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Understanding the Effectiveness of 360 Motion in VR Simulators

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Abstract

Virtual Reality (VR) is a technology that enables people to interact with an artificial 3D visual environment. VR simulators are an emerging market that aims to enhance already-existing simulations with the added features of VR immersion. Most VR Simulators are limited in how motion is experienced: as it is typically constrained to movement in the X or Y-axis. This leads to a less realistic experience when trying to simulate a real, physical world. The NOVA is a unique, untethered VR motion simulator, which provides an opportunity to provide 360 degrees of motion. This industry project will create an artifact to assist in researching the question of "how effective is 360 motion for VR experiences?" A study was conducted with 5 participants, who experienced a VR with and without motion. The results found that the NOVA increased presence, realism, and the effectiveness of the VR simulation. There are implications that the NOVA may increase sickness, meaning that VR sickness mitigation techniques should still be used, but this requires further research.

Acknowledgements

I'd like to thank a variety of people for their help in this project. First and foremost is my project supervisor, Craig Anslow, who supported me and provided me with invaluable feedback for this report. He was the driving force initially and was the one who made this all happen.

Secondly, I'd like to thank Terry Miller, the founder of Eight360, for providing me with the platform and the opportunity to do this project. Without him, this would not be possible. Not only was he supportive in my efforts, but he also provided me with guidelines and ideas which directly led to this project is as good as it is. I'd like to thank Brendon from Eight360, who babysat me and helped me get this working when I was having issues.

I'd like to thank Chris Maymon from the School of Psychology, who helped with the study design and even with selecting participants when it came to the final hour. I'm grateful to the volunteers who participated in my study, even if it was at the very last minute. The Victoria University of Wellington HCI Group helped me by advising me with various different aspects and providing me with research material. And finally, I'd like to acknowledge my family, friends, and cat who all helped with keeping me sane throughout this final year, even through lock-downs and various emergencies.

This year has been a stressful one for every student - something I've felt the effects of quite keenly. The aforementioned people were invaluable for helping me get through these troubling times. Without the help of all of these people, this report would be much shorter and the project would have gone nowhere.

Contents

Chapter 1

Introduction

1.1 Problem and Motivation

Virtual Reality (VR) is an emerging technology. VR enables people to interact with an artificial three-dimensional visual environment [1], allowing people to experience previously impossible scenarios. VR, however, does have its issues, especially in the realm of VR simulations. Specifically, VR simulations have an issue where one's immersion, or presence, is reduced. From motion sickness, to simply not feeling realistic, there is plenty of research looking into this phenomenon [2, 3, 4]. One area that has limited research is utilizing motion to help increase presence. This could potentially be solved by an invention from Eight360[1] called the NOVA. This industry project explores utilizing 360 motion in a VR simulator.

(a) Outside of the NOVA, note how there are no wires.

(b) Interior shot of the NOVA, with a user inside.

Figure 1.1: Pictures of the NOVA sourced from [5].

The NOVA (refer to Figure 1.1) is an untethered motion machine to support VR simulations. Their motivation for doing so was to reduce the costs for simulations - currently, a proper VR simulator can cost millions of dollars. Not only is the NOVA cheaper (coming to around 500,000 NZD), but it can provide a wider range of motion and experiences than a typical custom-built simulator.

[1] Eight360 - https://www.eight360.com/

By working with Eight360, this project hopes to both provide a module that may be used elsewhere, but may also open up avenues for further research.

1.2 Engineering Solution

To investigate the effectiveness of 360 motion, three aspects were developed. The overall research question is ”does 360 Motion increase the Effectiveness of VR simulations”. To address this research question, the following sub-questions were investigated:

RQ1: How immersive is the 360 motion?

RQ2: How effective was 360 motion for presence?

RQ3: How much more involved were people with 360 motion compared to non-360?

RQ4: How much more realistic was 360 motion?

RQ5: How much does 360 motion affect VR simulator sickness?

The following components were be developed to help study this question:

- A **rollercoaster-like experience** was developed, which incorporates various types of motion to help evaluate, or showcase the NOVA.
- The second module, a **demo module**, was developed. The demo modules allow for repeatable experiences, without any user input needed.
- A **user study** was conducted to determine the effectiveness of 360 motion in VR. This user study contains three different types of questionnaires to determine how effective 360 motion is.

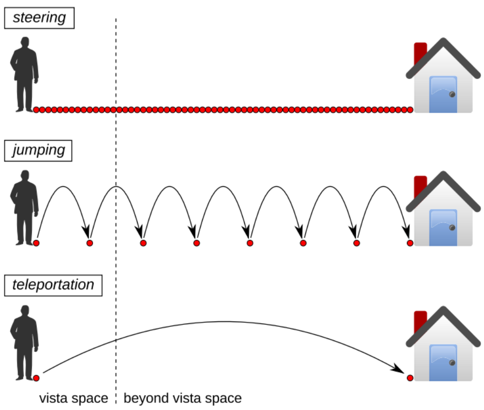
The 360 Motion Tester - or the rollercoaster module - is finished. A track was created that supports a wide range of motion. A basic demo module was implemented, which was used in the study. A study has been conducted, although it is limited in its relevancy due to the small sample size. While some meaningful conclusions can be made from it, it does show promise in future research with the NOVA.

This report discusses the results of the engineering project and any changes that occurred during the software development process. The report will also discuss potential changes for the future and how the modules mentioned were made. Finally, the study and its results are described and presented; an analysis of the data collected will be provided and used as a basis for future expansions.

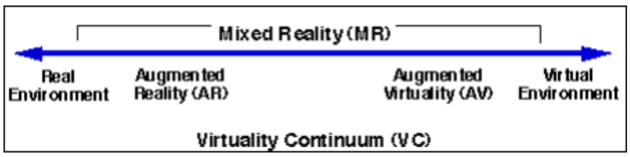
Chapter 2

Background

There is currently limited research into the effect of 360 motion on virtual reality. There has, however, been extensive research into VR in general, and the effect it has on vehicle simulations. Ever since 1993, with Paul Milgram and Fumio Kishino's paper on mixed reality displays [6], there have been countless studies regarding the effects of VR. Simulations have been a focus since 1996 [7], and still are today [8]. One of the hopes for this project is to provide validation for further research using 360 motion, which has been less explored.



(a) VR control methods [9].



(b) Milgram's Virtuality Continuum [6].

Figure 2.1: Examples of research into control schemes and scale of reality.

One major worry with this project is Visually Induced Motion Sickness (henceforth, VIMS). VIMS in VR has been extensively studied, with studies looking into cybersickness with rotational movements [4] among other reasons. Different methods have been tried to reduce VIMS - from olfactory stimulation [3] to software solutions [10]. With the NOVA, there are hopes that motion sickness can be avoided in all cases outside of cases that one would expect (i.e. incredibly violent motion). As one of the main causes of VIMS is "a conflict between the visual, vestibular and somatosensory senses" [3], the introduction of 360 motion may help reduce this with vehicle simulations.

Traditional VR experiences have three different types of control methods - steering, jumping, and teleportation [9]. These all have their downsides, which come down to the fact that there is either a loss of spatial awareness or an increased chance of VIMS. The NOVA can potentially solve this, with the introduction of 360 motion with the steering control scheme. While it may not be suitable for all forms of VR, it can be argued that it will help with vehicle simulations. This is what the research portion of this project investigates.

VR has been used to investigate reactions in dangerous scenarios [11], training students without danger [12], and help with various illnesses [13]. Without VR simulators, it wouldn't be possible to safely perform any of the aforementioned activities. One such example of studying a reaction to a dangerous scenario is the Victoria University's Plank Experiment, as showcased in figure 2.2. This is an experiment conducted by the Cognitive and Affective Neural Psychology Lab [14, 15] (henceforth referred to as CANLAB) from the School of Psychology. The Plank Experiment uses a dangerous scenario (walking on a plank on the roof of a tall building) as a way to measure the different reactions of participants.

Figure 2.2: An image of the VR experience of the Plank Study

If the NOVA can be used to heighten immersion and produce more effective VR experiences, it could help these studies by producing more realistic reactions. For example, a study was performed to test people's reactions when doing a takeover request on a self-driving car [11]. The NOVA could potentially enhance this study by leading people to believe it's more realistic, leading to more realistic results.

This study will apply the standard methods found within these studies but applied to the NOVA to understand how 360 motion affects VR simulators. It will investigate whether or not it increases immersion and its effectiveness as a simulator by measuring participants' presence and how sick it makes the participants.

One aspect that can help with VIMS is presence. Presence, or perceived realism, is a measure of how immersed one is in VR. According to Schubert et. al, presence is "a certain sense of being in the virtual environment" [16]. Presence has been in literature, with its impact investigated for entertainment [17] and one's awareness of their self-position in VR [18]. A lack of presence can often mean that the VR simulator's effectiveness was reduced. 360-degree motion, in the context of the NOVA, is the ability to rotate a user in all angles. This means that one's presence within VR can potentially be heightened, due to the additional motion that is usually absent.

For research projects, a platform is required to build the VR experience on. One of these platforms is Unity. Unity is a closed-source game development engine and has been used for both commercial products and scientific studies. Unity provides an easy way to quickly develop small game ideas. There's support for various platforms, allowing it to be deployed to different platforms with ease [19]. Unity uses C# as its scripting language. Unity, among other game engines, have been used in research studies before, including VR studies [11].

Chapter 3

360 Motion Tester & Recorder

To address the Research Questions, we built the 360 Motion Tester and Demo Modules. These were both written in C# for Unity. A considerable number of design choices were made. From the platform that would be developed, the subject matter of the experience, to even whether or not a custom application should be made for this project, this chapter looks into those decisions.

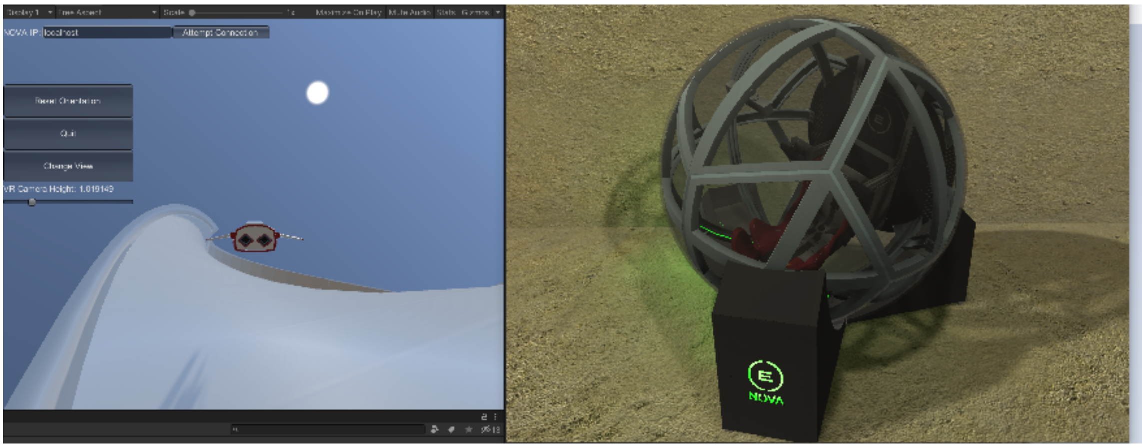


Figure 3.1: A screenshot of the NOVA simulator and the final 360 Motion Tester, running with the demo module. Note how the NOVA simulator (on the right) is twisted.

