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Virtual Reality Video Game Spectating

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## **Abstract**

The effects of wearing a Virtual Reality headset is something that had not been fully investigated due to how new the consumer devices are. Using an Oculus Rift DK2, an accelerometer and adapting past studies by Geri (2002) and LoPresti (2003), a purpose made application was created that studied the effect of a Virtual Reality headset on head movement. While it was found that Virtual Reality headsets do not affect head movement, the process of creating the test application uncovered a potential issue with the Unity game engine where data spikes occur at regular intervals when a stream-reader is used to parse string output from a Python process. As the application provided a base on which to further investigate the effect of Virtual Reality headsets on head movement, the application was made freely available for others to replicate or adapt for use in further research regarding this area.

Because there had been no studies that explored viewer preference within Virtual Reality, the second study investigated which camera view was preferred when spectating a Virtual Reality game in Virtual Reality. Using the HTC Vive and several camera angles, it was found that having a first person view of the gameplay is least preferred by spectators whereas having free roam around the game level is the most preferred view. Furthermore, a panning transition between cameras is preferred over an instant switch. Additionally, the level of presence felt in each view, determined by the Spatial Presence Experience Scale (Hartmann et al, 2015) had no effect on spectators preferred view. Although, results suggested a larger study may uncover a significant link. This study also led to the created application being made available for anybody who wished to continue research in this area as it provides a platform to implement and test other Virtual Reality spectator views.

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## Chapter 1 - Introduction

Virtual Reality is defined by Greenbaum (1992) as “*An alternate world filled with computer generated images that respond to human movements*”. It has recently emerged at the forefront of consumer gaming hardware, with the Oculus Rift (Oculus, 2016) and HTC Vive (HTC and Valve, 2016) being two of the most advanced headsets released in 2016. As Virtual Reality gaming increases in popularity, the assumption could be made that the public are likely to want to spectate those playing Virtual Reality games as they do today with the live streaming of conventional games through sites such as twitch.tv (Twitch, 2016) and YouTube (Google, 2016). For example, 14 million people watched the final of the 2015 League of Legends (Riot Games, 2009) World Championship through live streaming platforms, compared with 11 million the previous year. As Virtual Reality is a new way of playing games and therefore a new way of spectating games, the benchmarks of what makes a successful Virtual Reality spectator experience have yet to be fully established.

Furthermore, as the usage of Virtual Reality headsets increase, the time spent wearing them for prolonged periods will also increase. Additionally, the increased usage of these headsets could affect head movement and cause injury or permanent damage. This could be due to an increased weight load on the head and neck. This thesis documents two studies which cover the previous points; the first investigates the difference in head movement when wearing a Virtual Reality headset and the second looks at the Virtual Reality viewing preferences of spectators through a comparison of different camera views and transitions.

The idea for the first study was drawn from the observation of conventional video game spectators. it was noted that when spectating video games, head movements can change based on the type of game that is being watched and the viewing preferences of the spectator. For example, an RTS (Real Time Strategy) such as Starcraft 2 (Blizzard, 2010) could illicit different head movements from the spectator. Firstly, fast, darting head movements looking at each unit moving across the map, Second, a slow scanning pattern searching for flanking attacks by the enemy and third, the tracking of a specific unit making its way across the map. Furthermore, virtual reality will allow spectators to view games in several new environments. For example, a game could be projected onto a large up-close screen, forcing spectators to increase their head movement to look at each side of the screen. If these conventional head movements were found to be negatively affected when using a virtual reality headset, developers could tailor spectator modes to reduce head movement or implement new viewing angles fulfilling the viewing preferences of the spectator with a reduction in head movement. Additionally, new health

guidelines regarding the use of headsets could be implemented for the safety of users if increased head movement was found.

Additionally, the first study was influenced by anecdotal evidence that suggests wearing a Virtual Reality headset has an impact on head movement. Determining the strength of this effect, or whether its observation is due to headset weight or immersion in Virtual Reality has not been recently explored. Furthermore, understanding these relationships may help designers of both Virtual Reality software and hardware by having a greater knowledge of the headset effect on users. The aim was to investigate these effects by seeing if there is a difference in head movement between Virtual Reality, non-Virtual Reality and Weighted Headset conditions. This study builds on non-empirical observations by Regan (1993) who noted that some users who wore a Virtual Reality headset moved slower and made fewer head movements than a non-Virtual Reality condition. Various research into the effects of headset use have been completed, but only Geri (2002) has conducted a study that is similar to the one presented in this thesis, albeit with night vision goggles. In contrast to Regan's observations, Geri found that night vision goggles did not significantly affect head movement.

