An investigation into ways virtual reality can influence sensory perception.

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Contents

1 Introduction

Virtual reality provides visual experiences via optical immersion. A key feature of VR is its capability to induce complete visual immersion. If a user is completely immersed within their virtual domain, the domain itself could be altered to enhance their experience. Redirected walking is an example, where subtle rotation of a virtual plane subconsciously prompts a user to change direction (Razzaque, 2001) emulating a larger domain for walking.

The aim of this project is to understand ways virtual reality can influence sensory perceptions of reality. A key part of the project experiment will use VR to make small nuanced changes to a users sensory perceptions without their knowledge. Such an influence should make a participant believe they are operating in one way, when in a real world domain they are subtly acting in another.

This dissertation will comprise three separate experiments. Both experiments will exhibit a scenario in both a real and virtual environment. The virtual domain however, will dynamically alter in order to divide real and virtual world perception. From this, differences in participant actions between the two domains will be exhibited. Therefore VRs influence on a users reality can be evaluated and discussed.

Initially experimental scenarios have to be defined, this will require research into how perception can influence a humans decisions. Next, the Unity 5 game engine will be utilised in order to create and animate a virtual environment. A HTC Vive headset will place a user in the virtual environment. Its software plugins will be added to Unity 5 in order to create an intractable domain. Depending on scenario choices, real world apparatus will need to be sourced for interaction in real and virtual planes.

For the future, VR has applicability in social media. Since VR creates a sense of presence, it may provide a more personal way to communicate over long distances instead of web-cam chats. It is therefore understandable why Facebook acquired Oculus in 2014.

VR has also potential applicability within the gaming industry. However, its emancipatory confounds restrict exploration and varied motion, which in turn breaks the illusion of walking around a real domain. This problem has been addressed with add-on hardware such as the Virtuix Omni. However two key obstacles face a 3rd party hardware solution (such as the Omni). Metaphorically its integration with developed software and literally its potential size. This indicates the need for a different solution. One way investigating VRs influence on real perception could form a solution, is by examining how virtual motion could simulate real motion. Therefore giving a player the sensation of traveling a long distance virtually than that in reality, and thus increasing the perceptive size of the virtual domain.

2 Aims and Objectives

- Investigate how virtual reality can influence sensory perceptions of reality.

2.1 Objectives

1. Research at least 5 pieces of literature which have a concurrent theme involving human sensory perception, before designing an experimental scenario.

    - This research will be a crucial asset when constructing a system and scenario that targets the primary aim. Information will be discovered through research of academic journals and books relating to VR and cognitive science.

2. Design 3 experimental scenarios, which force a participant to rely on a sensory system to achieve a given goal.

   - A scenario presents a task and prompts the user's to achieve a goal. A given task will to be very simple, i.e. walking in a straight line towards a point. Simple tasks will enable a clear and concise way to gather evaluative data. The scenario will be displayed within a virtual environment; therefore technological possibilities and limitations have to be considered.
   - Scenario designs will be in the form of storyboards.

3. Design 3 VR systems which appropriately meet the needs of each scenario design, before any software implementation.
   - The system design will incorporate all requirements from the scenario.
   - Hardware and software requirements will be considered in order to outline realistic capabilities of the system.
   - Designs will be in the form of UML diagrams.

4. Develop 3 VR systems which accurately follow their design schematics and appropriately presents the scenarios.
   - The system will adhere to the design schematic using the Unity 5 Game engine to create the virtual environment. A HTC Vive will be utilised to display the scenario and track the user within a virtual plane.

5. At the end of the project, evaluate future applications of the developed technology.

3 Literature Review

3.1 Previous Work

The aim of this research is to explore the extent to which VR has an influence ones sensory perception. However, this is a broad topic area since there are numerous ways of deceiving a user within VR. The main focus in VR is to provide visual immersion. Recent research suggests a strong presence in VR can even be experienced within isolated space of an FRMI machine. This proves the visual device of a HMD can have a dramatic influence on a users perception. As a result, it is important to understand how perception can been deceived via the VRs visual component. Perception of space and movement is one area which is constantly being addressed in VR research and again broadly uses the visual component of a HMD.

Perception and VR In particular, rotation in VR has been referenced as a possible solution to navigational restriction within real space. Grechkin (2015) suggests using a rotate and walk technique. His idea rotates the world to a new position once a user has reached the compound of their walkable box. The user can then turn to the correct position and continue walking. They are directed to each endpoint using a visual goal. This method can extend the virtual space without the user physically changing its orientation. However, the user is likely to notice a sudden rotation, which consciously leads to the understanding that their environment is being manipulated. In some way the user has to explicitly change their actions to compensate for the deviation. Although this method may create the small illusion of walking around a larger environment, it does not make a user unconsciously perform one action when thinking they are doing another. Nevertheless, the concept of rotating a virtual environment at certain cues will be tested, in order to examine the extent ones perception detect this form of deviation. Another caveat to Grechkins technique is the fact that there are no attempts to distract the user during each rotary change. This is another feature which could be explored.

Like Grechkin 2015, Steinicke 2012 has used goal based strategy in his research. In aid of Grechkin, it examines the amount of rotational deviation is tolerable to a users perception in a virtual environment. His experiment instructs a user to turn to a red dot (the goal), which is either to the left or right of their visual field. Once the user has turned to the red dot, they state whether their virtual rotation is smaller or larger than in the real world. Results suggest that users can be turned physically about 49 percent more or 20 percent less that the perceived virtual rotation. However, in the experiment the user is stationary with no translational movement (only rotational). Steinicke here is not investigating the influence walking whilst deviating a virtual environment.

In using both Grechkin and Steinickes technique, one could form an experiment which could rotate a user without their conscious knowledge of rotation occurring. This would be one way to investigate modern VRs influence on proprioceptive perception using the HTC Vive. Bruder (2015) has explored the idea of constant redirection whilst a user is walking. His research instructs a user to follow a path which remains visually straight in the virtual world, but is constantly being offset to a certain rotational value. Unlike the prior research, this does not incorporate sudden redirection, instead it provides a constant change to a users proprioception. This approach could provide a better illusive experience in terms of rotating a user without their knowledge. However, he uses this study to understand how well tasks can be performed during unconscious movement. Results, research suggest redirection subconsciously forces a user to use additional cognitive resources which can detract from performance in a task. From this, giving a user tasks to perform whilst walking, could inversely increase the opportunity scope for rotational deviation of a virtual environment.

Virtual environments also have the capability of fooling ones sense of distance estimation. Often users of VR underestimate travel distances in virtual environments (, 2013). Bruder 2014 suggests using visual manipulations to compensate for a users underestimation. Results show that this can work to a certain extent. This suggests that in using visual manipulations one could also make a user over estimate travel distances. However, visual manipulations are simply not consistent with actual vision in the real world and therefore are likely to lead to the user understanding their environment is being deviated to a certain extent.

A key part of human perception is automatic spatial updating. It aids in keeping humans oriented within their surroundings before, during and after movement cues. If a human recognises the blueprint of a room, they likely able to navigate around it blindfolded. In VR however, with the same handicap, it is often the case that one may find navigation more difficult. One reason for this is because objects cannot be physically touched in a virtual environment, as a result one cannot create a mental picture. Sigurdarson on the other hand suggests that graphics play a key role in automatic spatial recognition. He states, in using high quality graphics on can create a more naturalistic environment which directly aids a user's sense of automatic spatial recognition. In his experiment a user is seated within their virtual world. Modern day VR technology such as the HTC Vive and Oculus rift enable complete body movement around a section of a scene. From this it seems Sigurdarson's research requires updating to understand how bodily movement can also impact a user's sense of automatic spatial recognition.

Motion is another element which influences the proprioceptive senses of a user in VR. It is already apparent that user can have a sense of motion in VR. A basic example of this is in virtual rollercoaster experiences. Vection is a term which constantly appears when viewing research relating to self motion and VR. It is a feeling of self-motion as a result of external movement cues. For example, it is likely that when being stationary on a train, as other trains pass by one may feel a sense as if they are moving. Anatole 2017 suggests that self motion can be improved using various forms of haptic feedback. In Anatole's research haptic feedback is provided via a chair. The problem here is the fact that a physical chair is not a malleable device in terms of application. Results suggest that feedback from a chair can aid the perception of self motion, but only when a user is seated. This suggests the need for a device which can provide haptic feedback to users in multiple orientations. The HTC Vive controllers have the ability to vibrate. Therefore, one could measure if a similar sense of self motion could be emulated using the controllers instead of the chair. This would enable a user be positioned in multiple orientations within VR I.e. walking or seated. This project will utilize these results and provide haptic feedback to a participant via the HTC Vive controllers, in order to evaluate the extent to which feedback solely to a user's hand can form a similar sense of self motion.