3.1 360 Motion Tester

The 360 Motion Tester (see Figure 3.1) - or, the ”roller coaster” - is a game made in Unity[1], designed to allow for free-form rotation. The theme is a futuristic racer that can rotate around any surface. This allows for an interesting visual for the end-user, as well as giving a realistic scenario for feasible impossible motion. Motions such as twists, turns, flipping one upside down, and rotating around the different axis are all supported.

3.1.1 Requirements

Eight360 provided some requirements that this project should aim for. This provided some guidance and inspired the subsequent ideas that were made for the project. They wanted

[1]Unity - A cross-platform game development engine [19]

"some kind of reproducible non-interactive fixed-length on-rails ride" which could be used to determine the following requirements:

MT Req. 1: The game should have motion accuracy (i.e. motion in-game matches up with the NOVA)

MT Req. 2: There should be a realistic-feeling motion by utilizing motion-mixing algorithms

MT Req. 3: There needs to be a way to measure nausea

MT Req. 4: The game should demonstrate the strong features of the invention, such as the ability to roll on an arbitrary axis

MT Req. 5: A variety of motion should be included, such as:
- single-axis rotations (i.e. pitch, yaw, roll)
- complex time-variant motion (i.e. rotation around combined axes)
- full complex motion (i.e. corkscrews, twisters, etc.)
- impulse/step motion (i.e. simulating bumps, swerves, collisions)
- motion-mixing motion (i.e. acceleration, deceleration, cornering, sustained upside-down)

DM Req. 6: The game should have varying speeds, to show off how the NOVA can handle speed changes

MT Req. 7: There should be interesting scenery and set pieces to maintain visual interest

DM Req. 8: The game should include effective, realistic sounds appropriate for the theme and scenarios

DM Req. 9: There should be different tracks, to showcase different types of motion

While not every aspect was met in the project, due to the COVID-19 lockdown, (and some are certainly subjective, such as requirement 8), requirements 1 through 5 and 7 were all met. The most prominent functional requirement that was missed was requirement 6 - a greater variety of speed would have allowed for the NOVA to be showcased further. Requirement 8 needs an additional person to help with sound design. Requirement 9 was in the original plan but is one of the changes which will be discussed.

The engine used for the experience was Unity. This was primarily because NOVA has an SDK already for Unity - although, one is currently being developed for Unreal Engine as well. This meant there was a choice between Unity and Unreal Engine. Unreal Engine, however, wasn't considered as it would be more difficult to utilize the in-built systems for 360 motion. The physics engine of Unity is much more open - you're able to change gravity and tweak various parameters. In Unreal Engine, it's been designed around first-person games where gravity is always down. To use the theme, one would need to re-implement the physics.

3.1.2 Theme

A futuristic racer theme was used to allow for feasible impossible motion. A visual of the track was implemented so that motion sickness would be reduced. Several different themes were considered, such as a submarine and a drone.

The futuristic racer theme was used for a number of reasons. The most prominent reason was to reduce motion sickness: having a visual of where the user is going to go, would help to reduce motion sickness for an automated rollercoaster-like experience. This wouldn't be an issue if the user were to input motion themselves - but as the study needed a controlled environment, an on-rails experience was opted for. The other themes could have other visualisations to help (such as a wireframe track for drones, or some kind of path for the submarine), but it was decided a solid track would be the easiest to develop and display. This helped in decreasing the development time.

3.1.3 Experience

The 360 Motion Tester was designed to last for about four minutes. This was done to limit the amount of time experienced in VR, due to the VUW Human Ethics Committee guidelines. This was also to limit the amount of exposure of motion to the user.

Multiple different scenarios are presented through the track - such as turning, going through a corkscrew, a loop, and jumps. This is to test a variety of motions - such as having the NOVA rotate in a number of arbitrary axes. It will also see how effective simulating falling can be in a vehicle.

The track was designed with the idea of keeping motion sickness to a minimum. There are some extreme portions - but nothing one wouldn't find on a rollercoaster. The speed was also reduced for this purpose - alongside to help account for NOVA's limitations of rotations per minute.

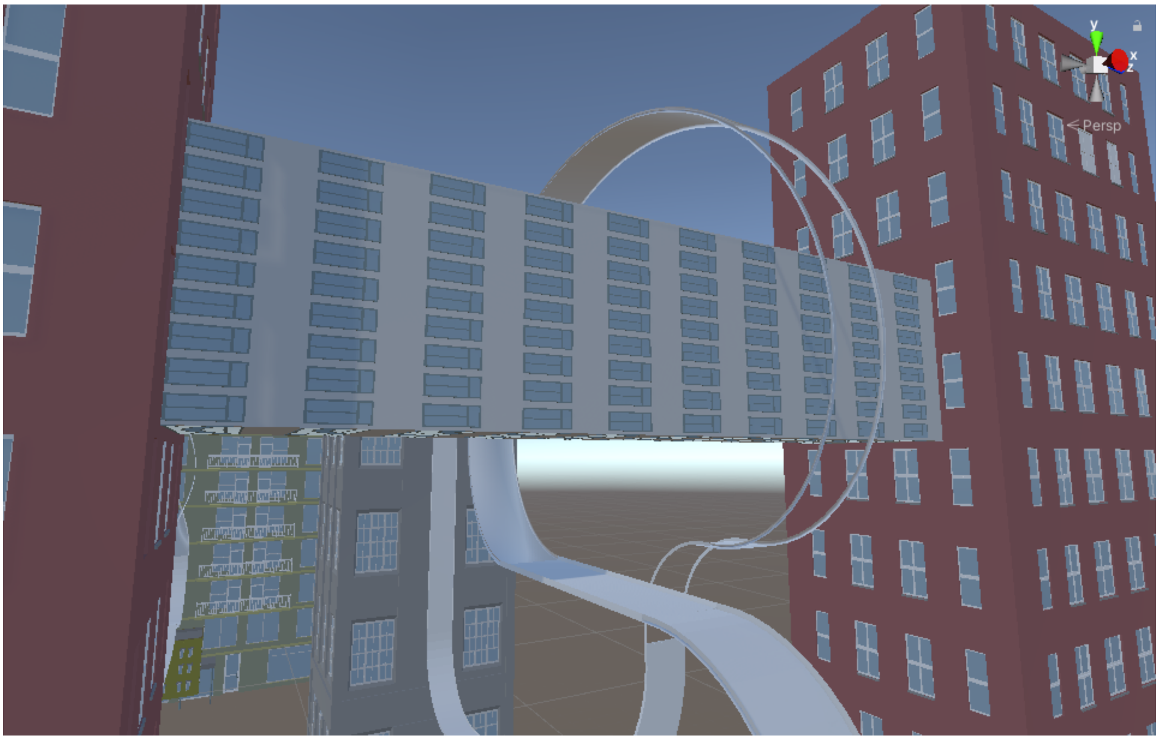


Figure 3.2: Part of the track used, showcasing a loop. The light-blue track is what the player goes along - note that it goes around the bridge between the buildings. The buildings provide a background to help the player's sense of direction.

Only one track was developed, with a wide range of motion. Track pieces such as corkscrews, loops, twists, and jumps were added to showcase different types of motion, which can be seen in Figures 3.2 and 3.3. A wide range of angles was also tested as well - such as doing corkscrews while turned on one's side.

One potential issue with the current track is that there may not be enough downtime between each different motion. The study was originally advised to focus on one motion every 30 seconds by the CANLab. This change can be seen in Figures 3.2 and 3.4: there's not a lot of time between the different types of motion experienced. As the track was being developed, it was discovered that only 10 motions would be able to be tested if this was followed. Variations would have to be discarded in this case, such as those seen in Figure 3.4 (which is a combination of the motions found in Figures 3.3(a) and 3.3(b)).

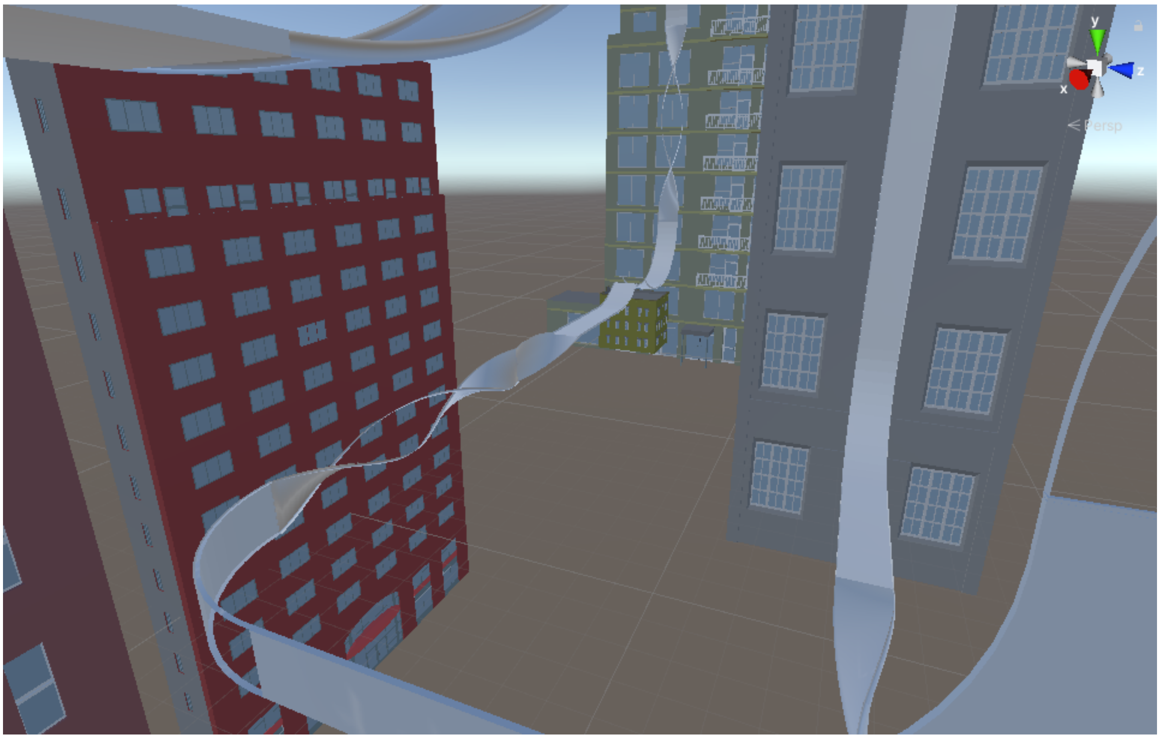
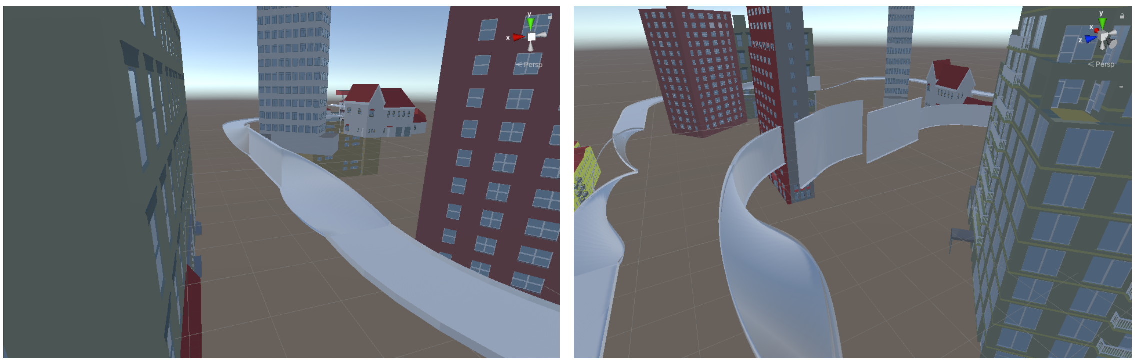