For the second study, an analysis and review of current and potential virtual reality spectator views were implemented to provide statistical evidence and qualitative data as to the most and least preferred spectator views within virtual reality with the aim of helping the design of future virtual reality spectator modes based upon these findings, improving the experience for spectators.

The second study used the Spatial Presence Experience Scale (SPES) by Hartmann et al. (2015) to measure how "present" spectators felt within a virtual environment. The SPES was used to see whether presence felt within this environment contributed to view preference. That is, the greater the presence felt by the user in a level, the more they prefer their current view. Measuring presence in this study was influenced by Steuer (1993) who stated that the key to defining Virtual Reality is the concept of presence. By testing multiple camera views and transitions that are present in conventional media and Virtual Reality, the spectator's opinion was recorded and their presence in each view was measured. This enabled a recommendation to be made as to the most favourable method of displaying Virtual Reality content to a spectator and to gauge the opinion of current Virtual Reality spectator modes. Due to how relatively new this technology is, Virtual Reality spectator methods have not been fully investigated although

have been implemented. An example of such is the DOTA 2 (Valve, 2013) spectator program, summarised by The Verge (2016).

This thesis follows the chronology of processes used by the two investigations and aims to justify them as relevant to the research community. Firstly, the literature relevant to the first study looks at the current state of Virtual Reality, including a brief history of the technology. It also explores the associated health risks as well as previous work into the effect of head mounted displays on head movement. The literature then presents previous work related to the second study by reviewing current Virtual Reality spectator experiences within games and other Virtual Reality platforms. Current spectator methods within conventional media such as film, television and current video games are also reviewed as these methods could provide guidance to future Virtual Reality spectator views. Each study is then looked at in-depth regarding its design, methods, implementation, results, discussion and conclusions.

## **Chapter 2 - Literature Review**

### ***Existing Virtual Reality Spectator Modes***

The second study aimed to present and test various spectator views within Virtual Reality. Therefore, it was necessary to explore what type of games and platforms were available at the time to either base the study upon, or influence the design of the study platform. However, as the emergence of Virtual Reality games is a recent development, there is a lack of these games that include spectator modes. However, one of the most predominant modes that exists presently is the DOTA 2 (Valve, 2016) Spectator Experience. Valve describes it as a set of experiences that let you enjoy the world of DOTA (Defence of the Ancients) inside Virtual Reality, enabling you to watch live matches, replays and streams in a Virtual Reality theatre with up to 15 people. It also allows spectators to jump into the world itself to view the action life-sized and browse through DOTA's wide array of heroes to see all of them in full scale. An example of this spectator mode has been filmed by Polygon (2016). Another spectator mode that has been implemented, albeit with the intention of viewing the footage outside of Virtual Reality is Job Simulator by Owlchemy Labs (2016). This mode allows the player within the virtual environment to place a camera within their level which lets spectators view gameplay from multiple angles. Furthermore, Battlerite by Stunlock Studios (2016), features a natively implemented Virtual Reality spectator mode where viewers navigate around the map as the game is being played. It also allows viewers to direct their own coverage of matches too, by moving the in-game camera using virtual reality controllers.

Cameras which allow real world filming to be implemented within virtual reality have also become more widespread, with social media platforms such as Facebook and YouTube allowing the upload of 360-degree videos and images that can be viewed inside or outside Virtual Reality. Known as immersive or spherical videos, 360-degree videos are recording using either multiple cameras or an omnidirectional camera recording in each direction. This footage can then be stitched together to create the illusion of being within a picture or video. Virtual Desktop (Guy Godin, 2016) is one of several applications that have been designed to display 360-degree media. It allows users to render their desktop view within Virtual Reality and use their headset as an additional computer monitor. It also allows users to stream and play 360-degree videos from their own files or those which have been uploaded to an online media platform.

Outside of game implementations, there are other methods that have been, or will be implemented to allow conventional video games to be viewed within Virtual Reality. JauntVR (2015) uses multiple 360-degree cameras to place the viewer within the crowd at various esports events. UploadVR (2015) noted that JauntVR intends to capture at least three different angles, with one camera behind each team and another placed at the front of the stage overlooking the audience. While Jaunt intends to focus on the core experience initially, they may experiment with some graphical elements such as statistic boards or overlays. Outside of Virtual Reality games, companies such as NextVR (2016) have utilised 360-degree cameras and placed them at various real world events allowing viewers using Virtual Reality to experience being within the crowd.

