness.

PlayStation Store Rating Data

45% of VR games in our analysis contained no player locomotion at all, and it was clear from reading online reviews of PSVR games that some players found VR locomotion difficult and frustrating. Consequently we were interested in finding out if the inclusion of player locomotion in a game was having a negative effect on player ratings for those games.

Average game scores (0-5 stars) and the total number of ratings were recorded for all 38 digital titles using publicly available data from both the European and North American PlayStation Stores. All values were recorded on the same day (4th March 2017) using Google search requests, as these provide more precise fractional scores which are not visible on the storefront.

	Title	Digital/ Physical	Locomotion	Europe		North America		Weighted
				Stars	Ratings	Stars	Ratings	Stars
1	THE PLAYROOM VR	D	-	4.3	4303	4.5	1513	4.4
2	Tomb Raider: Blood Ties	D	ARC	N/A	N/A	N/A	N/A	N/A
3	Batman™: Arkham VR	P	NODE	-	-	-	-	-
4	BattleZone	P	VEHICULAR	-	-	-	-	-
5	Driveclub™VR	P	VEHICULAR	-	-	-	-	-
6	EVE: Valkyrie	P	FLIGHT	-	-	-	-	-
7	Loading Human™: Chapter 1	P	FREE	-	-	-	-	-
8	PlayStation™VR Worlds	P	VARIOUS	-	-	-	-	-
9	RIGS	P	FREE	-	-	-	-	-
10	Super Stardust™ Ultra VR	P	VEHICULAR	-	-	-	-	-
11	Ace Banana	D	-	3.3	27	3.2	23	3.3
12	Harmonix Music VR	D	NODE	4.0	115	4.2	129	4.1
13	Hatsune Miku: VR Future Live	D	CAMERA	3.8	684	4.3	413	4.0
14	Headmaster	D	-	4.5	237	4.6	112	4.5
15	Job Simulator	D	-	4.3	687	4.4	667	4.3
16	Keep Talking and Nobody Explodes	D	-	4.6	197	4.5	173	4.6
17	Superhypercube	D	-	4.2	75	4.4	158	4.3
18	The Assembly	D	BLINK	3.3	178	3.3	45	3.3
19	Tumble VR	D	-	4.5	372	4.2	153	4.4
20	Fruit Ninja VR	D	-	4.5	315	4.4	111	4.5
21	Pixel Gear	D	-	3.9	154	4.1	127	4.0
22	Hyper Void VR Levels	D	-	4.6	255	4.4	422	4.5
23	Weeping Doll	D	GHOST	2.3	162	3.0	85	2.5
24	Call of Duty®: Jackal Assault VR	D	FLIGHT	3.5	11227	3.8	4539	3.6
25	The Brookhaven Experiment	D	-	4.1	312	4.2	198	4.1

Table 1 (part a). The PlayStation VR games included in the analysis (in chronological order of release) showing the player rating data from the European and North America PlayStation Stores.

	Title	Digital/ Physical	Locomotion	Europe		North America		Weighted
				Stars	Ratings	Stars	Ratings	Stars
26	Here They Lie	P	FREE	-	-	-	-	-
27	Moto Racer 4	P	VEHICULAR	-	-	-	-	-
28	Eagle Flight	P	FLIGHT	-	-	-	-	-
29	Robinson: The Journey	P	FREE/CLIMB	-	-	-	-	-
30	Space Rift - Episode 1	D	FLIGHT	3.3	92	2.8	34	3.2
31	The Martian VR Experience	D	VEHICULAR	1.5	375	2.1	169	1.7
32	O! My Genesis	D	-	4.0	327	3.8	128	3.9
33	Time Machine VR	D	FLIGHT	3.3	90	3.7	66	3.5
34	NBA 2KVR Experience	D	-	2.8	33	2.5	35	2.6
35	Crystal Rift	D	GRID	3.9	137	3.8	84	3.9
36	HoloBall	D	-	4.3	142	4.3	121	4.3
37	How We Soar	D	FLIGHT	3.8	75	4.0	31	3.9
38	Surgeon Simulator: Experience Reality	D	-	2.8	129	2.8	129	2.8
39	Battlefront™ Rogue One™:VR Mission	D	NODE/FLIGHT	4.4	8359	4.0	1306	4.3
40	Starship Disco	D	-	3.6	20	4.2	26	3.9
41	Resident Evil 7 biohazard	P	FREE	-	-	-	-	-
42	Carnival Games®VR	D	CLIMB	3.9	129	3.8	169	3.8
43	Fruit Ninja VR	D	-	2.8	240	4.1	154	3.3
44	Gunjack	D	-	4.1	428	4.1	180	4.1
45	Lethal VR	D	-	3.8	191	3.5	98	3.7
46	Perfect	D	NODE	2.3	382	2.5	138	2.4
47	Pinball FX2 VR	D	-	4.6	303	4.4	98	4.6
48	Sports Bar VR	D	-	3.5	317	3.5	237	3.5
49	Waddle Home	D	-	4.1	15	4.3	14	4.2
50	Werewolves Within	D	-	4.8	229	4.8	147	4.8
51	Windlands	D	FREE	4.4	143	4.1	72	4.3

Table 1 (part b). The PlayStation VR games included in the analysis (in chronological order of release) showing the player rating data from the European and North America PlayStation Stores.