Although the visual component of a HMD is the most dominating of a users sensory input, it is by no means the only way to influence sensory perception. Stefania Serafin has attempted to understand how audio can direct a user in a virtual environment. Within her study a user turns to the direction where they hear an audio cue. Serafin found that vision has more influence on a users direction compared to audio in terms of directing a user to a certain point. This makes sense since as said prior the visual part of a HMD is the most dominant in terms of sensory input. Audio on the other hand can require more from a user to facilitate a valid response. For example, one can look at a picture of a tree and instantly recognise it is a tree, whereas one can listen to a description of a tree and have to cognitively apply more overheads to understand it is a tree. In the same way, it takes more time for a user to turn the sound queue look over here than a visual queue of a person waving. Serafins research does not however attempt to use audio cues in conjunction with visual cues. Riecke (2015) explores the influence of audio on a users sense of vection. Rieckes research suggests that although audio alone cannot create a feeling of motion but can enhance a perception of motion when combined with visual stimulus. In viewing both Riecke and Serafins research, it appears that audio could provide a reliable aid to enhance or deceive a users sense of perception. This project will explore this theory using the 3D audio system within Unity 5.

3.2 Current Applications of VR

Once perceptive factors such as distance estimation and automatic spatial recognition can be emulated in an identical form to that in the real world, VR could have a foothold in the area of Industrial training. For example modern day flight simulators, which are expensive due to their general structure, power consumption and maintenance costs. General aircraft are getting older which suggests a demand for new planes in the upcoming decade. Its likely that airlines will wish to increase simulation hours and decrease real-life training hours to reduce cost (Quote). Today companies such as D-Box are integrating VR with small scale hydraulic systems to aid a users sense of proprioception. However once VR alone can completely deceive the senses of a user, it could serve as a cheaper alternative for todays hardware simulators.

In terms of research into cognitive sciences, virtual reality is being recognised as a possible aid to mental health treatment. Nararro-Haro et.al investigates using VR to increases the availability of Dialectical Behaviour Therapy (DBT). DBT is realised as one of the most effective treatments for Borderline personality disorder (BPD). They found that VR reduced urges to commit suicide, self-harm and quit therapy (Nararro-Haro et.al, 2016). Furthermore the use of VR was well accepted by the patient. The VR program used was not in any way complex, it consisted of a basic river scene and audio from the DBT. Although scientifically inconclusive, these results are encouraging and greatly suggest VRs applicability in the field of mental health treatment.

Fire safety is another area where VR could have useful applications. Kinateder et al (2014) argue that VR complements laboratory tools in understanding human behavior in the event of a fire. This makes sense since ecologically valid data is difficult to acquire in relation to human and actual fire situations, due to the safety risk of fire itself. VR seems to offer a "Goldilocks" medium in realism and safety for participants. Furthermore it can be created at a low cost, and offer real-time feedback for results. However, as prior stated there are still technical limitations which detach from presence in VR which could impact on participant reactions to a fire safety simulation. One factor is the navigational confines of VR. Research into rotational techniques provided by both Bruder et al and Steinick et al have the potential to aid this problem.

VR has become popular as a result of its current application in the field of gaming. However, a standard for a conventional playing orientation has yet to be set. The HTC Vive enables a user to physically move round a world domain whilst the Oculus rift favors a seated approach. The different ways in which a users sensory perception can be deceived is likely to have an impact on the standard play orientation in VR. Krupke (2015) uses a combination of illusive motion physics and a physical harness to create flying game. The user can direct where they want to go using their hands. Although this orientation is an extreme example, it displays the possible scope for immersive playable positions. Other research suggests this scope can be used to increase the life quality of the elder population (Crespo et al., 2016). Here, an application which enables a user to pilot a virtual UAV (Unmanned aerial vehicle) by using arm movements. One of the main effects of old age is a sedentary life style which can lead to indirect health problems. This shows that the application of VR is being targeted at older age groups as a past time and as a clinical activity.

4 Project Methodology

4.1 Project Management

The system has been developed following the evolutionary model. It hosts four stages, investigation, design, implementation and testing. The implementation stage incorporates iterative cycles. Each cycle has its own sequence consisting of a design, implementation and testing phase.

Since perception is subjective, during development we had to test the artefact with a number of participants to make sure it:

- Did not create motion sickness
- Did not let a participant perceive alteration of the world.
- Had some capability of fooling a humans sensory perception.

For this reason, the waterfall methodology was not an adequate choice, because of its lacks participant feedback after the requirements stage (Mahalakshmi et. al, 2013).By the end of the process we would in a sense be gambling the results of this project. At worst we could produce an artefact which does not alter any perceptions of a participant.

It is also important to note, once a phase is complete we cannot attempt to restart or adapt it (Balaji and Obaidy, 2016). So even if we found the finished implementation made participants motion sick, we could not recurse back to change it until after deployment.

In contrast, the evolutionary ethos of iterative change corresponds well. Scenes could be developed, tested and tweaked depending on feedback from participants at the end of each cycle. Although Waterfall maximises the need for planning (Munassar, 2017), the evolutionary model also incorporates rigid requirement and design stages, but at the same time has iterative implementation cycles. As a result, it had good development practice and the openness to change which were two key features required for this projects success.

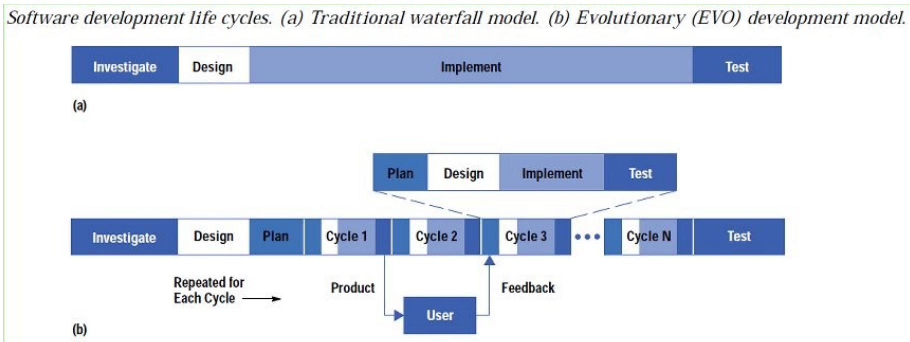

Figure 1: Evolutionary Model

SCRUM is an agile methodology, development is facilitated over a series of short iterations. A SCRUM a team must have the following cross functional roles:

- Product Owner
- SCRUM Master
- SCRUM Team (Designers/Developers/Testers)

Since this project has been conducted by one person, in using SCRUM there would be no risk of unavailable members, but at the same time, some of its features for example meetings at the start of every day (Ruparelia, 2010) are unnecessary. Furthermore in testing the system, a single product owner could not completely depict the need of the client/participant, due to the subjectivity of perception. Here the evolutionary method is better suited, we can test with a number of participants instead of referring to just one source of feedback. We could then assume if the majority respond in a certain way, the likelihood of other respondents reacting in a similar manner is high.

The spiral methodology has also been considered. It works by iteratively defining objectives, resolving risks, developing and then testing the output (Boehm, 1988). By following this process we could certify that the artefact alters sensory perception to the best of its ability. However the time to get to this point would likely surpass the time limit set in the GANT chart. Furthermore, spiral is mainly used to minimise risk. Since the highest risk to a participant is receiving motion sickness, Spiral seemed an unnecessary use of time and resources.

5 Requirements Stage

The previous chapter introduced evolutionary development. With requirements gathering being its first stage, we will cover ways which this data was acquired to lay foundations for the project. Usually requirements gathering is facilitated by liaising with a client to ascertain their want. However this project is not being developed for a client, instead it is for a set of participants. In light of this, requirements have been determined by the prior aims and objectives, reading various forms of literature relating to illusive experiments in VR and polling. From these, the following requirements have been understood.

- Attempt to fool a participants sense of Direction, Distance and Rotation
- Display a set of goal landmarks for a participant to reach in virtual space.
- Display an environment which is of high graphical quality.
- Display an environment which adheres to a concurrent Sci-Fi theme.

5.1 Polling

As said prior, informal polls were sent out to a pool of 10 people who have used VR in the past. The poll was used to cement an idea on the theme of the environment and how a participant should be oriented when using the artefact. The poll sheet fig 5 asked 2 questions.

1. When using VR which orientation has provided the most immersive experience? Seated or standing?
2. What theme would you find the most enjoyable whilst being within VR?

In all, 85% of participants stated they felt they had received their most immersive experience in VR whilst 'standing'. Results also showed that 65% of people would enjoy a Sci-Fi themed scene for the artefact. As a fictional domain it was understood that participants could not entirely associate it against a real world alternative which could detract from the immersive experience.

5.2 Efficiency in Unity 5

Frame rate is another factor which has been considered in the requirements stage. Even though the experiment is run on a higher end graphics card, VR a resource intensive on a computer. In fact a GTX 970 is the minimum requirement for a PC to be VR ready. From this, it was understood that the system had to utilise polygons, colliders and textures in a way that maintained frame rate. Mesh colliders are highly processor intensive (Unity, 2013). As a result it was understood that when designing, the scene should try to use either box colliders or no colliders at all (in non-walkable areas) to achieve best performance for the system.