### ***Conventional Spectator Modes***

Looking at conventional spectator methods provided a different perspective of consuming media and helped to broaden the potential spectator views that were considered to implement within virtual reality for use in the second study. Heiderich (2016) stated that cinematography is the art of visual storytelling, controlling what the viewer sees and how the image of a scene is presented. Mascelli (1998) defined the “Five C’s of Cinematography”; camera angles, continuity, cutting, close-up and composition whereby each component is essential to the success of the spectator experience. Chandler (2001) elaborated on these factors by stating that television and film often use common conventions referred to as the “grammar” for conveying meaning through camera techniques. Although, these conventions are often broken for deliberate effect. Regarding the distances used in camera views, Chandler notes that there are four. The long shot, which shows all or most of a large subject and usually much of the surroundings. The establishing shot, which is used to set the scene and is often a variation of the long shot called the “Extreme long shot” where the camera is at its furthest away from the subject, emphasising

the background. The medium shot, where the subject or actor and its setting occupy roughly equal areas in the frame. Finally, the close-up shot which shows the subject in detail so that it fills up the screen.

Chandler (2001) provided examples of camera angles in film and television which are used. For example, a high angle, where the camera looks down upon the character, is used to make the viewer feel more powerful, suggesting an air of detachment. In contrast, a low angle shot, where the camera is placed below the character, exaggerates the importance of that character. A point of view shot is made from a camera position at the line of sight of the performer who is to be watching the action shown. Additionally, wide-angle shots are used to give a broad field of view within the scene using a wide angled lens. In terms of camera movement, traditional filming techniques include zoom, whereby the camera does not move, but focuses from a long shot to a close-up while the subject is still being shown and therefore magnified upon completion of the transition. This transition can also be reversed whereby the opposite effect is achieved. A following pan and “Dollying” are two additional camera movements that are used to track a subject. The following pan involves the camera swivelling to follow a moving subject whilst remaining in the same position. Dollying tracks the position of the subject just as the following pan but involves the camera itself being moved towards or away from its subject.

Tomlinson et al (2000) stated that most movies adhere to the same basic conventions about shot choice, sequence assembly, scene construction and lighting. Examples of these conventions include looking over the shoulder of a character to see what it is seeing, placing a moving character in the frame such that it is moving toward the centre of the screen and choosing a shot of a character’s face to show that character’s emotion. Chowdhury (2016) discusses the subject of broadcasting live sports events, where the camera angles and viewing methods must change based upon the type of sport that are being viewed. For example, American Football games are viewed using a wide-angle camera to view a large section of the pitch, Basketball has the width of the court within the entire shot, panning as the players move around the court. Finally, Volleyball is viewed with a single camera view, which displays the entire court in an elevated, wide-angle view.

Tomlinson et al (2000) also noted that the difference between conventional media and interactive media such as games is that the visual experience is different every time it is viewed. Video games by nature are spectated when they are being played, using multiple camera angles

to increase immersion or to provide a static view of the world. In terms of spectating of games through a defined spectator mode, examples being those included in Starcraft 2 (Blizzard, 2010) or League of Legends (Riot Games, 2009) the spectator methods often provide a different viewing experience compared to those playing the game. For example, the Starcraft 2 spectator mode provides information to those spectating that would be considered cheating if the player had access to the same information. Spectators can display overlays which show how many combat units each player has, resources collected, position on the map and buildings in each base. This altered view is similar to the League of Legends spectator view, where the spectator of the game views the same camera angle as those playing the game, but has access to more information, such as the position of enemy players and the gold collected. If this information was known by every player, it would diminish the competitiveness of the game. The spectators also have the option to switch between players in the game, letting them view actions of each player independently.

### ***Previous Virtual Reality Spectator Work***

Although few studies have been completed into spectating Virtual Reality games specifically, looking at what has been investigated allowed the second study to be targeted where new knowledge could benefit the research community most. It is worth noting that Amerson and Kime (2000) proposed a system called FILM (Film, Idiom, Language and Model) that aimed to create an interactive narrative experience within three dimensional virtual worlds. The FILM uses common cinematographic techniques to construct camera placements based on input from a narrative planner. Information about common film idioms were encoded within a scene tree using the created FILM programming language. These encoded objects were used in conjunction with the narrative planner inputs to constrain the location and orientation of the camera for viewing an action at execution time. Similarly, Cavazza et al. (2010) presented a prototype of a real-time cinematic control for interactive storytelling, whereby a virtual director chose camera views within the three-dimensional world based upon the specification of the current event occurring within the scene. Examples such as the type of event, number of scene participants and story context were all used by the virtual director to choose the correct cinematic idiom. These methods could potentially be utilised within a video game spectating context, where the view of the game is automatically curated by tools such as these to display the most interesting segments of the game.