Figure 3.4: Further portions of the track, showcasing the variety of motion that can be experienced.

Some consideration went into whether or not the user should be able to influence the experience in some way. Some examples included



(a) An early portion of the track, showing some basic motion - this is a case of turning the player sideways.

(b) This motion is much more complex in comparison to 3.3(a). It contains a corkscrew and two jumps.

Figure 3.3: Different portions of the track, showing the variety of motion.

- Items the user could use
- Allowing the user to slow down or otherwise influence movement through brake pedals
- Having the user do a secondary task (i.e. count number of dots, navigate through hoops)
- Letting the user use a controller or joystick for movement

Ultimately, this was discarded as the intention is to measure the effect of VR motion. To evaluate motion's effectiveness, the variance between each participant should be reduced as much as possible.

3.2 Demo Module

The demo module is the second part of the development aspect for the project. As one of the goals for the 360 motion tester was for a repeatable experience, a demo module was needed to provide repeatable experiences. For this purpose, a demo module was created that could attach itself to a game and record demos.

3.2.1 Requirements

While no requirements were formally given, the demo module was born out of the desire for a "reproducible non-interactive fixed-length on-rails ride." To this end, a reusable script was developed that could utilize Unity's default physics to recreate basic scenes found in different games. The requirements for this module was:

MT Req. 1: The demo system should be reusable between projects
MT Req. 2: The demo system must record inputs and play them back
MT Req. 3: The system can recreate scenes with the player
DM Req. 4: The demo system can swap between different demo files

These requirements were met, albeit with some changes. The demo script is reusable between projects, but some aspects must be designed around it. This ties in with Req. 2, which is the need for it to be able to record inputs and play them back. The demo script needs some editing to record the inputs to pass the vertical and horizontal inputs to the script. Alongside this, support for buttons outside of movement currently isn't supported.

Req. 3 was met, but there are some minor bugs still found in the playback system. The rotation doesn't appear to fully match up, making the player object slightly askew. However, outside of that minor visual bug, it is possible to fully replay play sessions. Req. 4 isn't fulfilled as there is no easy way of swapping between demo files.

3.2.2 Description

The demo module is fully functional and has been trialled in two pilot studies and the actual study itself. There have been some changes across the development of the module, mostly in regards to its scope. The primary difference is the absence of any user-defined inputs (without editing the script directly) and the need to add in the Controller to record input.

The demo module can be recorded either inside or outside of the NOVA, provided that the recording function is enabled. For the experience, it was determined that it wasn't necessary to enable this. This functionality can be enabled in the Unity Editor. However, the 360 Motion Tester must be used to record the experience.

3.2.3 Recording

The demo module records the current position, velocity, angular velocity, and inertia of the ship at fixed intervals. The rotation is handled by the ship itself: recording it would lead to jerky motions if the physics do not match up. As the physics are not deterministic[2], recording the rotation will lead to irregular motion.

There were multiple changes to how the demo file was made. Originally, it would record the inputs and game state when inputs were made. However, this leads to issues with the physics system - again, due to its non-deterministic nature. This was changed to allow for more consistent playback.

3.3 Implementation

The architecture diagram (Figure 3.5) illustrates the general structure of this project. There are three scripts developed for this project - two that come together to make up the player object, and one for the demo module. The Unity SDK, NOVA SDK, and NOVA hardware were not modified by myself. Variables were adjusted in the NOVA SDK to achieve better motion, but none of the core logic was adjusted.

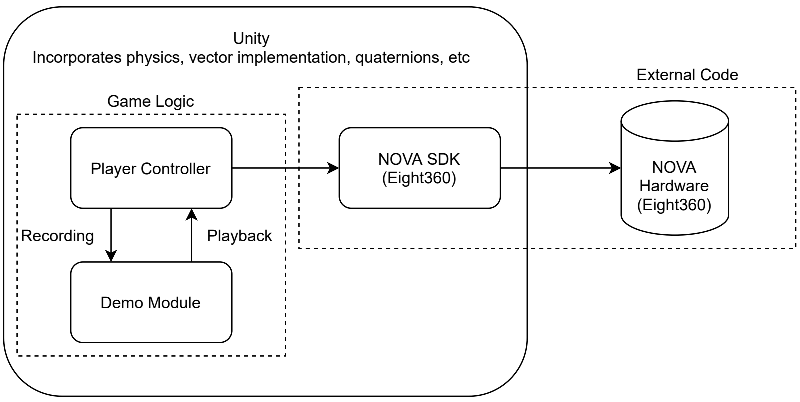


Figure 3.5: The architecture diagram for this project.

3.3.1 360 Motion Tester

One aspect that changed throughout the project was the presence of the hover-car twisting when turning. In the final project, the car twists slightly when turning. Multiple different avenues were taken to achieve this.

The code for twisting the hover-car changed multiple times throughout the project. Solutions such as measuring how far the ship had turned, setting the current rotation, and adapting the original tutorial code were all considered. The main flaw with all of these methods is that they need to work in every direction.

Unity's physics engine also caused issues. The rotation would continually need to be set and be accounted for the thrusters, as twisting the body causes the thrusters to correct the car's orientation. This has been accounted for in the current version, which continually adds in a rotational force.

[2]Determinism is where the same inputs will lead to the same output, regardless of what happens.

```
1 Vector3 rotateTorque = transform.forward * maxAngle * -horizontalInput;
2 rotateTorque = rotateTorque * Time.deltaTime * rigid.mass;
3 rigid.AddTorque(rotateTorque);
```

Figure 3.6: The code for twisting the hover-car.

Figure 3.6 works by adding a certain amount of torque along the forward vector (which twists the current object when rotated). This is added on line 3, but the actual vector is calculated on line 1. To ensure that the result is not tied to the framerate, the `DeltaTime`[3] is considered, alongside the object's mass. As the hovercar will naturally attempt to correct itself, a constant amount of torque must be added - as seen here.

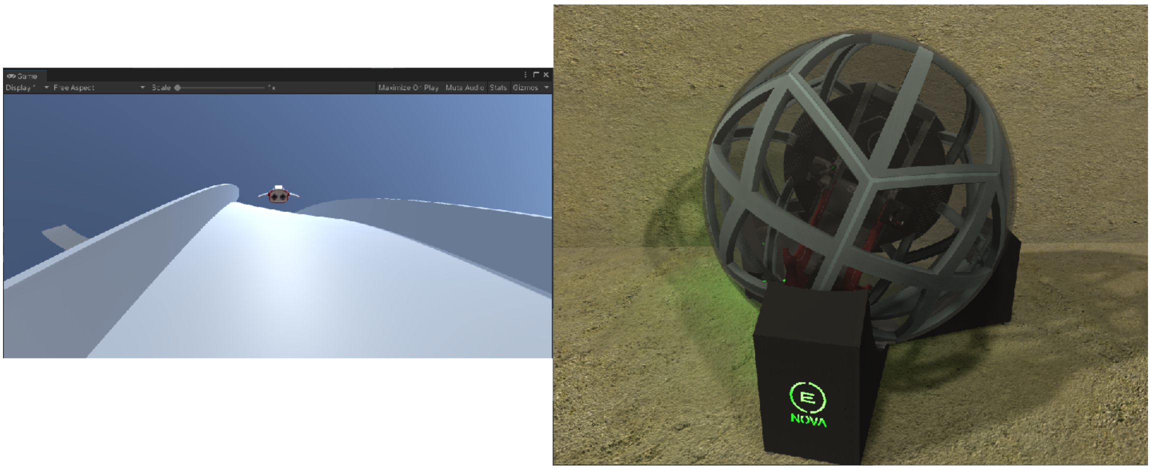


Figure 3.7: A screenshot of the NOVA simulator and an early version of the 360 Motion Tester. A video can be found here or in the Appendix under §A:B.

Figure 3.7 is an early version of the 360 Motion Tester The movement in this version is quite similar to the final product. The primary difference being the settings for the NOVA motion algorithm and the lack of twisting for the hovercar. These were adjusted to provide something more realistic. Relying solely on motion cueing causes the rotational aspect to be ignored, leading to less accurate motion.

3.3.2 Demo Module

The demo module can be imported to any Unity project that uses a rigid body and the experimental Input System. The module writes to a file that's specified - and loads from the same file. With this, it would theoretically be easy to implement loading in different files as needed.

Files are loaded in as a `StreamReader` and written as a `StreamWriter`. This was for optimization purposes - the demo file is currently a text file that can be several megabytes in size. While it wasn't necessary to optimize it this much, this means that larger files will be kept in memory, taking up several megabytes memory.

Alternatives were explored, such as utilizing Unity's `TextAssets` and loading in the file that way. This came with one major limitation - you had to load the entire string into memory and then parse through the said string. Rather than `StreamReader` reading the file line-by-line, it would need to be loaded and stored in memory.