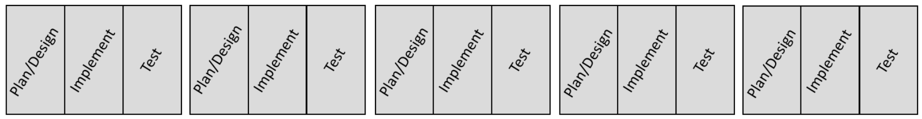

Figure 2: Implementation Cycle Progress

5.3 Further Comments

When proposing this project a swing was outlined a medium, which would be used to demonstrate how a users sensory perceptions can be fooled in VR. However, it became apparent that sourcing a physical framework to attach the swing would add more requirements to system, increasing development time. As a result it was decided to have participants either stood up, or sat on a chair for each experiment. This seemed fine since the HTC Vives lighthouse IR boxes enables 1:1 tracking within a 4 X 4m space. Here, a high level of immersion can be easily incorporated into the system in a small space of time using the Newton VR camera Rig.

6 Design, Implementation and Testing

Within this chapter we convey how system was designed, implemented and tested. A scene can be viewed as a game level, which inhibits the entire environment obstacles and decorations (Unity, 2013). Here we display the creation of four Unity scenes, each of which have explored different ways to trick a humans sensory perception. For each, we show an overview of the design, the mechanics behind the implementation and improvements made in subsequent cycles.

At the end of each cycle, a component was deemed successful or unsuccessful depending on its of functional and non-functional requirements.

- From a functional standpoint; each scene had to seamlessly augment the world.
- From a non-functional standpoint; each scene had to provide a fluid experience which matched a participants real movements with the perception of their movements during VR.

As a result of this, not every component has been reviewed by participants at the end of each cycle. In many cases if a component, such as *a scene animation* worked, it worked. Participant review at the end of every cycle would likely slow down the development process. Respondents were only required in test critical parts of the system, such as its ability to deceive their perception.

This project has been implemented in four cycles. Figure 2 shows each stage of the process. In each subsection we show the final implementation with their following improvements during iterative process *marked in green.*

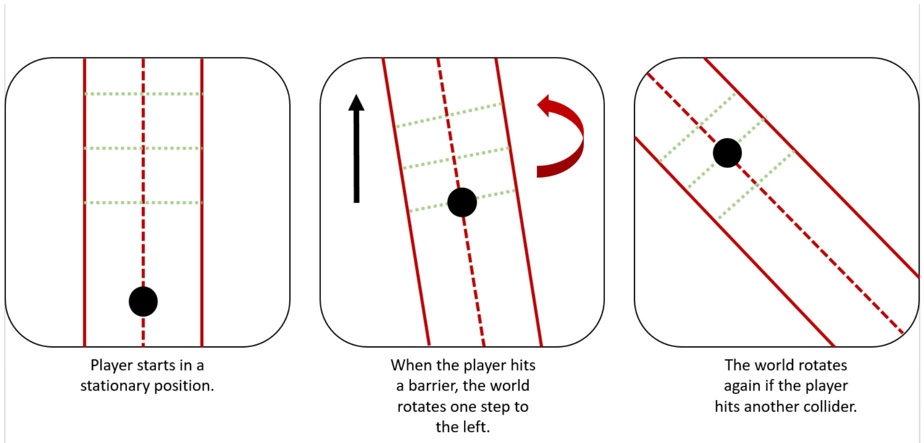

Figure 3: Initial storyboard design for direction scene (Design A)

6.1 Cycle One

6.1.1 Direction Scene

Within the first cycle, it was decided to concentrate solely on creating a single scene/scenario. In testing the output it was thought that pitfalls would be exposed and used to refine development techniques for the other scenes in the subsequent iterations.

For this scene, we have attempted to make a participant unknowingly stray from a straight trajectory in the real world. Previous work by R Gretchkin (2013) evaluates the task performance of participants when forced to subconsciously use cognitive resources to compensate for a directional offset. Here, their sensory perception is being fooled using VR, but the extent of the influence is never measured. In contrast, we focus solely on the measuring the distance a user strays of a straight course.

As shown in Fig 3 when a participant passes a collider *marked green*, the world rotates a small amount. After the world rotates, the participant should subconsciously compensate for the offset (Riecke, 2015). Consequently, they should unknowingly alter their direction and veer of a straight line in the real world. Fig 6 shows an initial attempt at implementing a solution.

In Fig 2.1, Player infers the position of the Vive HMD in virtual space. Once a collider encounters a collision with the player, it calls the "rotateWorld" method *Fig 2.1 & 2.2 - highlighted blue*, which incidentally rotates the world one step. The world rotates by calling an in-built Unity function "RotateAround()". Here, we pass in the center point of the collier *pink* object and the rotate amount *blue.*

Only one class/script has been designed for this mechanic. Here, the idea is to place a single script onto each collider object. Our class inherits from the MonoBehaviour MB class. MonoBehaviour is an API which gives the

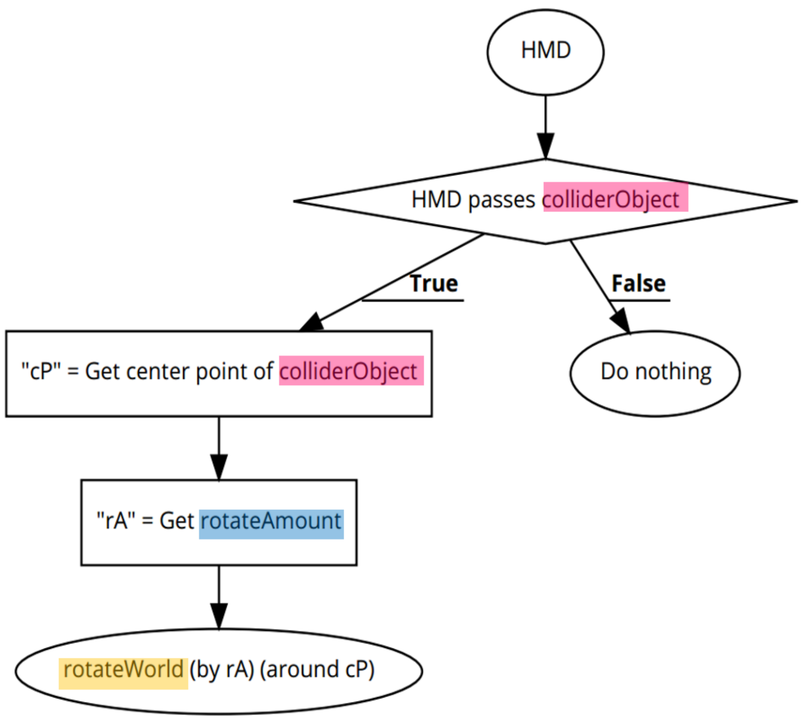

Figure 4: Flowchart design for Direction A scene

script several abilities such as, placement on GameObjects, reception of Unity events, and adjustable variables in the inspector (Unity, 2013). OnTriggerEnter is another MB function which is called if the collider is passed.

Please note this design is not 1:1 with the actual implementation, for source code see appendix.

As shown in Fig 6, three triggers are set in order to enable two small alterations to the environment whilst the participant is walking. Here, a minimum of 2 meters walking space is required to:

- Space each collider in a way which alters the world...
- ...but does not distract from the overall experience.

All objects in the world have to be parented by a single game-object so they rotate at the same rate.

The Rotate and walk method has been used in various forms of other research (Gretchkin, 2013) (Razzaque, 2017) (Steinicke, 2013). Gretchkins experiment, rotates the world at a 90 degree angle. Generally, a participant is likely to notice this kind of deviation in 3D space. Our design shifts the yaw orientation by no more than one degree. Nevertheless after testing this scene at the end

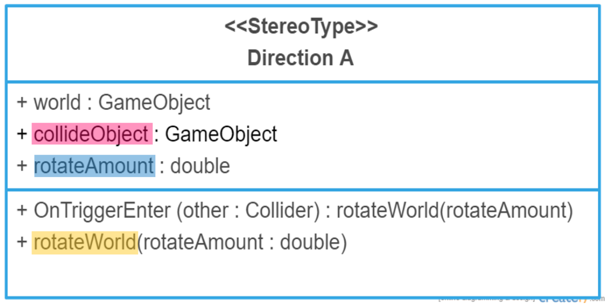

Figure 5: UML Design for Direction A scene

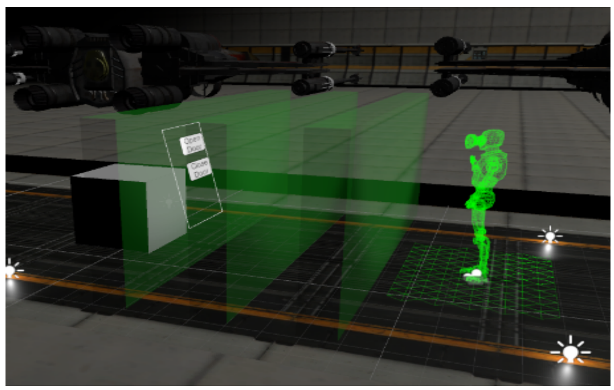

Figure 6: Implementation of the Direction A scene

of an implementation cycle, a sudden alteration always occurred no matter the extent of change in the y axis. This is a key disadvantage to our technique, and caused participants to perceptive manipulation of their environment, which is the antithesis of what we are trying to achieve here.