Another spectator method involves the projection of Virtual Reality using methods such as the CAVE developed by Cruz-Neira et al. (1993). The CAVE surrounds viewers with video projection

displays, in combination with head tracking and stereoscopy. This allows multiple people to share a virtual reality experience without the need to wear a head mounted display. Czernuszenko et al (1998) described the CAVE as a multi-person 900 cubic foot theatre, with images projected on the walls which are screens and projected down onto the floor. Four projectors, one for each screen, are connected to separate or split graphics pipes in one or more high end workstations. In its current configuration, 1024 x 768 resolution stereoscopic images are displayed on each screen at 96Hz and viewers wear shutter glasses to view the images. One user's head is tracked with a six degree of freedom tracking system, and images are generated from that user's viewpoint. Additionally, a tracked "Wand" is used containing three buttons and a small, pressure-sensitive joystick that viewers can use to control CAVE applications. The CAVE produces a large angle of view, panorama and stereo high-resolution head-tracked images in an environment where five to ten people can share the experience.

Czernuszenko et al (1998) presented two other projection based virtual reality displays, the ImmersaDesk and the Infinity Wall. The ImmersaDesk, developed in 1994 is a drafting table Virtual Reality display. It features a 67 x 50-inch rear-projected screen at a 45-degree angle. Up to five users wear shutter glasses to view high resolution, stereoscopic, head-tracked images. The ImmersaDesk screen fills most of a user's field of view, and at the same time enables the user to look forward and down. One user's head is tracked, allowing an accurate perspective to be generated. A tracked wand is also used, so that the user can interact with the environment. The Infinity wall is an extension of the PowerWall designed by the University of Minnesota and is designed for a larger audience group featuring larger screens compared to the CAVE. Although it sacrifices panoramic view for increased screen resolution, the Infinity Wall features a stereoscopic display and six degrees of freedom tracking, with users wearing shutter glasses as used in the CAVE and ImmersaDesk projectors.

### ***Presence and Virtual Reality***

Steuer (1993) stated that the key to defining Virtual Reality in terms of human experience rather than hardware is the concept of presence, defined as the sense of being in an environment. Furthermore, it refers to the experience of natural surroundings. That is, surroundings in which sensory input impinges directly upon the organs of sense. This link between presence and Virtual Reality influenced the question asked in the second study of if these two subjects are statistically linked. Whereby the level of presence felt effected the positive or negative experience when in a virtual environment. If a link was found, future implementations of virtual reality spectator modes could put more emphasis on increasing the level of presence felt by the

spectator, improving their overall experience and making virtual reality spectating a more compelling choice over conventional methods.

Presence was defined by Barfield and Weghorst (1993) as the sensation of non-mediation while experiencing a mediated environment. In other words, media experiences such as Virtual Reality can be so absorbing and compelling that the observer loses sense of his or her physical surroundings and responds physically and emotionally in a way that is analogous to being in the mediated place. Additionally, Gibson (1966) stated that many perceptual factors contribute to generating presence, including input from some or all sensory channels, as well as more mindful, attentional, perceptual and other mental processes that assimilate incoming sensory data with current concerns and past experiences.

This is elaborated by Loomis (1992) who added that presence is closely related to the phenomenon of distal attribution or externalisation, which refer to the referencing of our perceptions to an external space beyond the limits of sensory organs themselves. Presence has also been subdivided further by researchers who have coined the term “Telepresence”, defined by Michitaka (1998) as the sense of being in some remote location represented by the medium and “Social Presence” defined by Zhao (2003) as the sensation of being with and interacting with someone in another place.

Burdea and Coiffet (2003) linked virtual reality and presence by stating that the hardware and software used to create a Virtual Reality system are designed to replicate the information available to the sensory and perceptual system in the physical world. In other words, a computer and its peripheral devices produce outputs that impinge on the body’s various senses, resulting in convincing illusions for each of these senses, inducing a sense of presence. Furthermore, Bohil et al (2009) states that the more one can provide the human sensory system with sensory inputs that simulate and effectively mimic those encountered in nature, the more convincing the resulting perceptual and cognitive experience will be for the user. Bohil et al. (2009) continued by saying that the most compelling virtual reality environments are implementations that envelop the user in a virtual world, surrounding the user with stereoscopic visual imagery and sound, tracking body motion, and responding to behaviour in the environment. Biocca (1996) stated that the goal of Virtual Reality environments is a computer-generated simulation that is indistinguishable to the user from its real-world equivalent.