[3] The time, in seconds, from the last frame being calculated to the current frame.[20]

```
1 frame = Time.frameCount;
2 reader = new StreamReader("Assets/Resources/DemoFile.txt");
3 currentString = reader.ReadLine();
4 ...
5 if (Int32.Parse(demoData[2]) == (Time.frameCount - frame)
```

Figure 3.8: The original frame-based playback code.

The Demo Module had a major change in the timing used to record data. Originally, it was based on the framerate. This wasn't feasible as there was no guarantee that the framerate would remain consistent: meaning that subsequent runs could be faster (or slower) depending on the framerate. The original implementation can be found in Figure 3.8, with the starting frame variable set on line 1. Note that, on line 5, it only checks to see if the current frame is the same. This means that *dropped* frames would cause the game to stop the playback entirely.

When writing to the file, the frame would be calculated by looking at the starting frame variable found from Figure 3.8 and subtracting it from the current frame count. This meant that, if the recording started late, it would account for this difference. You can see this on line 5 in Figure 3.9.

```
1 String demoString = String.Format("{0}...", (Time.frameCount - frame)...
```

Figure 3.9: The original, frame-based write code.

After the proof of concept, it was decided to change the module to be time-based instead. Rather than using the current frame, the current time was used. This would ensure that the demo would not change based off of the framerate. In a frame-based implementation, a faster framerate would lead to a faster playback. The opposite would be also be true.

```
1  recordTime = Time.time;
2  currentTime = recordTime;
3  try
4  {
5      reader = new StreamReader(Application.dataPath + "/" + "DemoFile.txt"
           );
6      currentString = reader.ReadLine();
7      loadedFile = true;
8  }
9  ...
10 String demoString = String.Format("{0}...}", (Time.time - recordTime)...
```

Figure 3.10: The time-based code - not that it's using Time.time instead of Time.frameCount.

As Figure 3.10 shows, the current time is now used. This didn't need much changing, outside of a changed variable on line 2. There was no change needed to how it was read in, as the system was designed to allow for easy replacement of these values. Early on, it was determined that the recording method might need to change. The system was, as a result, designed to not be flexible, provided the parsing method was changed to account for it.

Another addition that came with using the time was checking to see if the current time is before the recorded time. This is necessary due to how the times would not be synced up between the recording and playback sessions. A check is present to see if, on that frame, the

```
if (float.Parse(demoData[0]) <= (Time.time - recordTime))
```

Figure 3.11: The check to see if the parsed time is before or after the current time.

current time is less than or equal to the time found in the demo file. If it is, then it'll playback that line and progress to the next. If an error occurs, and the times become unsynced, then the file will progress through as normal.

One other major change in the implementation was how often the data got recorded and played back. The original proof of concept had this been implemented in `Update()`, which is called each frame. However, this means that the demo module was coupled tightly to the framerate.

```
1 private void Update() {
2 if (isPlaying)
3 {
4     var demoData = currentString.Split(' ');
5     if (Int32.Parse(demoData[2]) == (Time.frameCount - frame))
6     ...
```

Figure 3.12: The framerate-based playback method.

Figure 3.12 changed twice during development. The first change was to make the demo system write to the file each time a new input was detected - or in other words, moving it from the `Update()` method seen in line 2 of Figure 3.12 to the input method. This was changed since Unity's physics system is not deterministic, meaning that the same inputs do not equate to the same result.

Finally, this piece of code was changed from being used in `Update()` to `FixedUpdate()`. As per the Unity documentation, `FixedUpdate()` is a "Frame-rate independent MonoBehaviour.FixedUpdate message for physics calculations. ... Compute[s] Physics system calculations after FixedUpdate." [21]

This makes it ideal for capturing conditions at a consistent rate, while also tying them to the physics calculation. As we wish to recreate the conditions before the physics for that frame are calculated, `FixedUpdate()` allows us to do this.

3.4 Discussion

3.4.1 360 Motion Tester

There is one question that has, so far, been ignored. Why bother making a custom game for the study, when there's already games out there that do the same thing? Games that the NOVA already has? The NOVA has integration in multiple different projects, including a roller-coaster simulator. The experience discussed so far is quite similar to a roller coaster - so why not use that instead?

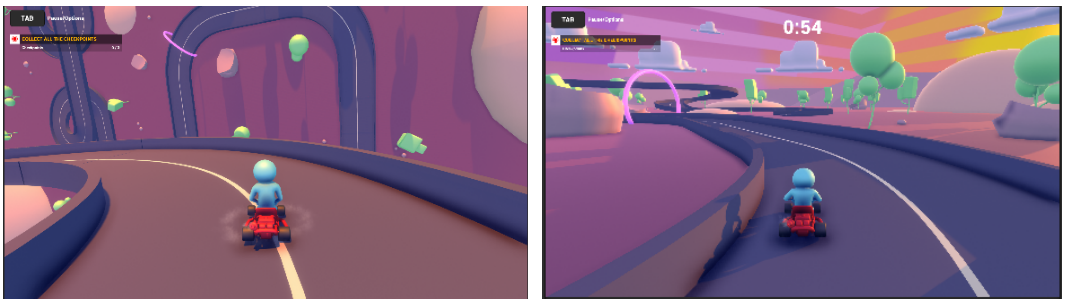
There are multiple reasons which will be discussed. The primary two reasons for avoiding this approach was that **the existing material is not suited for research** and **there's no recorders that could be used**. At its core, this is an engineering project and not a research paper. While there is a user study looking into the effects of 360 motion, and the effectiveness of the artifact will be assessed with said user study, the study is only one of the focuses of this project.

The current applications used for the NOVA, such as X-Plane and Project Cars, are not designed with research in mind. They do not have a way to record sessions and play them back: which is part of what Eight360 wanted. With this in mind, a way to record and play-back games would need to be developed.

While it is true that a demo system could be made for different games, it is outside of the technical scope of this project. To implement a system that can create repeatable experiences for a game, without the source code for said game, would take both time and skills that the student involved does not possess. If more time was given and there was guidance from someone who had experience in reverse engineering and the NOVA, then it could be possible. This solution, however, would likely not be universal. Each game likely has similarities - such as, for example, using Unity as a basis. Each game may as likely have differences that would need to be designed around or accounted for when creating a demo system.

In short, this would provide not only a greater opportunity for engineering to come through, but it would produce something that Eight360 could potentially use elsewhere. They can use the demo module in other projects in Unity to create a unified demonstration for potential customers. The 360 Motion Tester could be used to demonstrate different types of motion, while also allowing for a unified experience.

The 360 Motion Tester had a fast prototyping phase due to Unity's design accommodating easy prototypes. The biggest issues occurred at the start. Originally, the kart microgame was edited to try and fit this project (see Figure 3.13). However, this proved to be harder than originally thought. There were multiple issues with this approach - such as the physics misbehaving, the kart not turning properly when changing directions at other angles, such as the angles found in Figure 3.13(a).



(a) An Edit of the Kart Microgame (b) The Kart Microgame, as it normally is.

Figure 3.13: The kart and kart edit done for this project at the start.

This was due to how the kart turns in the game. Instead of adding torque to the kart, the game rotates the forward acceleration vector. While this does better simulate a kart, it doesn't work as well when you turn that kart in an arbitrary angle. As seen in line 3 of Figure 3.14, the forward acceleration Vector is multiplied by a Quaternion, `turnAngle`. This is produced by angling the Up vector of the transform[4] by an arbitrary amount. This creates a Quaternion that can be applied to the Vector to rotate it.

The issue is that rotating the vector in this way causes issues once the kart rotates past 90 degrees on the Z-axis when rotating the player's transform's forward vector. A potential fix to this would be to instead decouple the rotation of the kart from the forward acceleration. This is what's done with the final 360 Motion Tester.

[4]The position, rotation, and scale of any Unity object[22]

```
float turningPower = IsDrifting ? m_DriftTurningPower : turnInput * m_FinalStats.Steer * 0.5f;
Quaternion turnAngle = Quaternion.AngleAxis(turningPower, transform.up);
Vector3 fwd = turnAngle * transform.forward;
Vector3 movement = fwd * accelInput * finalAcceleration * ((m_HasCollision || GroundPercent > 0.0f) ? 1.0f : 0.0f);
```

Figure 3.14: The turning code in the Kart Microgame.

These turning issues were indicative that these issues may prop up elsewhere. Considering the time spent investigating this issue (roughly 2 weeks), it would have been faster to create something from scratch. While there would potentially be help online, they would have to be adapted to fit the design requirements. One big design requirement was a need to go upside down; the microgame was not meant to have their racers go upside down.

After experimenting and attempting to fix these issues, it was decided to approach it from scratch - making a custom solution. A racer template, such as the one found in Figure 3.15, could have been used. However, one aspect that hasn't been touched on is integration with the NOVA. The NOVA SDK requires an experimental input system from Unity to be used. Likely, the vast majority of these racer templates do not use this new input system.

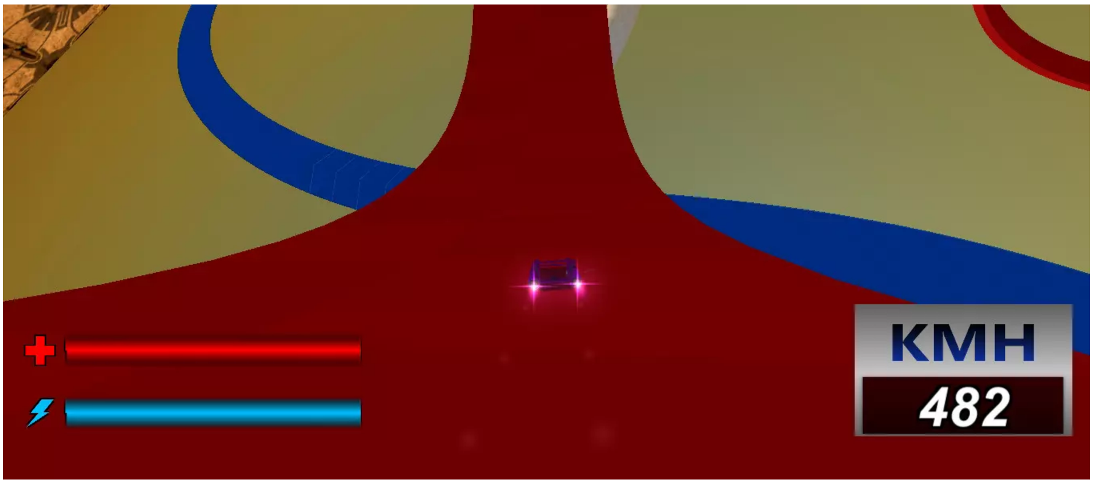


Figure 3.15: SBP Hover Racing Physics, an example of one such racer template. Image sourced from [23].