As shown in fig 7 and 8, an evolution of the prior cycle incorporates animation and audio distractions. Here we have tried to counteract the noticeable change in Y axis orientation when passing a trigger. Models have been animated using Unity 5s inbuilt animator component system. The cues follow a set sequence. Once a collider is passed

1. An audio cue is played. *The aim here was to make a player turn to the sound.*
2. A second audio cue is player alongside a distractive animation.
3. The world then rotates after this series of events.

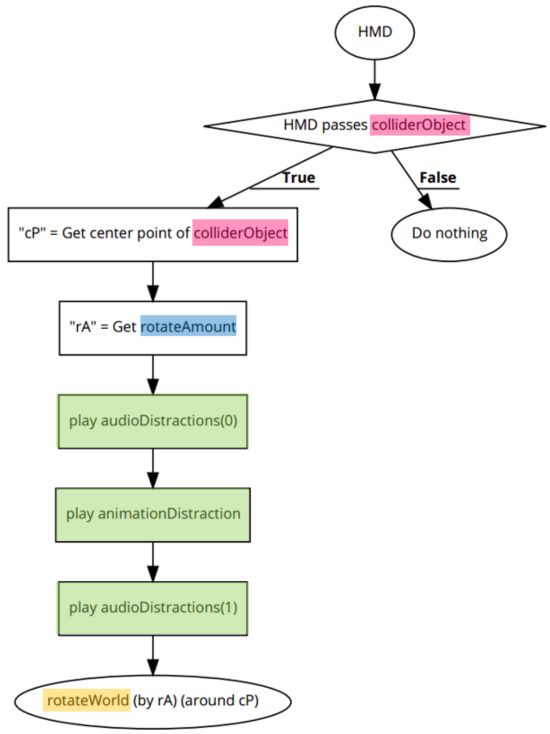

Figure 7: Iteration of the flow chart design for Direction A

6.2 Cycle Three

Due to time it takes to test the implementation of a single scene, we could not continue to develop a scene per cycle. As a result both the Rotation and Distance scene were designed and implemented within cycle 3. In addition the Direction scene was also improved from the in response the cycle 2. In doing this, we tested multiple scenes within testing stage of cycle 3, any improvements required were added in cycle 4.

6.2.1 Direction B Scene

In testing Direction A iteration with participants, they still noticed its jarring effect. This distracted from the illusive experience we were trying to create, ironically even with the addition of counter acting audio and animation distraction cues. As a result, we again iterated in cycle three swapping the Rotate and walk idea with a nuanced Rotate *while* walk technique. So at any point in time, if the participant moves, the world responds by shifting (left or right). This measure aimed to offset a participants direction but to also minimise any chance of participants becoming aware of world alteration, like in the previous

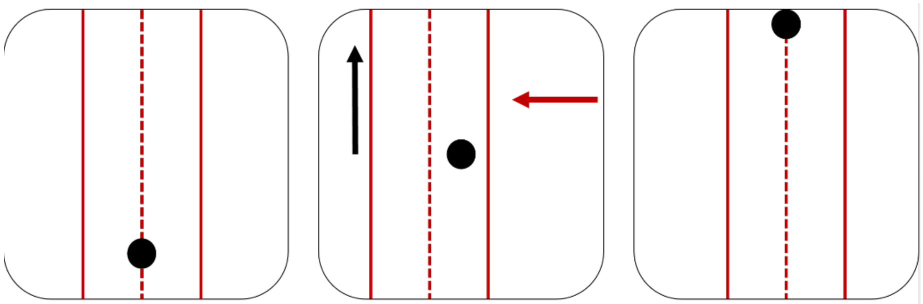

Figure 8: Second storyboard design for direction scene (Design B)

cycle *see Figure 6*.

Like the prior design, this technique tracks the virtual position of the HMD. However in this case we continuously store the change in its X position transform. So as the participant moves their change in forward or backward movement is recorded. This value is then added to the Y vector position of the world game object, causing it to shift left or right. This cycle is continuous *see figure 9*, so any time a participant moves forward, their virtual domain shifts. All objects have to be encapsulated within one single 'World' GameObject, this way all objects maintain their position when shifting.

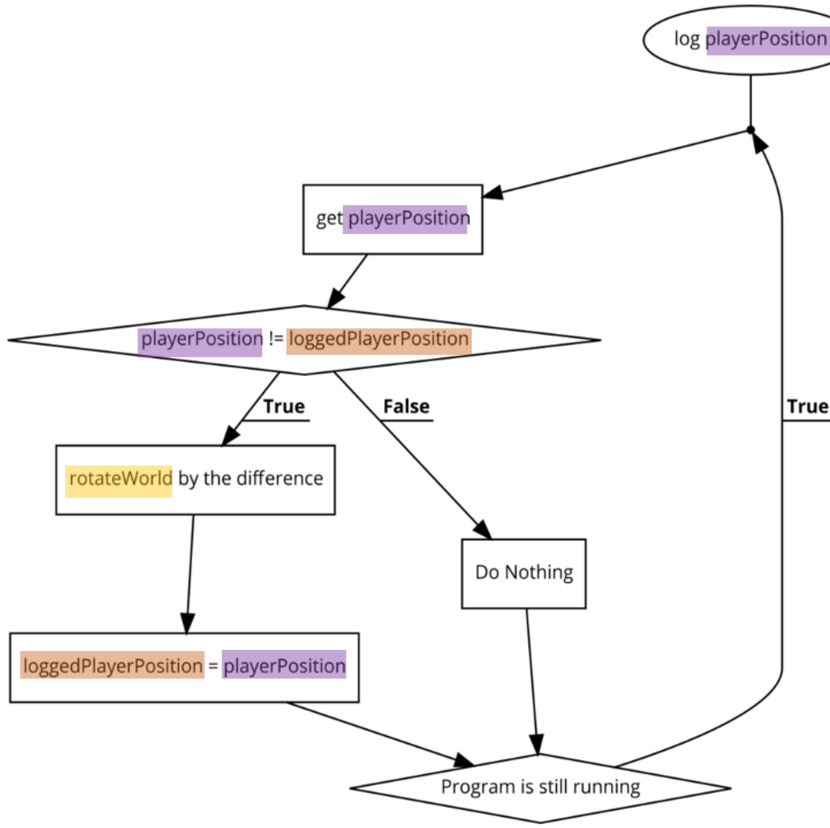

Figure 9: Flowchart design for Direction B scene

In testing this scene, the world was being altered at a rate which was noticeable to participants. Furthermore, because it was understood that the world was shifting they seemed to fight the deviation, staying in a relatively straight walking trajectory. To improve this, in cycle 4 we added a scale factor s *see figure 12*. The variable holds the HMDs change in virtual position is multiplied by s. As a result, we have direct control of the rate the environment shifts. When changing the scale factor to 0.1 (multiplying the changing movement by 0.1) the world shifted in a nuanced manor, but was undetected by participants. Results are displayed in the Results section.

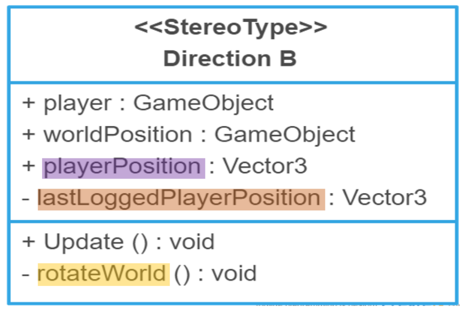

Figure 10: Alteration in the worlds Y Position transform

The audio and animations from the first implementation have been added to this scene. Like before when triggered; they play. For the experiment we test whether the addition of these cues change how a participant reacts to the constant shift of their world.

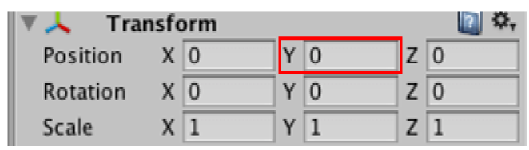

Figure 11: Alteration in the worlds Y Position transform

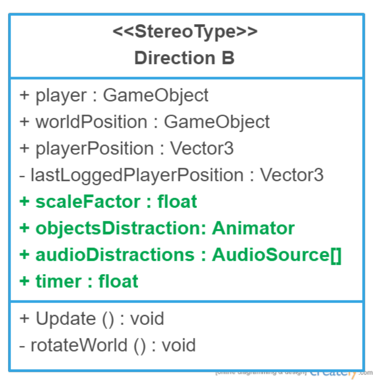

Figure 12: Iteration of the UML design for Direction B (Added scale factor and animations)

6.2.2 Rotation Scene

The aim of this scene is to fool a participant into rotating less than they consciously perceive. Within VR, they are asked to turn to a landmark. As they turn, the world also rotates in the opposite direction *see figure 13*. As a result, less rotation is required to get from point A to point B. Previous work which investigates rotation and VR, suggest circular vection (rotational self-movement) can be induced using a large projector (Hankinson, 2013). The difference here, is our practise of both a participant movement *and* circular vection *world rotation*. The fact we are using a HMD as opposed to a projector is a also a key difference in technology between the experiments.