Combined weighted average game scores were also calculated (weighted according to number of ratings for each region). This data is shown alongside the relevant digital titles in table 1.

An independent samples t-test was conducted to compare the weighted average game scores for PSVR games which contained 'player-controlled locomotion' (those in our analysis) with those that didn't. This revealed a significant difference in scores ($t(35)=2.546$, $p=.015$, Cohen's $d=0.861$) with PSVR games that included 'player-controlled locomotion' receiving more than 10% lower scores ($M=3.46$, $SD=0.78$) than those that didn't ($M=4.03$, $SD=0.58$).

Some caution should be taken in interpreting this result as the choice to include player-locomotion in a game may not be independent of other factors. A limited budget may necessitate a simpler locomotion approach, but also affect the quality of other aspects of the game that influence player scores (e.g. graphical quality, general polish). Nonetheless, we might expect this to yield the opposite result (lower scores for no locomotion), and it's not hard to find online examples of players casting scorn on big budget titles for inducing motion sickness through player locomotion. All this highlights the critical importance of finding an accessible locomotion mechanic for REVEAL.

LOCOMOTION IN REVEAL

A number of alternative locomotion methods were explored for REVEAL before settling on the final approach, but the following design principles guided the implementation of all of the approaches.

Single Button Interaction

To maximize accessibility, it was decided that all interactions in the game should be controlled by pressing any button on the controller. New users to PSVR (as expected in a museum context) would be unfamiliar with the controller layout and cannot see the controller with a headset on. Allowing players to press any button reduces the cognitive load associated with learning new control schemes. Some games introduce virtual controllers in line with research into physical VR interfaces [5] (see figure 4), but the team felt this was incongruous with the game's historical setting.

Figure 4: A virtual PlayStation controller in PieceFall VR (copyright Steel Minions).

Segmented Rotation

In keeping with the findings of our review, rotation was performed in segmented increments of 30 degrees with a fast turning speed (10 radians per second) and no acceleration /deceleration. In our trials, user feedback would often suggest both slowing down the turning speed and introducing continuous rotation, but both

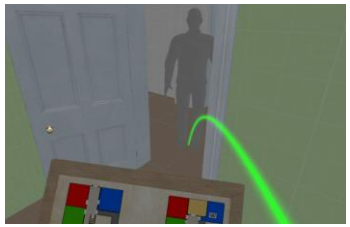

Figure 5: An arc-based control technique trialed for REVEAL.

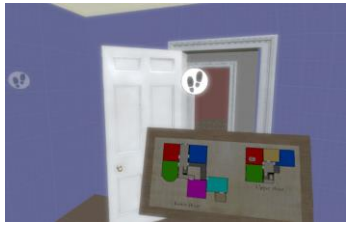

Figure 6: The node-based control technique trialed for REVEAL.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 732599

resulted in increased feelings of motion sickness. Wherever possible rotation was assigned to both left and right controller joysticks, again to simplify the communication of controls necessary to play the game.

Rejected Movement Techniques

A number of different control schemes were implemented and trialed with users for REVEAL. The first was a free movement approach in which continuous movement was provided through the left analogue stick (forward, back, sidestep left, sidestep right). This was the most common humanoid locomotion technique found in our review, and while it was popular with some users who frequently played videogames, it typically provoked the strongest feelings of motion sickness in other players. Another technique trialled was based on the arc-based approach seen in *Tomb Raider: Blood Ties*. This allowed the player to use the positional tracking of the Dual Shock controller to place a movement arc in front of them while they held down any button on the controller. A humanoid figure appeared at the end of the arc to show where the player would teleport to once the button was released again (see figure 5). This technique was preferred by a minority of users, but most reported that it didn't work very well in the relatively confined spaces of Edward Jenner's house and so it was rejected as well.

Node-Based Movement

This was the second most common approach to humanoid locomotion in our review, and the one chosen for REVEAL. The system implemented was modelled on the approach used in *Batman: Arkham VR* with the same continuous rapid 'swooping' movement used in that game (see figure 6). All accessible nodes are visible within the environment in a semi-transparent form, but become opaque and increase in size when the player looks at one. Pressing any button on the controller at this stage instigates a rapid continuous movement to the selected node. The team felt this provided an additional level of immersion compared to node teleportation, and short, rapid movements were less likely to induce motion sickness.

CONCLUSION: SHORT, FAST MOVEMENTS

The most surprising finding of our locomotion review has been that short, fast movements in VR (with no acceleration or deceleration) don't appear to induce significant feelings of motion sickness for most users. This seems to be true of both rotational and positional movement. Previous academic research into the relationship between navigation speed and motion sickness in VR has observed a stabilization of nausea ratings at high speeds, but not a drop of the kind that would naturally lead to this conclusion [13]. Other research has simply concluded that infinite velocity techniques (teleportation) cause less discomfort [8]. Even the *Oculus Best Practices Guide* states that, "Whenever possible, we recommend implementing movement speeds near typical human locomotion speeds" [18] and stops short of suggesting anything similar to this rapid node-based locomotion technique.

In conclusion, we believe that examining the body of published work on PlayStation VR has enabled us to quickly identify an appropriate locomotion technique for REVEAL in a way which would not have been obvious from reviewing the published research literature. As the commercial market for Virtual Reality gaming grows it will continue to offer up innovative new solutions and will prove a key driver in pushing the state of the art forward in Virtual Reality HCI.

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