Porting this system would not be a difficult task, but the demo module would also need to be built around it. If it was difficult to build the demo module with the template, for example, then progress would grind to a halt until the technical difficulties were sorted. By creating a controller from scratch, both the demo module and game module can be created to serve each other.

As Unity is designed for easy prototyping, it wasn't difficult to create something that worked quickly. One design choice made early on was to adapt an example hovercraft. This example did not support 360 motion, meaning that the example had to be adjusted to account for this aspect. While some portions of the example were kept (such as the thrusters on the bottom to provide a realistic bobbing motion), portions were also rewritten to fit the project's needs.

There were some risks with the project. As it was reliant on the NOVA, the testing week was reliant on the NOVA being functional. As experienced in the project, if the NOVA wasn't functional, it meant having to wait until it was fixed. Integration was delayed once due to this reason. While part of the testing (the non-NOVA control tests) can be done, half of it would have to be postponed.

As COVID-19 hit New Zealand once more, and country entered a level 3 or higher lockdown, it caused the entire project to be delayed. The lockdown happened, unfortunately, the week as integration was to be done. Due to the nature of the NOVA, it was unlikely that integration was going to be done. Instead, other aspects of the project were developed during this period, such as refining the procedure plan and ensuring that the content was ready.

3.4.2 Demo Module

The demo module was something that had to be created from scratch. Demo systems are typically tailor-made for games, due to the differences between each game.

The way the demo system can be made is based on some different factors. One of the biggest factors is whether or not the game is deterministic. This can vastly change how the demo system can be developed. If it's deterministic, only the **inputs** and the **current time** would need to be recorded.

This isn't the case with non-deterministic games. Unfortunately, the Unity physics engine is not deterministic. Without determinism, you need to measure other aspects of the system to recreate the conditions as they were at that point. To use an example, for this project, the **inputs**, the **current time**, **current position**, **velocity**, **angular velocity**, **inertia** (as vectors) needed to be recorded.

This is the minimum that's needed to recreate the player object's movement. This gets complex as more variables are introduced: such as any artificial intelligence, surrounding systems, and any other physics-based objects. As the game created was simple (it's just a simple racing game with no AI racers or any other objects), the demo module was simple in turn.

Originally, the demo module was going to be plug-and-play for most Unity projects. This is still true - the demo module can be exported and used in different projects. However, the biggest hurdle to overcome is input handling. Currently, inputs must be handled in a custom manner and adjusted based on what the project requires. For example - the 360 Motion Tester uses two floats to determine if up, down, left, or right are being pressed. If further buttons were required, then those would need to be added to the script and recorded as necessary.

The demo module also cannot handle custom inputs without editing the script itself. For example, any other variables that may need to be recorded (such as, for a typical game, a score) do not have an easy and intuitive way of being recorded. The demo module can be extended by the end-user to support these custom variables, such as a score or an item ID in memory, but it proved to be outside the scope of this project. This could be done currently, but the `record()` and `replay()` methods would need to be adjusted.

In summary, both modules were developed to simulate a rollercoaster-like experience in VR, and a demo module to help record and playback said VR experience. The majority of requirements for both were met, but some requirements weren't met due to time constraints and the impact from COVID-19. The 360 Motion Tester was integrated, can provide a wide variety of motion with the NOVA. The demo module can record a game session but is limited in what it can record. It can only track the player's values and record those and has no support for user-defined variables.

The next chapter describes a user study which was used to explore the effectiveness of the 360 Motion Tester with the NOVA.

Chapter 4

User Study

To determine the effectiveness of 360 motion in VR, a study was conducted. The aim of the study was to determine whether or not it was worth investigating 360 motion further. The research question was, does 360 motion provide any benefit to presence over not having 360 motion in VR simulators?

4.1 Design

The study was a within-subjects test[24], where the non-NOVA and NOVA experiences are both trialled. This was to investigate whether or not 360 motion affects VR simulators. By counter-balancing the experiences, we can reduce any potential learning factors. The research questions for this study were:

RQ: Does 360 Motion increase the Effectiveness of VR simulations?

RQ1: How immersive is the 360 motion?

RQ2: How effective was 360 motion for presence?

RQ3: How much more involved were people with 360 motion compared to non-360?

RQ4: How much more realistic was 360 motion?

RQ5: How much does 360 motion affect VR simulator sickness?

The design of the study went through a few iterations, due to feedback from my pilot study and the Ethics Committee. The CANLAB [14, 15] were consulted, due to their experience with VR studies. Without their help, the study would not be as refined as it is now. They explained various aspects of their experiments. Alongside this, they allowed me to participate in one of their experiments - specifically, their Plank Experiment (see §2:2.2). This allowed the study portion of the project to be designed in detail, as I had little experience in conducting studies.

While not all of the advice was used, such as using the Empatica E4[1] for more in-depth results, other aspects of the evaluation plan was influenced by their advice. For example, the decision to interview the participants for how they felt was taken from this experiment. The decision to not allow the participant to influence the experience, as well as the time limit of 20 minutes in VR was informed by this experience.

[1] A piece of psychological study equipment which allows for various readings non-intrusively - such as Blood Volume Pulse, measuring the skin temperature, among other things [25]

Both the Simulator Sickness Questionnaire (SSQ) [26] [27] and the iGroup Presence Questionnaire (IGPQ) [28] were both included as a result of the advice from CANLAB. These questionnaires are standard VR questionnaires, used in different studies in academia. These questions are both critical to measure the effect that the NOVA has on the participants. The IGPQ showcases the level of presence and realism one feels while in VR. The IGPQ asks the participants how realistic the world felt if they paid attention to the real world, and so on.

The SSQ allows us to take a measure of how sick one felt after the experience. This is important, as one aspect that the NOVA could potentially improve on is simulator sickness. This is due to how simulator sickness is a disconnect between what your body is seeing and what it's feeling [29]. With the introduction of motion, this aspect should be mitigated - which is why the SSQ is needed to measure this important aspect.

Finally, there was a control variable in the form of the non-NOVA trial. This is to provide a baseline experience to compare the NOVA trial to. As VR experiences typically contain no motion, we can assume that the control trial is a typical VR experience.

The Ethics Application (#0000029606) was approved with three rounds of feedback. The most prominent change was including a Health and Safety document which details how participants will be filtered, the safety mechanisms found in the NOVA and the software, and more. All of the relevant documents for the ethics approval can be found in the Appendix.

This ethics application is to do with the evaluation of the content made. It was anticipated that up to 20 participants will participate in the study. These participants have been filtered to reject anyone under the age of 18, and anyone with potential medical or physical complications that will potentially impact them. The methods in which these participants will be selected is through random selection.

4.2 Participants

Participants were to be selected at random. A call for participants, advertised on the Kelburn Campus and via email, would be complete about two weeks before testing. After a week and a half, participants would be randomly selected. To ensure proper randomness, random.org would be used to generate the numbers. This would also filter out any bias that the selection may have, due to the pool of participants including friends and colleagues.

If less than 20 participants apply, then all volunteers were asked to come in. The study did not attempt to filter out anyone with more or less VR experience, although this would be asked to them in their pre-experience questionnaire, as it may have a potential impact on the results. Only an employee from Eight360 and the researcher had been present during testing. This is to ensure the privacy of the participants, and their reactions, during testing.

Due to the delay from the COVID-19 lockdown, the entire project's schedule was delayed for 3 weeks: meaning that the preliminary testing and pilot studies weren't doable until after lockdown. This meant that it was significantly difficult to recruit participants in the manner described in the Ethics Application - there were two weeks left after the NOVA integration. In the end, personal friends and colleagues (such as the people from the School of Psychology) were called upon for some data.

Five participants (all male) were recruited and all had experience in VR. The participant table, Figure 4.1, documents the number of participants, whether or not they had experience in VR, and how long they spend in VR weekly. The majority of the participants had high exposure to VR. 60% of the participants use VR for 6 or more hours a week, and every participant had used VR in the past. This potentially skewed the results, as the participants may be used to VR sickness already and had been exposed to many VR experiences already.

ID	Gender	VR Experience	Weekly VR Usage (Hours)
1	M	Y	6+
2	M	Y	6+
3	M	Y	0 - 1
4	M	Y	6+
5	M	Y	0 - 1

Figure 4.1: The Participant Table

4.3 Procedure

Counterbalancing is used for the order of which experience the participant does first, to reduce any potential learning factors. A verbal interview with the participants and a questionnaire were completed before and during the VR experiences. Within-subject testing was be used to ensure that the variance experienced between subjects is at a minimum.

The game will be trialled with the demo module, to ensure each experience is the same between participants. The order of which goes first changed. These results can not only determine the effectiveness of the NOVA, but also the demo module. All 5 participants used both the NOVA and a no-motion VR experience.

The procedure for the study is as follows. The participants will be given a health and safety induction before the study took place. Upon arriving, the participant will be given a safety briefing of the NOVA and the VR experience. They will then be asked to complete a questionnaire to record how they felt and their demographics. Afterwards, they will spend 4 minutes inside of the simulation with motion, or without. Once that is finished, they will be given a small break with some additional questions about their experience - before they do another 4 minutes. The second experience will always be what they hadn't experienced prior (i.e. if they had done the experience with motion, they'll now do it without motion). During the experience, the participant were to do a verbal questionnaire.

This study is intended to give a greater understanding of what effect 360-motion has on VR simulations. These questions are intended to gain a perceived subjective understanding of each participant's experience with the NOVA. If a participant has a high fear or excitement rating, we can infer that they were properly immersed.

This procedure was allocated an hour per participant, including errors, however the procedure only took 30 minutes during testing. The experiences took roughly about 10 minutes to complete, with 4 minutes per VR trial. This time limit is within the Human Ethics Committee regulations. 4 minutes was with motion and 4 minutes was without. A Health and Safety demonstration was given before the participants were allowed inside the NOVA, which may take up to 10 minutes. 15 minutes was be given for the questionnaires, allowing for a 10 minute leeway period for any errors.

Health and Safety are incredibly important considering the nature of this study. Not only is it using VR, but it is motion intensive VR, which often incurs visually incurred motion sickness. Considering this, the application was designed to minimize VR sickness: roads were shown in the simulator game, which the user will naturally follow. Any extreme motions have been reduced - with most twists and loops elongated to ensure that there are no sudden movements.

The NOVA itself has an emergency stop which forces the machine to an upright position. In conjunction with this, the experience has a method to bring the NOVA upright and stop the simulation. This is to ensure that the effects of VR sickness if felt, can be stopped as soon as possible. As it is in the best interest of everyone to keep themselves non-sick, this was an incredibly important feature.