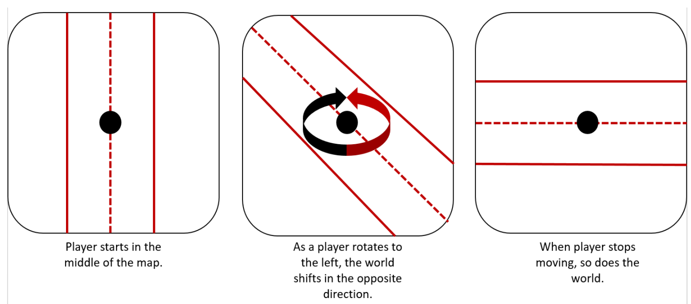

Figure 13: Storyboard for the rotation scene

Another investigation relating to circular vection, suggests it is more effective if an environment contains pictorial depth cues (Desmond, 1012). For this reason the floor of the environment is tiled. Essentially with this, it is easier for a participant to differentiate between a close and far away point by referring to the tile lines. This increases immersion, which in turn decreases the chance of participants understanding their world is being altered.

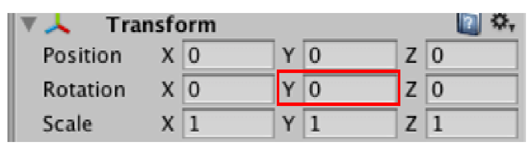

Figure 14: Alteration in the worlds Y Rotation transform (Euler Angle)

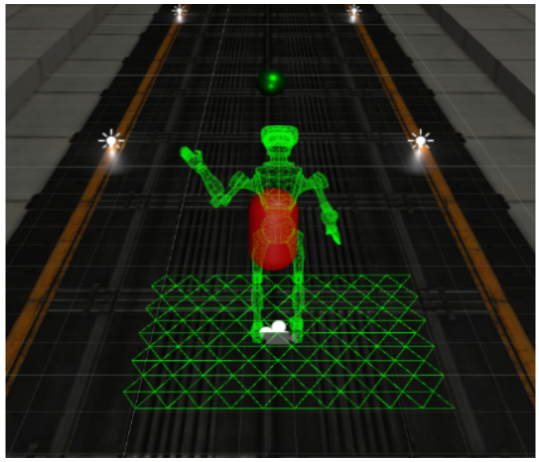

Figure 15: Implementation of the Rotation Scene

When rotating (180:90) (VR to real world), no participant had any idea their world was being altered. It was only when we increased the scale factor to 270:180 that participants started to perceive deviation of world space. As a result, it was noted for the real experiment we would only use the (180:90) scale factor.

6.2.3 Distance Scene

This scene attempts to fool a participants perception of travelled distance. Specifically, we want to make a participant move forward and overestimate the distance they have travelled. As shown in figure 16, if a participant moves forward, the world moves at in the opposite direction. Here a participant will walk fewer steps to reach further distances in virtual space, but should perceive their movement as normal to that in the real world. Research in the past has explored the illusion of vection (Riecke, 2015). Like Riecke we have incorporated the vection trick, but specifically aim to fool a participant travelled distance instead of just measuring their general feeling of movement. It is also important to note, that in Rieckes experiment, the participant is stationary. Evidently in our case, when the environment is moving so will the participant. Our method also utilises the HTC Vive, which will encapsulate a user in a more detailed and manoeuvrable environment than the visual display used in Riecke experiments.

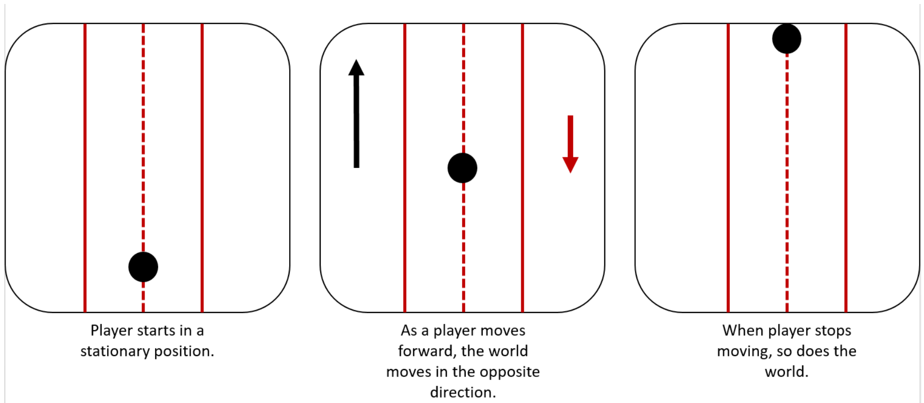

Figure 16: Storyboard of the distance scene

Initially this scene was designed as a seated experience. Here, a participant would be wheeled forward on a chair. However, mapping a HTC Vive controller to a real world object added a level of complexity in implementation, which had the chance of taking the project off its progressive track. As a result the final implementation is a stand up walking experience. This uses the standard Vive toolset, which consequently has saved time for the project.

As displayed in figure 18, the mechanics of this implementation are similar to the Direction scene where change of a participants forward or backwards movement is stored. In this case however, the stored value is added to the X transform of the world *see figure 17*. As a consequence, a participants change in forward or backward movement makes the world move backwards *and vice versa*.

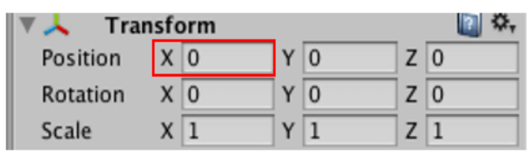

Figure 17: Alteration in the worlds X Position transform

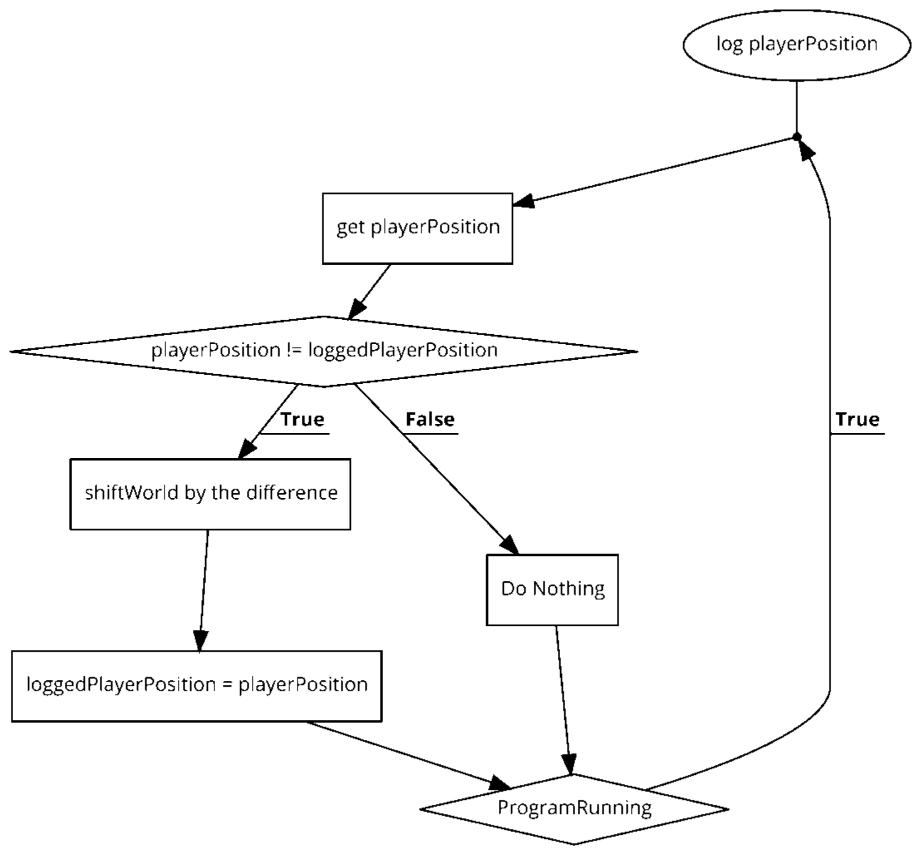

Figure 18: Flowchart design for Direction B scene

In the initial implementation, participants were asked to just walk forward and stop when told. Here there is no objective in the scene, which participant stated would have provided "a more purposeful experience". As a result in cycle 4, we introduced the goal state (square box). Here a participant has an anchor point in which they can walk towards. At the same time this focus may distract them from the worlds deviation. The point is removed for some experiments to test its effect. Once approached the participant is rewarded with the ability to open the space dock doors. Note, this goal point was added to the Direction scene.

7 Gant Chart Discussion

A Gant chart was designed *see appendix* before starting this project. It set a basic foot print on how time would be allocated during each work process. In this chapter we discuss the success/failure of staying within the time barriers allocated for the project, with reason to why they were altered. Altogether there were ten key stages of which six were associated with the development of the artefact.

7.1 Research Stage

Time to complete the Research stage was under estimated by 4 days. Within the chart, time is only allocated to Literature reading for the collection of requirements. However, after reading various forms of literature, there was a lack of understanding in how the artefact would look and the kind of experience the artefact would provide to the participant, for example desired playing orientation when in VR. As a result polls were sent to a number of people. In creating these polls and gathering their feedback the research stage exceeded the Gant limit. This was a necessary set back, it made it certain that the artefacts look and playing orientation created an immersive experience for participants during the experiment. This extension did not push back the design stage as the scenarios could be designed without feedback from the polls.

7.2 Scenario stage

The Scenario stage was completed within the time constraints of the GANT chart. It was also possible to design a third scenario. By the end of this stage we had three storyboards designed for; Direction, Distance and Rotational alteration of a virtual world. As shown in figure 5 they had no mechanical or experimental specifics, just a general idea showing the premise of each scene.

7.3 System Design & System development

The choice to follow the evolutionary development methodology was decided after creating the GANT chart. As a result the System design and System development sections do not correlate with how we conducted the implementation. In following evolutionary both sections was implemented in an iterative manor as opposed to the linear depiction in the Gant chart. Development time in general was also underestimated by two months. This was due to the time taken to conduct participant testing and implement system improvement as a result. As said earlier, to speed up this process multiple scenes were design and developed in one cycle 3.

7.4 Testing

The most important parts of the system i.e. unknowingly altering a participants world was tested and improved during the implementation stage. As a result testing the system as a whole only required a single day. Here, we would just go through each scene following the experiment design to make sure they were seamless and bug free.

7.5 System Revisions

System revisions were incorporated within the implementation stage and did not need to be addressed again.

8 Research Methodology

Within this chapter we introduce the research methodology. This outlines the projects research approach. It also displays the method in which information has been collected, to improve the artefact at the end of each development cycle.

8.1 Research Method for Testing the Artefact

In the testing each scene with participants, we have used a qualitative method to inductively collect data. This method allows a phenomena to be described from a users experience (Kneale and Santy, 1999). As such there is no explicit intention to quantify the findings (Carr, 1994). Instead we are trying to understand how a participant feels within VR to see if they detect any form of deviation in their environment. A quantitative method would not be suitable in this case, it would only display the degree imperfection within the artefact. With a qualitative approach we have been able to interpret the language collected (Leach 1990), and use it to form new requirements in the artefacts design see software implementation section.

8.2 Research method for Experiment

The developed artefact has been creating with self postulation and the influence of previous research. As such we want to test the artefact to see the extent to which it can fool a users sensory perception. Ergo, for the main experiment a quantitative research methodology has been used to gather data. Its basic advantage is its ability objectively collect and process numerical data (Burns, 1987) to measure the artefacts deceptive ability. We could also examine any cause and effect relationship between the state of a virtual environment and a participants immersion within VR, for example the added audio and animation cues. A qualitative method would only output descriptive data, which could have led to different interpretations depending on the reader (Kneale and Santy, 1999). For the actual experiment, we wanted to produce concrete findings, which displayed the extent to which each scene deceived a users sensory perception.

8.3 Types of questions asked

Need to do this section, and take

8.4 Data collection for Testing the Artefact

For the purpose of testing, in depth interviews were used. Here, we asked a set of semi structured questions to a small pool of participants after they used the artefact. In doing this we could explore each participants perspective and get a real sense of their perception when using VR. Some interviews deviated to sub topics of VR see discussion, but enriched the design for the subsequent development cycle.

8.5 Data collection for the Experiment

Quantitative interviews were used to collect data from participants. Quantitative interviews are fact driven and structured. During the experiment, participants were asked a series of closed ended questions from a pre written questionnaire see appendix. The benefit being, users did not have to leave VR at the end each of each scene. As a result they could instantly use their proprioception to measure their location in the real world. The cumbersome enter and exit of VR may have led to participants forgetting their perceived location, thus creating irrelevant results. Furthermore it gave participants the opportunity to receive clarification if misunderstanding a question.

8.6 Sample Selection for Experiment & Sample selection for Testing

Purposive sampling has been used to select participants for the experiment. Here sample members are selected based on their past exposure to virtual reality. It was important to get a varied pool, since we not know how the extent previous exposure changes a participants sense of perception in VR.

8.7 Participant gathering process

The experiment panned out over a day. By talking to various people across the university campus, we gained a number participants to attend the day of research. People were allocated time slots and given the researches contact details in case they were unable to attend.

8.8 Experimental Methods

8.8.1 Direction Experiment

The goal for this experiment is to make a participant unknowingly deviate of a straight line trajectory in the real world whilst they perceive walking straight in virtual space. To measure this we follow four steps:

- A two meter long tape is placed from the far wall to the participants position in the room Fig 1.

The participant is asked to:

1. move towards the goal state in the virtual world, (which is mapped the same distance to the monitor in the real world).
2. Answer a question from the structured questionnaire

- The distance to which the participant strays off the white line is measured.
- They are then walked to the side of the room and asked to take their headset off.

For some participants, animations and sound have been enabled in the scene.

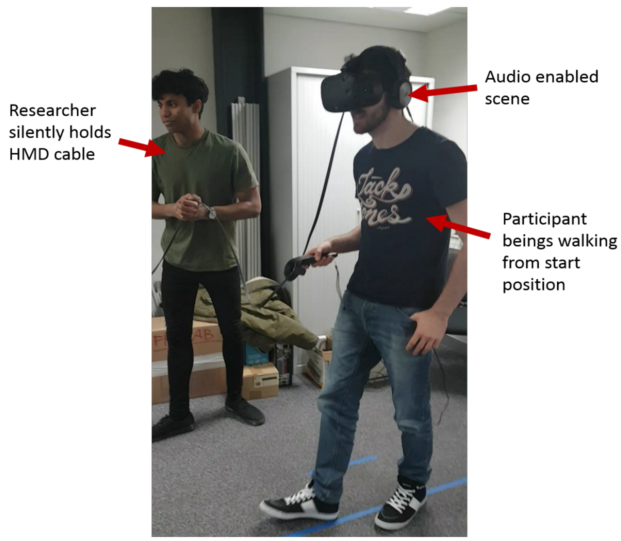

Figure 19: Direction Scene Experiment

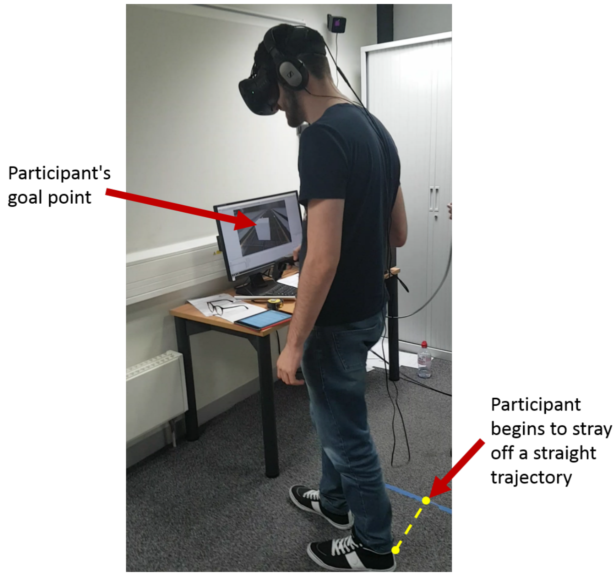

Figure 20: Direction Scene Experiment

8.8.2 Distance Experiment

The aim in this scene is to increase a participants perception of distance. The experiment has six main steps:

- A two meter long tape is placed from the far wall to the participants position in the room Fig1.
- The tape is marked 2 meters away from the participants starting position.

The participant is asked to:

1. Move forward.
2. Stop (once they reach the marked point)

- They are walked to the side of the room and asked to take their headset off.