The track itself has been designed with health and safety in mind. To reduce discomfort, certain aspects (such as staying upside down) was kept to a minimum.

4.4 Tasks

The tasks for this study are as follows:

- Motion
  - Verbal Questions
  - Motion Experience
  - Verbal Questions (During Experience)
  - Written Questionnaire (Out of NOVA)
- Non-Motion
  - Verbal Questions
  - Motion Experience
  - Verbal Questions (During Experience)
  - Written Questionnaire (Out of NOVA)

The Motion Experience is non-interactive. It is akin to a rollercoaster ride, with no interaction or tasks for the user to do outside of experiencing the motion. The verbal questionnaire is given to the participant before and during the experience, while the written questionnaire is performed afterwards.

4.5 Data Collection and Analysis

There were two sources of data collected for this evaluation - the verbal questions and the written questionnaire. The verbal questions are to gather qualitative feedback, while the questionnaires provide **qualitative feedback**, the **iGPQ** and **SSQ**.

Before each VR experience, a series of questions will be given to the participant verbally. The same set of questions were asked during the VR experience.

- From a scale of 1 to 10, with 1 being the least, and 10 being the most, how immersed were you in VR?
- From a scale of 1 to 10, with 1 being the least, and 10 being the most, how fearful were you?
- From a scale of 1 to 10, with 1 being the least, and 10 being the most, how excited were you?

The numeric values allow the participants to give a value to their presence. This is to not only aggregate the data but also to help give the participant a scale to make a judgement on. The various questions will help with judging the effect that the VR experience had. As the game module will have similarities to a rollercoaster, emotions typically associated with rollercoasters (fear and excitement) were picked.

Two questionnaires were made to ensure that the data remained distinct between the motion and non-motion experiences. This meant that proper analysis could be accomplished. Unfortunately, specific analysis to see how people's opinions changed isn't possible due to the anonymous nature of the data. The questionnaire uses the **iGPQ** and **SSQ**, alongside some questions to determine the emotional state of the subject before and after the experience for qualitative feedback. The first two were used due to their wide usage within VR studies.

The **SSQ** allows for the measurement of effectiveness through sicknesss. One of the prevailing reasons for VR sickness is a disconnect between what you're seeing and feeling. If one experience has a lower trend of simulator sickness, then we can infer that the experience was more effective and immersive.

Other questionnaires were consulted, such as NASA TLX, on the recommendation of my supervisor and others. However, they were deemed irrelevant to the study. NASA TLX measures the workload "subjective workload assessments on the operator(s) working with various human-machine interface systems"[30]. This is the same case for other usability questionnaires, such as the System Usability Scale [2]. This study is about measuring the effectiveness of motion in VR, by looking at one's presence. No task would be measured, as the experience is a non-interactive repeatable ride akin to a rollercoaster.

Chapter 5

Results

In this chapter, we present the results from the pilot and actual full study §4. The pilot study was conducted to determine if any changes to the procedure needed to be done. Alongside this, it was also used to test the integration of the NOVA with the 360 Motion Tester and ensure that no issues were missed during development.

Two pilot studies, and an actual full study, were conducted in the process of this project. The pilot studies were performed with personal acquaintances, while the actual study was intended to have participants selected at random. Due to scheduling issues from COVID-19, this plan was changed. Participants were instead selected from a group of colleagues and friends.

5.1 Pilot Study

A total of two pilot studies was performed to ensure that the project's procedures were proper and that the study didn't have any obvious flaws. It also allowed for the testing of the actual project itself - ensuring that further features weren't needed and that the NOVA integration had no issues.

The first pilot study (P1) was conducted with just the non-motion portion of the study. **Two** participants took part in P1. It was to test the user study protocol and adjust it as necessary. P1 also allowed for the identification of any issues with set-up, how long the non-motion segments will take, and so on. No major adjustments to the procedure were made following P1.

The biggest takeaway from P1 was that there needed to be a higher degree of control for when the experience could start. A start button was planned, so that the participant, or user, could set up their environment before starting. Another piece of feedback that was given by the participants was that the track's sides were too high in VR. This lead to it being harder to see the world from the first-person view and made the participants focus on the motion more. By forcing the participants to focus on the motion, it would lead to a greater chance of the participants feeling sick.

The second pilot study (P2) was to test if the 360 Motion Tester worked with the NOVA and see how long the full user procedure described in §4 took. **One** participant took part in P2. The results were not used, as the questionnaire was further extended after this point. This pilot study was vital in realizing that the study would only take 30 minutes to complete and that some issues had to be sorted for the real test. One such issue was the fact that the camera height in VR was too low, and had to be raised.

The entire track was tested as well, to see if the track was too long or too short. This was determined to be of an adequate length. It was also used to see if there was enough variety

(a) The NOVA in the middle of the study.

(b) A user experiencing the inside of the NOVA. Note that this is not a study participant.

Figure 5.1: Images of the NOVA

in the motion - which it was determined there was. While there weren't any proper procedures related to this (as there is an element of subjectivity), the participant in P2 enjoyed the experience and felt that no real changes were needed to the track or motion.

This study highlighted the need for there to be two separate surveys, to allow for a clearer understanding of the data. It also refined the procedure for the verbal interviews, where the time was recorded to allow some identification of what the verbal and written questionnaires mapped to. This would allow for a greater understanding of the psyche of the participants, and the effectiveness of VR motion.

5.2 Study

The study showcased some interesting results. Five participants were taken through the study. They did both the non-motion and motion experiences, as detailed in chapter §4. While not enough participants were brought in to make a proper quantitative-based conclusion, the results provide a good basis for future studies.

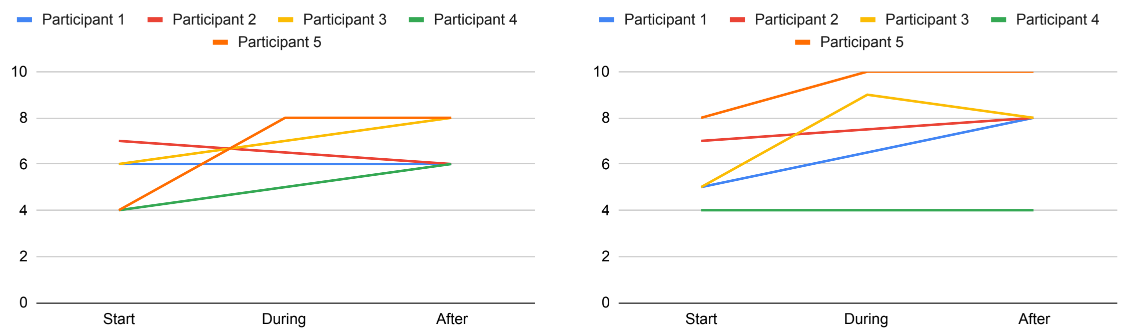
5.2.1 RQ1 – Immersion

Immersion was looked into the answer to the question of "How immersive is the 360 motion?" Participants were asked to rank their immersion on a scale of 1 to 10 before, during, and after the VR experience. This would give an idea of if their immersion increased, decreased, or stayed the same during their time in VR.

Notably, the procedure did change on the day. Participants 1 and 2 did not answer the questions during the experience due to an error on the part of the experimenter. To accommodate this, an average between the start and end values were taken to showcase the change on the graph. It should be noted that this value was not taken into account for the actual analysis, this is simply for visual clarity on the graphs. Participant 4 exited the non-motion experience early, meaning the same treatment was given.

The data has also been slightly changed to accommodate a different scale. As mentioned in §4, participants were asked to answer between 1 and 10 during the VR experience. The questionnaire asked the participants for an answer between 1 and 5. To bring these two scales together for Figure 5.2, the written questionnaire answers were multiplied by two.

On average, people felt that the experience was more effective with motion than without motion. Excitement was also overall higher, although fear was spread out. Generally, there was an increase in both fear and excitement as the experience went on.



(a) Non-Motion Results (b) Motion Results

Figure 5.2: How immersed did you feel during the experience?

As seen in Figure 5.2(b), the 4 participants answered 8 or above, where 10 is the highest value to give. There is one participant whose immersion was a flat 4 - this participant commented that they could not become immersed due to safety concerns. When you compare this to figure 5.2(a), where half of the people answered 6 for the post-experience questionnaire, this is a notable increase. The post-experience average for motion is 7.6, while non-motion is 6.8. This reduction is interesting, as it means that non-motion people were reportedly less immersed after the experience was over. The graphs reporting the other factors can be found in the Appendix.

5.2.2 RQ2, RQ3, RQ4 – Presence

Presence was measured via the iGroup Presence Questionnaire to answer the question of ”How effective was 360 motion for presence?” The iGroup Presence Questionnaire (henceforth referred to as iGPQ) shows that motion was more effective for increased presence. There was an overall increase in presence, although interestingly, it was near 50/50 split on whether or not the participants were aware of their real environment - with the average score being 3. This is potentially explained by the various noises the NOVA makes while moving, alerting the users to the real world. Meanwhile, the non-motion experience had an average score of 3.6 for this question.

This can be seen in Figure 5.3, which shows that the Non-Motion answers have a larger variance. Compared to its motion counterpart, motion often lead to increased presence, with the majority of answers answer 4 or higher. The only exception to this is the ”I felt like I was just perceiving pictures” question, which scored lower as people tended to disagree.