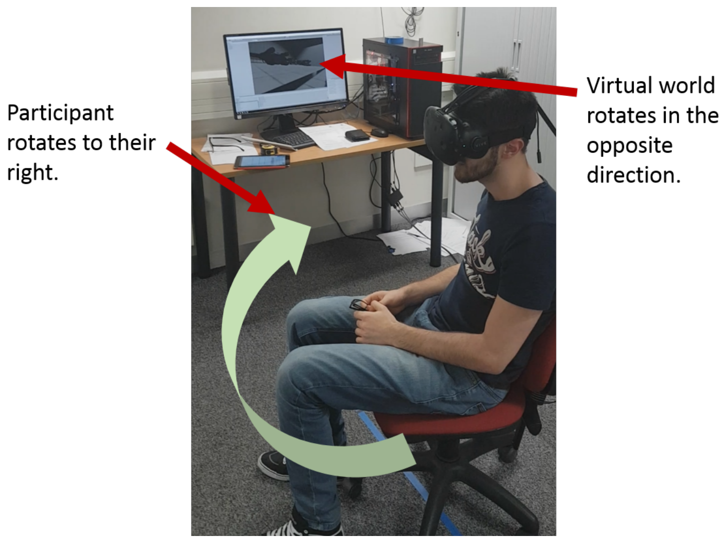

Figure 21: Direction Scene Experiment

For some experiments the animations and sound have been enabled in the scene.

8.8.3 Rotation Experiment

If a participants perceived rotation is more than their real world rotation this experiment is deemed successful. To test this we follow three main steps.

- A chair wheel chair is placed on the floor.
- A line of tape marked with an arrow is placed in the middle of the seat.
- Another line marked with an arrow is placed on the floor (both the line on the seat and floor have to be matched in the same direction).

The participant is asked to:

1. Sit on a chair and the VR program is run.
2. Turn to a landmark (which is 180 degrees behind them in VR).
3. Answer a question from the structured questionnaire

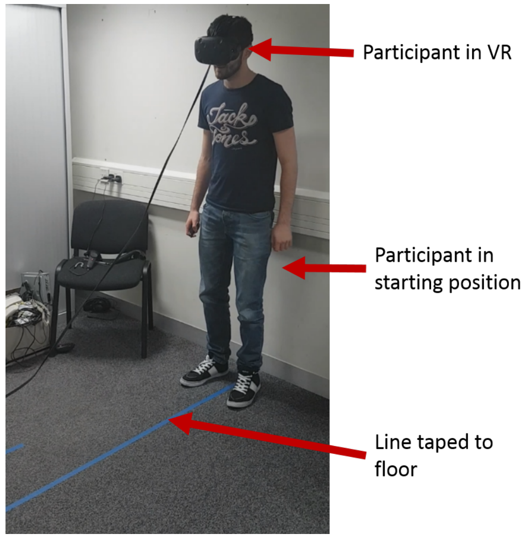

Figure 22: Distance Scene Experiment

Figure 23: Distance Scene Experiment

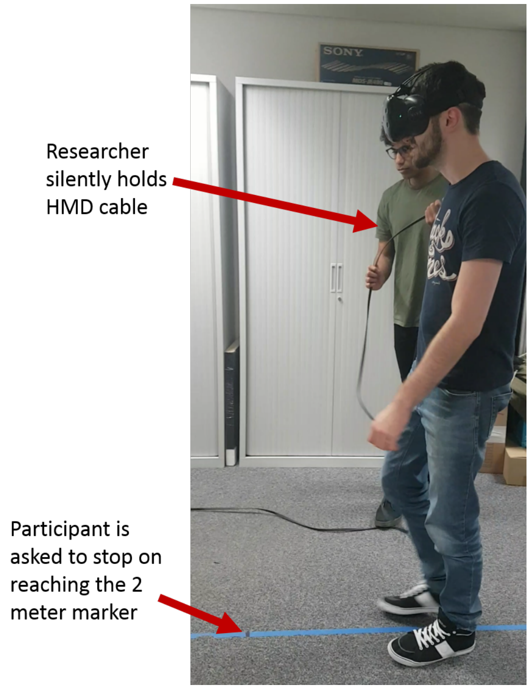

Figure 24: Direction Scene Experiment

8.9 Ethical Considerations

The experiment was subject to certain ethical guides. All participants were given two forms before starting the experiment. - Form A: Informed the participant on what they could expect from the experiment, and how data collected would be handled. Specifically it outlined the risk of motion sickness, but specified that they could quit the experiment at any time. - Form B: Asked for a final confirmation of consent from the participant to take part in the experiment. To be confirmed, this required a signature from the participant and researcher.

9 Results

This chapter displays the results from the questionnaire. It was handed to each participant at the end of every scene. Sample description For the experiment, data has been collected from 16 participants. The majority were university students aged between 18 and 24. 33% of the participants had never used virtual reality before. 46% of the people who had already experienced VR most recently used the HTC Vive, 31% used the Samsung Gear VR and 8% had used the Oculus Rift DK1.

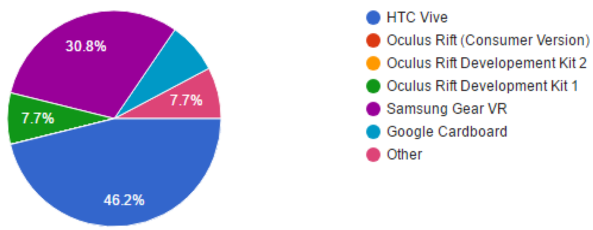

Figure 25: Participant most recent VR experience

9.1 Distance Scene

Participants are asked a quantitative estimation question after experiencing the Distance scene, which was used to see the extent to which a participant over estimates (if at all) their travel distance. As can be seen from the feedback, a significant 88% of respondents felt like they moved more than the actual 2 meters measured in the real world. The mean estimate from this set of results is 3.8 meters. This shows some success when creating this kind of illusion, with an average 1.8 meter overestimate, modern day VR can effectively be used to fool a participants distance perception.

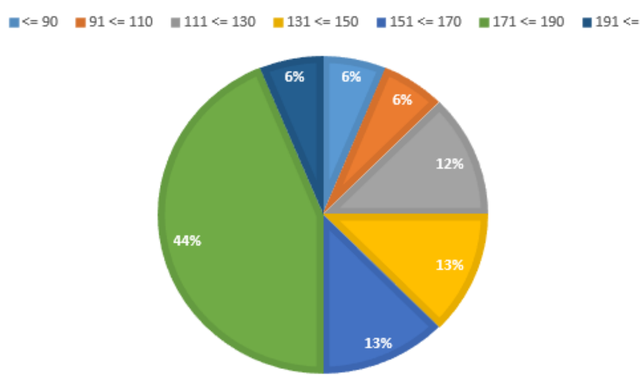

Figure 26: Distance scene pie chart

9.2 Rotation Scene

The following result is similar, here participants were asked another estimate question after experiencing the Rotation scene. This question was used to see the extent to which a participant over estimated their rotation. The feedback shows that 94% of participants perceived rotating more than 90 degrees. Again this displays VRs capability of fooling a users sense of rotation.

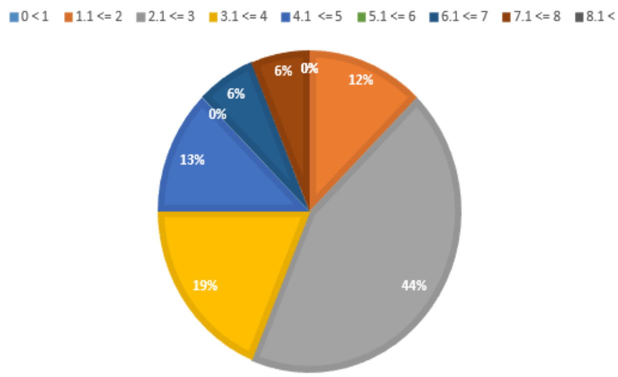

Figure 27: Distance scene pie chart

9.3 Direction Scene

In testing the Direction scene we split the participants into two groups "Group 1" and "Group 2".

Group 1:

- Experienced the Direction scene without audio and animations.

Group 2:

- Experienced the scene with audio and animations.

Below are the results.

The eight participants in group 1 were asked a dichotomous question. It was used establish if a participant felt like they were walking in a straight line during the experiment. It is apparent that with 63% of participants saying No, the scene did not continuously fool the participant's perception of real world direction.

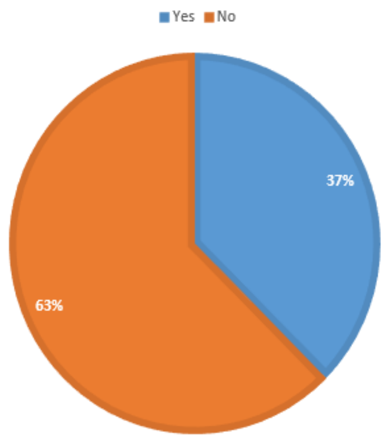

Figure 28: Dichotomous straight line question for Direction scene (No audio or Animations)

The participants who answered No were also asked to estimate the amount they strayed of a straight trajectory in the real world. Participants on average underestimate this amount by 2.8 inches. This shows that even with respondents understanding they are not walking in a straight line, the scene was still influencing their perception of trajectory.

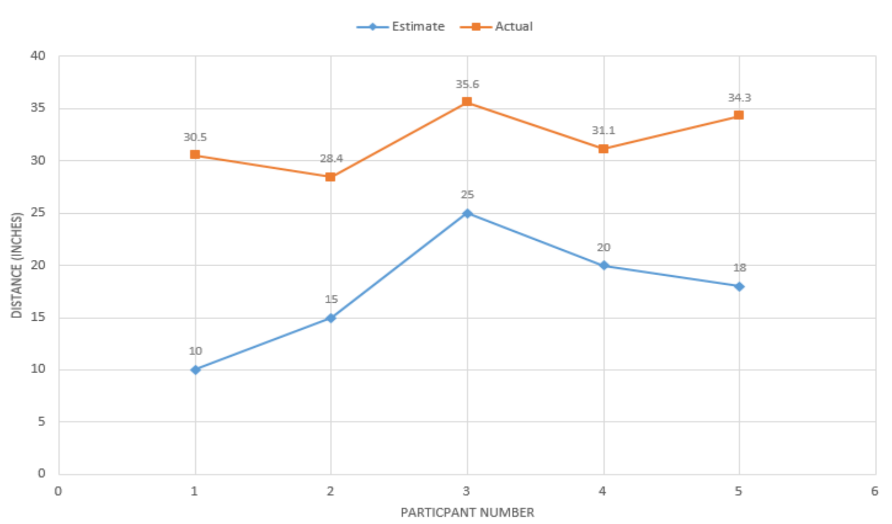

Figure 29: Comparison of the estimated distance vs the actual distance a participant has strayed off a straight trajectory for participants who did not perceive walking in a straight line.

The participants who did perceive walking in a straight line stayed off a straight trajectory by an average of 15.2 inches.

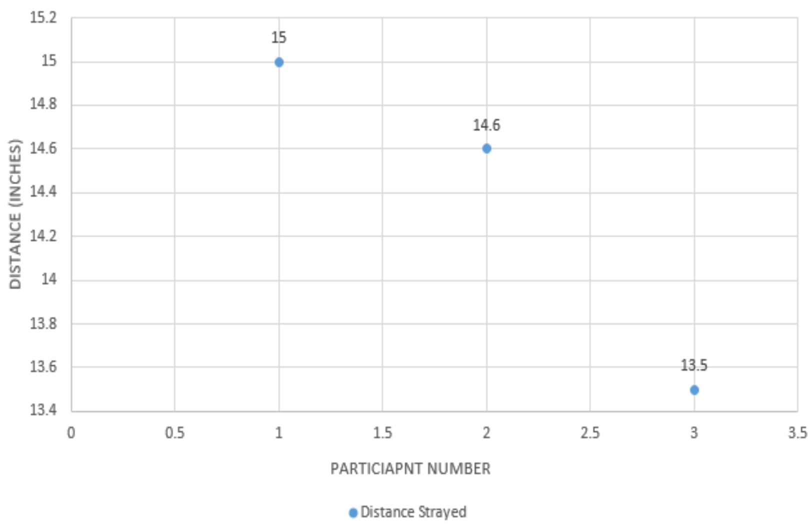

Figure 30: Actual distance a participant has strayed off a straight trajectory for participants who perceived walking in a straight line.

In running the scene for Group 2, 75% of participants had a perception of walking in a straight line. This clearly demonstrates that audio and animation is an immersive utility which can increase the rate of success when trying to alter a humans real world trajectory without their conscious thought.

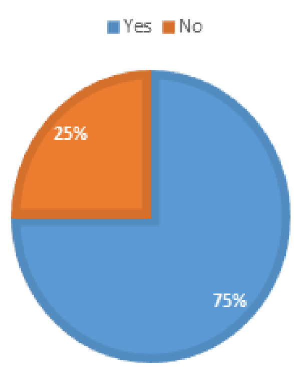

Figure 31: Dichotomous straight line question for Direction scene (With audio and Animations)

Like for Group 1, the participants who answered No were also asked to estimate the amount they strayed of a straight trajectory in the real world. The two participants underestimated this amount by 3.6 inches (average).

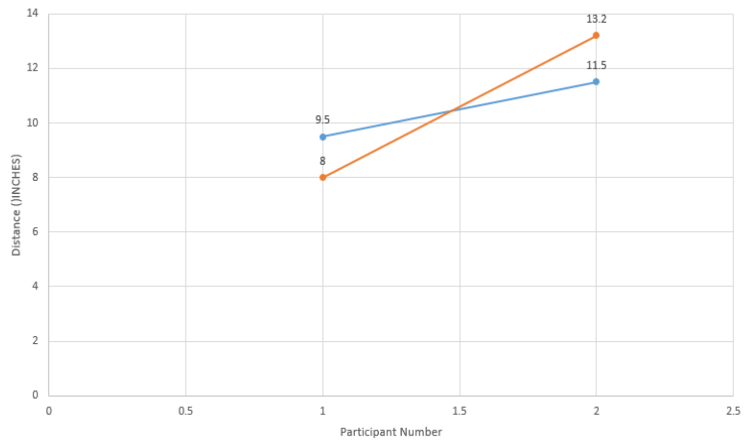

Figure 32: Comparison of the estimated distance vs the actual distance a participant has strayed off a straight trajectory for participants who did not perceive walking in a straight line.

Those who did perceive walking in a straight line stayed off a straight trajectory by an average of 15.23 inches.

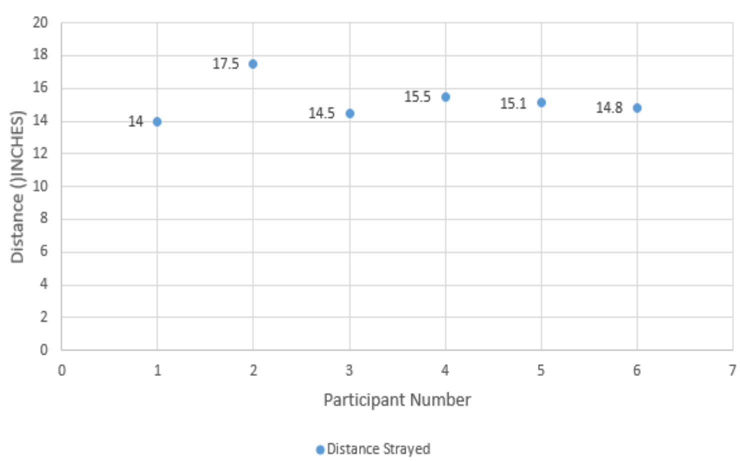

Figure 33: Actual distance a participant has strayed off a straight trajectory for participants who perceived walking in a straight line.

The last question broadly examples if the VR scenes matched the respondents perceived real world movement. 87.5%of participants from Group 1 perceived 1:1 movement in the Rotation and Distance scene, this fell to 25% for the Direction scene. This shows generally that the first two scenes had the best method at fooling a users sensory perception without their knowledge.

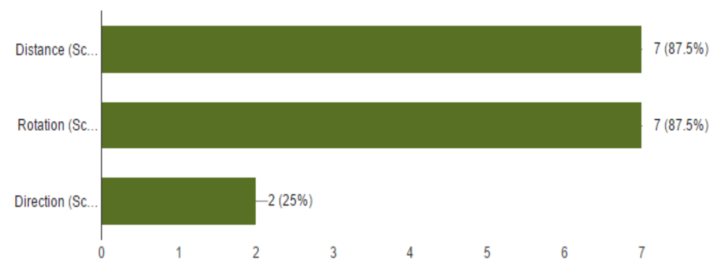

Figure 34: Percentage of participants who perceived 1:1 (movement to perceived movement) in VR

Data collected from Group 2 show all participants feeling 1:1 movement in the Distance scene and 75% in the Rotation scene. For 'Direction' we see a 50% increase of people feeling correlated movement in VR and the real world. This again is displays the impact sound can have on the feeling of immersion in VR. It clearly shows its aid in altering a humans perception of direction. For both groups, the Distance and Rotation scenes appear to be the best methods at unknowingly altering the participants sensory perception.

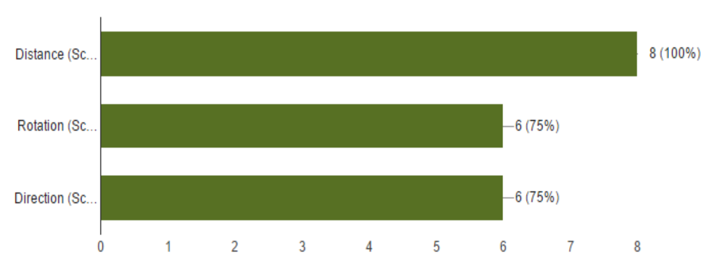

Figure 35: Percentage of participants who perceived 1:1 (movement to perceived movement) in VR

10 Conclusion and discussion

10.1 Evaluation

10.2 Conclusion

10.3 Future Work

11 Reflection

11.1 Reflection on Project Management

11.2 Reflection on Implementation

12 Appendix

Below are the complete EA1 and EA2 forms.