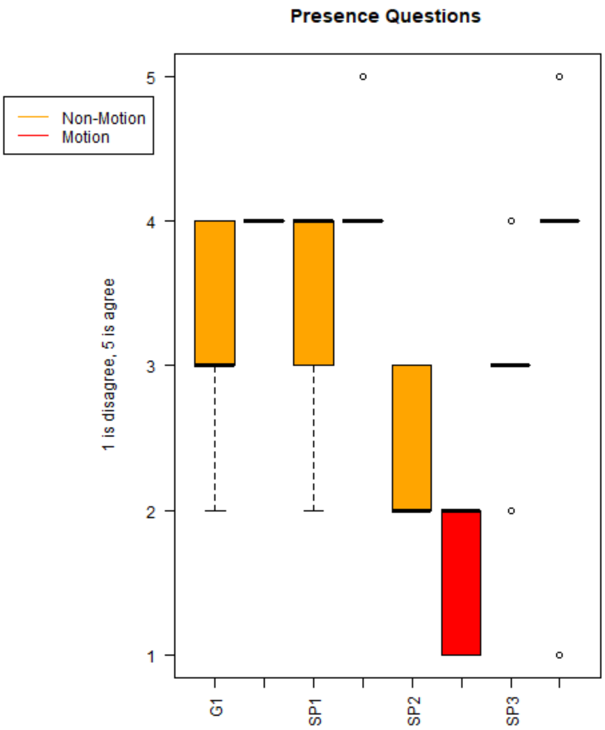


Figure 5.3: RQ2: A box-plot showcasing the range of answers between non-motion and motion for presence. Note that the lines means that the majority of answers were focused on that answer. Series: Non-Motion - Yellow, Motion - Red

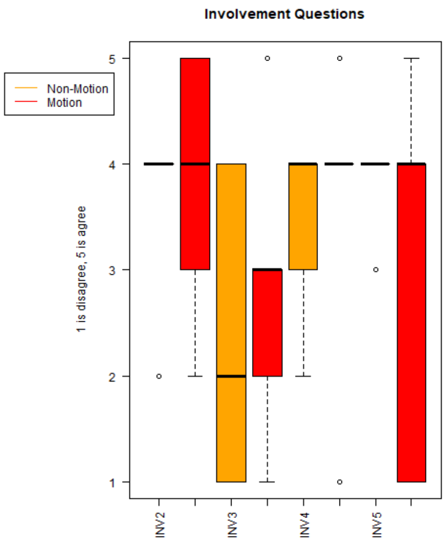
Involvement was measured through iGPQ, as the second category being measured. This was investigated through 4 different questions, the results of which can be seen in Figure 5.4(a).

Involvement is slightly tricky, but we can see that there was a wider range compared to the non-motion answers. Generally, most people agreed to all of the questions, except for "I was completely captivated by the virtual world." One question of note was "I still paid attention to the real world." Due to the sounds of the NOVA and the feeling of moving, this question was likely to have a higher agree rate compared to the non-motion version.

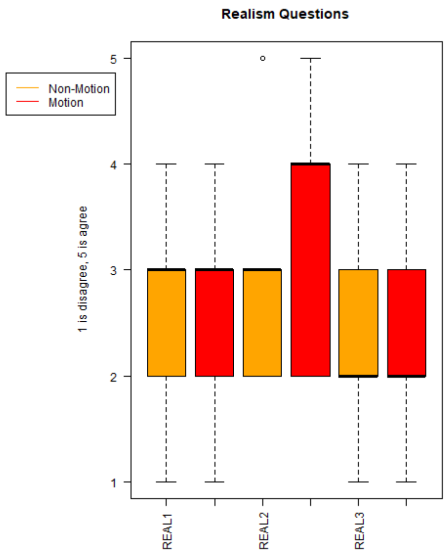
Realism was also measured via the iGPQ. This was to answer the question of "How much more realistic was 360 motion?" The results for these sets of questions can be found in Figure 5.4(b), where it can be seen that nothing changed between the motion and non-motion trials.

For realism, motion and non-motion were equal across the board. However, motion results had a larger variance for the question of "How real did the virtual world seem to you", with it having a wider range in the positive direction. This indicates that there is no decreased effect of realism with the NOVA.

Overall, the NOVA didn't appear to decrease immersion. There is a decrease in the realism average (see figure 5.5), but that is explained by one participant who felt unsafe due to safety concerns. This will be discussed further in the discussion section.



(a) RQ3: A box-plot showcasing the range of answers between non-motion and motion for involvement.



(b) RQ4: A box-plot showcasing the range of answers between non-motion and motion for realism.

Figure 5.4: Box-Plots for Involvement and Realism

	Presence Average	Spatial Average	Involvement Average	Realism Average
Non-Motion	3.2	2.93	3.3	2.66
Motion	4	3.13	3.3	2.53

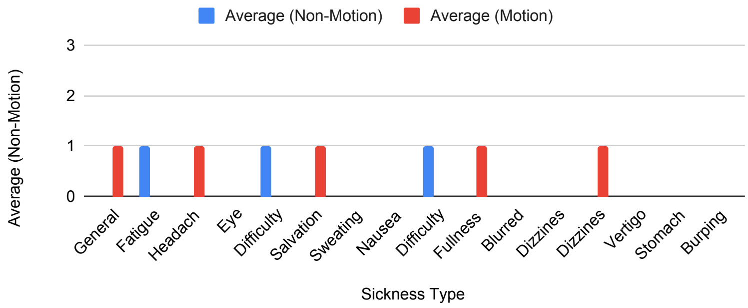
Figure 5.5: The iGPQ Results

5.2.3 RQ5 – Simulator Sickness

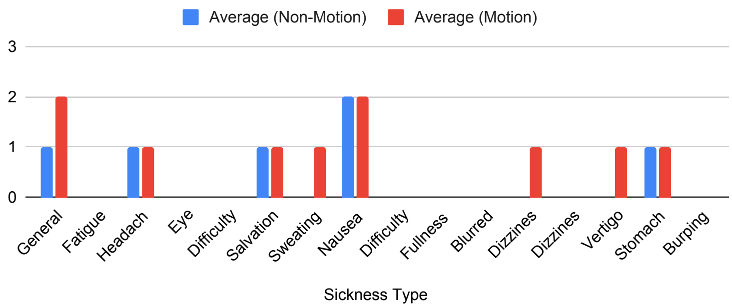
The purpose for looking into Simulator Sickness was to answer the question of ”How much does 360 Motion effect Simulator Sickness?” There’s plenty of literature surrounding simulator sickness [3, 4], and the NOVA provides a novel way of potentially mitigating it.

It was found that NOVA tended to increase sickness among those who are experienced with VR. Originally, it appeared that the NOVA increased sickness overall. However, once separated by demographic, it was discovered that the more experienced VR group experienced a higher degree of sickness according to the results from the SSQ. This can be seen in figure 5.6. The participants who use 6+ hours of VR weekly had a higher average degree of sickness compared to the participants with 0-1 hours. The VR-experienced participants said that they felt ”Slight” or ”Moderate” symptoms on average (see Figure 5.6(b)), whereas the non-VR experienced participants stated that they only felt ”Slight” symptoms on average. A participant in this demographic noted that they had felt sicker after doing the non-motion experience after the motion experience. Thankfully, none of the participants became sick enough to need a sick bag, although Participant 4 did terminate the non-motion portion of the study early.

There isn’t enough data to provide a proper conclusion, but it is worth investigating further. It may be that a larger exposure to VR causes one to become used to the lack of motion. Then, when motion is reintroduced, it causes one to become sicker than those who haven’t been exposed to VR yet.



(a) SSQ: 0-1 Hours VR Usage Weekly



(b) SSQ: 6+ Hours VR Usage Weekly

Figure 5.6: RQ5: Results of SSQ averages separated by demographic. 0 is no sickness, 1 is slight, 2 is moderate, 3 is severe.

5.3 Discussion

Without a larger participant pool, it's difficult to make conclusions. More study should be done to determine if these results are consistent at scale. Despite that, there are some positive results that have come through this user study. These results are in regards to the presence and involvement of the VR simulation.

The NOVA appears to increase presence (RQ2) and involvement (RQ3). It does not detract from the realistic nature (RQ4) of the experiences either, making it a net benefit to use. While there is not enough data to make any substantial conclusions, this is promising for the prospect of future studies using the NOVA. The majority of participants were pleased and excited when the NOVA started to move and made comments to the effect of it being ”amazing” (PID5) or ”cool” (PID3).

This is especially important due to the data point which showcases a lower sense of realism in the NOVA. Participant 4 reported safety concerns for not feeling immersed. Alongside this, they didn't complete the non-motion section due to feeling sick. More data could confirm if this data point is an exception or not. Without further study, it cannot be confirmed if the NOVA does increase immersion, as there is a chance that this data point is the norm, not the exception.

One comment that people had was that it was difficult to figure out where to place their feet. This was especially evident when going upside down. Participant 4 said

> With nova moving i was much more aware of the real world due to safety concerns. Mainly where to put my feet when it was upside down... When thr nova was not moving i didnt need to care about thr real world and was able to focus

> more on the virual world.

While Participant 1 said that it

> Would be better if feet were strapped in.

Considering the NOVA wasn't intended for long periods upside-down (such as the motion found in this experience), this makes sense. A foot-strap to keep the feet centered would have helped immensely - this is something that Eight360 has been developing, but was not part of the NOVA used for this study.

The SSQ showcases that there is a potential link to motion increasing sickness for those who are used to VR. This is something that should be explored further, as it could explain the results found in the SSQ. With the current data, it appears that nausea and general sickness were increased (going from slight to moderate) with motion. It should be noted that Participant 4, who stopped the non-motion portion of the experiment early, is included in the 6+ hours demographic. This is potentially why nausea is high for the non-motion data set.

Another potential reason for this distinction is that *both* 0-1 hour participants went with non-motion first, motion second. This was entirely by chance: the study swapped between motion first and non-motion first on each participant. It could be that doing the non-motion portion first allowed them to prepare themselves for the motion experience, making their sickness less than those who did motion first.

Currently, there isn't enough data to properly make any conclusions: a more diverse set of participants with a variety of VR experience is needed to conclude that is the case. If there was a trend where, the more VR experience one has, the more sick you felt due to the

The study had some minor errors due to procedure problems. Firstly, the questions weren't adjusted - the scales for the qualitative factors were different. The verbal questions were asked on a scale from 1 to 10, while the written questionnaire was asked on a scale from 1 to 5. This caused some issues when comparing the data, and should have been fixed before the user study went forward.

There were no major issues with the machinery or procedure otherwise. There were aspects that should have been changed, however. The participants should have been told that there were two experiences, as there was some confusion regarding that portion of the procedure. The questionnaire could have been revised to make the wording for some questions more clear: the iGPQ has two questions that are the same, but with different answers. Those questions should have been changed to be distinct from each other.

These results show that the NOVA can increase presence and involvement in VR experiences. Realism is not impacted in any way, although it does increase the awareness of the real-world. It's indeterminate if the NOVA increases sickness, as demographic who reported higher amounts of sickness have more VR experience. This demographic may potentially be unused to the motion which causes a higher rate of sickness.

Full-size charts can be found in Appendix J. The questionnaire and the questions used in the iPGQ can be found in Appendices M and H.

Chapter 6

Conclusions

Most VR simulators are limited in how motion is experienced. If there is motion, they are often tailor-made experiences, do not have the flexibility that one would like from virtual reality, and very few provide full 360 motion capabilities. Not only are these experiences more costly, but they are not reusable if different experiences are needed. This is what the NOVA was designed for, to provide a higher sense of immersion into VR simulators through delivering 360 motion experiences, while also being usable between different experiences.

6.1 Contributions

This project investigated the question of how effective 360 motion is for VR experiences. This project produced a software VR artifact that would aid in the study of evaluating this question. This artifact was a reproducible rails ride that showcased different motions. Alongside this, a study was conducted to properly assess the effectiveness of 360 motion.

An artifact was produced for a reproducible rails-ride. Not only does it showcase different types of motion, but it's also extendable: more types of motion could be showcased. A user study was designed, ethics approval was obtained, and the study was conducted in a limited manner due to COVID-19 lockdowns. Data was collected and analyzed, which showcases promise in the use of the NOVA in the future.

The results showed that the NOVA may increase presence without any downsides. Every participant reported either the same or an increased level of immersion. There was an increase in sickness, however, it should be noted that the majority of participants who reported the increase in sickness use VR regularly. In comparison, participants who were unused to VR only reported slight sickness. Therefore, further testing would need to be performed to see if this is simply because the participants are not used to it, or if it's a case of increased sickness with the NOVA.

The majority of the requirements were met. A study was produced, but its trialling was not tested for statistical significance due to limited numbers, caused by the COVID-19 lockdowns. A VR experience was created which can be used, and expanded upon, for future studies. Requirements **1 through 5 and 7** were met for the VR experience. Requirements 6, 8 and 9 were not met due to changes in focus in the project or a limitation in the skills involved.

The demo module was produced and met Requirements **1 through 3**. Requirement 4 was not met due to a lack of time and a change in the project's focus. As the 360 Motion Tester did not have any additional tracks, Requirement 4 wasn't necessary for the user study.

6.2 Future Work

Future work can expand on what's been established in this project. The Demo Module can be expanded to have more generic support. Currently, the Demo Module requires using Unity's in-built physics, rather than allowing the developer to define what variables to track. Alongside that, user-defined variables would be a beneficial addition, as that will greatly expand the support for the demo module.

A UI to select a file and reload files as needed would be a good expansion of the demo module's functionality. Currently, only one file can be loaded and saved to during run-time as a result of this lack of functionality. It would also make it easier to set up, as the file currently needs to be in a specific location for the demo module to work. Finally, some better benchmarking and testing would be greatly beneficial. This would allow for a guarantee that the functionality of the demo module isn't impacted when it's extended. Validating the demo module was simply done by visually comparing the two runs.

The experience needs some overall improvements. The sound design could be much better, as well as the visual aspect: this would potentially help increase the level of realism and presence inside VR. A greater variety of tracks could be produced, to provide a wider variety of motion. Not only that but it could also be used to see if the rate of sickness changes based on the extremity of the motion.

Further integration with the demo module could also be explored - with the ability to load in different demo files. Alongside that, one comment mentioned that the motion was slightly bumpy. An investigation into the movement of the experience could also be looked into, to make it more realistic.

Finally, more user testing could be conducted with a larger amount of participants for statistical significance. Due to the limited time for the project, not enough participants were recruited to provide any measure of statistical relevancy. With more user-testing, it'll be possible to determine if the results mentioned in (§5) are consistent at a much larger scale.

Bibliography

[1] E. Brittanica. Virtual reality — computer science — britannica. [Online]. Available: https://www.britannica.com/technology/virtual-reality

[2] J. Brooke. System usability scale - sus. [Online]. Available: https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html

[3] N. Ranasinghe, P. Jain, D. Tolley, S. Karwita Tailan, C. C. Yen, and E. Y.-L. Do, "Exploring the use of olfactory stimuli towards reducing visually induced motion sickness in virtual reality," in *Symposium on Spatial User Interaction*, ser. SUI '20. New York, NY, USA: Association for Computing Machinery, 2020. [Online]. Available: https://doi-org.helicon.vuw.ac.nz/10.1145/3385959.3418451

[4] W. Lo and R. H. So, "Cybersickness in the presence of scene rotational movements along different axes," *Applied Ergonomics*, vol. 32, no. 1, pp. 1–14, 2001. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0003687000000594

[5] Eight360. Home - Eight360. [Online]. Available: https://www.eight360.com/

[6] P. Milgram and F. Kishino, "A taxonomy of mixed reality visual displays," *IEICE Trans. Information Systems*, vol. vol. E77-D, no. 12, pp. 1321–1329, 12 1994.

[7] R. Macredie, S. J. E. Taylor, X. Yu, and R. Keeble, "Virtual reality and simulation: An overview," in *Proceedings of the 28th Conference on Winter Simulation*, ser. WSC '96. USA: IEEE Computer Society, 1996, p. 669–674. [Online]. Available: https://doi.org/10.1145/256562.256782

[8] S. Rangelova and E. Andre, "A survey on simulation sickness in driving applications with virtual reality head-mounted displays," *Presence: Teleoper. Virtual Environ.*, vol. 27, no. 1, p. 15–31, Mar. 2019. [Online]. Available: https://doi.org/10.1162/pres_a_00318

[9] T. Weißker, A. Kunert, B. Fröhlich, and A. Kulik, "Spatial updating and simulator sickness during steering and jumping in immersive virtual environments," in *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 2018, pp. 97–104.

[10] Łukasz Dziuda, M. P. Biernacki, P. M. Baran, and O. E. Truszczyński, "The effects of simulated fog and motion on simulator sickness in a driving simulator and the duration of after-effects," *Applied Ergonomics*, vol. 45, no. 3, pp. 406–412, 2014. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0003687013001130

[11] "Westdrive x loopar: An open-access virtual reality project in unity for evaluating user interaction methods during takeover requests," *Sensors*, vol. 21, no. 5, p. 1879, 2021, copyright - © 2021. This work is licensed under http://creativecommons.org/licenses/by/3.0/ (the "License"). Notwithstanding the ProQuest Terms and Conditions, you may use this content in accordance with the

terms of the License; Last updated - 2021-03-17. [Online]. Available: https://www.proquest.com/scholarly-journals/westdrive-x-loopar-open-access-virtual-reality/docview/2501793307/se-2?accountid=14782

[12] N. E. Seymour, "Vr to or: A review of the evidence that virtual reality simulation improves operating room performance," *World journal of surgery*, vol. 32, no. 2, pp. 182–188, 2008, cited By :207. [Online]. Available: www.scopus.com

[13] J. Li, H. Yang, F. Li, and J. Wu, "Application of virtual reality technology in psychotherapy," in *2020 International Conference on Intelligent Computing and Human-Computer Interaction (ICHCI)*, 2020, pp. 359–362.

[14] S. Schenk, K. Waldie, and G. Grimshaw, "Cognitive and affective neuroscience: approaches and applications," *Journal of the Royal Society of New Zealand*, vol. 51, no. 1, pp. 1–3, 2021. [Online]. Available: https://doi.org/10.1080/03036758.2020.1851732

[15] J. Murphy, C. Devue, P. M. Corballis, and G. M. Grimshaw, "Proactive control of emotional distraction: Evidence from eeg alpha suppression," *Frontiers in Human Neuroscience*, vol. 14, p. 318, 2020. [Online]. Available: https://www.frontiersin.org/article/10.3389/fnhum.2020.00318

[16] T. Schubert, F. Friedmann, and H. Regenbrecht, "The Experience of Presence: Factor Analytic Insights," *Presence: Teleoperators and Virtual Environments*, vol. 10, no. 3, pp. 266–281, 06 2001. [Online]. Available: https://doi.org/10.1162/105474601300343603

[17] I. P. Tussyadiah, D. Wang, T. H. Jung, and M. tom Dieck, "Virtual reality, presence, and attitude change: Empirical evidence from tourism," *Tourism Management*, vol. 66, p. 140–154, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0261517717302662

[18] Z. Xia and A. Hwang, "Self-position awareness based presence and interaction in virtual reality," *Virtual reality*, vol. 24, pp. 255–262, 06 2020, date created - 2021-05-17; Date revised - 2021-06-03; SuppNotes - Cited By: AMA Arch Ophthalmol. 1951 Apr;45(4):387-412 14818494] Percept Psychophys. 1982 Sep;32(3):201-10 7177758] Perception. 1995;24(2):215-35 7617426] J Vis. 2017 Jun 1;17(6):2 28586896] Vision Res. 2005 May;45(10):1321-8 15733964] Am J Optom Arch Am Acad Optom. 1950 Nov;27(11):531-53 14789950] Vision Res. 2016 Feb;119:73-81 26548811; Last updated - 2021-06-03. [Online]. Available: https://www.proquest.com/scholarly-journals/self-position-awareness-based-presence/docview/2528435209/se-2?accountid=14782

[19] Unity. Unity real time development platform. [Online]. Available: https://unity.com/

[20] ——. Scripting api: Time.deltaTime. [Online]. Available: https://docs.unity3d.com/ScriptReference/Time-deltaTime.html

[21] ——. Scripting API: MonoBehaviour.FixedUpdate(). [Online]. Available: https://docs.unity3d.com/ScriptReference/MonoBehaviour.FixedUpdate.html

[22] ——. Scripting api: Transform. [Online]. Available: https://docs.unity3d.com/ScriptReference/Transform.html

[23] S. Games. SBP Hover Racer Physics. [Online]. Available: https://assetstore.unity.com/packages/templates/tutorials/sbp-hover-racer-physics-122708

[24] J. Nielsen, *Usability Engineering*. Mountain View, California: AP Professional, 1993.

[25] Empatica. E4 wristband — realtime psychological signals. [Online]. Available: https://www.empatica.com/research/e4/

[26] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness," *The International Journal of Aviation Psychology*, vol. 3, no. 3, pp. 203–220, 1993. [Online]. Available: https://doi.org/10.1207/s15327108ijap0303_3

[27] M. P. Biernacki, R. S. Kennedy, and L. Dziuda, "Simulator sickness and its measurement with simulator sickness questionnaire (ssq)," *Medycyna pracy*, vol. 67, no. 4, pp. 545–555, 2016, date completed - 2017-01-31; Date created - 2016-09-15; Date revised - 2021-05-07; Last updated - 2021-05-16. [Online]. Available: https://www-proquest-com.helicon.vuw.ac.nz/scholarly-journals/simulator-sickness-measurement-with-questionnaire/docview/1819904121/se-2?accountid=14782

[28] iGroup. igroup presence questionnaire. [Online]. Available: http://www.igroup.org/pq/ipq/index.php

[29] A. Kemeny, C. Jean-Remy, and F. Colombet, *Getting rid of cybersickness: in virtual reality, augmented reality, and simulators*. Springer, 2020.

[30] NASA. TLX @ NASA Ames - home. [Online]. Available: https://humansystems.arc.nasa.gov/groups/tlx/

[31] H. K. Kim, J. Park, Y. Choi, and M. Choe, "Virtual reality sickness questionnaire (vrsq): Motion sickness measurement index in a virtual reality environment," *Applied Ergonomics*, vol. 69, pp. 66–73, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S000368701730282X