Van Baren and Ijsselstein (2004) found that post-test questionnaires are the most frequently used measure of presence and that many different questionnaires have been developed. Furthermore, the questionnaires vary widely in scope and appearance, depending on the author's conceptualisation of presence and their context of application. Some studies have used only one general item addressing presence, while others have tried to develop questionnaires reflecting the presumed multidimensional structure of presence of others. Lessiter et al. (2001) defined a criterion for presence questionnaires; Understanding of presence should not be assumed by asking how present participants feel, questions should avoid addressing two issues in one question, response options should ideally be consistent across items, questions should not make reference to specific media system and content properties, measures should be piloted on participants of a range of media systems/contents and questionnaires should be piloted with a sufficient number of subjects.

### ***Health concerns of Virtual Reality***

As virtual reality spectating of video games continues to increase, investigating the potential health issues that could arise from extended periods of time wearing a virtual reality headset was beneficial in informing the decision of which area to specifically target when creating the first study. One of the main discussions regarding the health effects of Virtual Reality is motion sickness. It is defined by Tyler and Bard (1949) as a specific disorder which is evoked in susceptible individuals after being subjected to movements that have certain characteristics. Kennedy and Frank (1985) elaborate by stating that motion sickness is a general term for abrupt, periodic or unnatural accelerations. Oman (1990) defines it as a general term describing a group of common nausea syndromes originally attributed to overstimulation of the vestibular organs of the inner ear. For example, you can get motion sickness when travelling by car because your eyes tell your brain that you're travelling at more than 30 miles per hour, but your vestibular system tells your brain you're sitting still (NHS, 2016).

Motion Sickness within a Virtual Reality context has been discussed as "Cybersickness" by Laviola Jr (2000) who states that it is distinct from motion sickness in that the user is often stationary, but has a compelling sense of self motion through moving visual imagery. Laviola Jr also notes that the effects of Cybersickness are like motion sickness in that the user can experience symptoms that include eye strain, headache, pallor, sweating, dryness of mouth, fullness of stomach, disorientation, vertigo, ataxia and vomiting. As with motion sickness, vestibular stimulation alone can be sufficient to induce motion sickness (Money, 1970) although vision can also be a contributing factor (Kennedy et al, 1988). However, Cybersickness can occur

with visual stimulation and no vestibular stimulation. Kellog (1980) suggests that Cybersickness can also develop in the hours following Virtual Reality usage and can linger for hours and in some extreme cases, for days (Gower, 1989).

Laviola Jr (2000) states that there are three main theories as to the cause of Cybersickness. The Sensory Conflict Theory, the Poison Theory and the Postural Instability Theory. The Sensory Conflict Theory is the most widely accepted view as to the cause of Cybersickness (Reason and Brand, 1975). The theory is based on the premise that discrepancies between the senses that provide information about the body's orientation and motion cause a perpetual conflict which the body does not know how to handle. The Poison theory, discussed by Treisman (1977) is an attempt to explain why motion sickness and cybersickness occur from an evolutionary standpoint. The theory suggests that the ingestion of poison causes physiological effects involving the coordination of the visual, vestibular and other sensory input systems. The adverse stimulation found in some virtual environments can affect the visual and vestibular system in such a way that the body misreads the information and thinks it has ingested a toxic substance, causing an emetic response. Finally, the Postural Instability Theory, developed by Riccio and Stoffregen (1991) is centred on the idea that one of the primary behavioural goals in humans is to maintain postural stability. Postural Stability is defined as the state in which uncontrolled movements of the perception and action systems are minimised.

As well as the theories outlined above, there are other technological issues that attribute themselves to inducing Cybersickness. For example, Pausch et al. (1992) stated that lag provides the user of Virtual Reality with an unsettling delay that can cause Cybersickness, where the user must wait for images to appear where they are expected to be. Lag was defined by Pausch et al. as the time between a user initiating an action and the action occurring. Biocca (1992) found that errors in the position tracking of users within a virtual environment has the potential to result in symptoms relating to Cybersickness such as dizziness and lack of concentration. Furthermore, Harwood and Foley (1987) stated that flicker, the perception of the user to the refresh rate of a screen, has been shown as a contributing factor in inducing Cybersickness symptoms. Pausch et al. added that the perception of flicker differs between individuals and depends on their flicker frequency threshold, the point at which flicker becomes visually perceptible. Laviola Jr (2000) stated that a refresh rate of 30Hz is usually good enough to remove perceived flicker. McCauley and Sharkey (1992) also noted that sickness frequency depends on the type of visuals within the Virtual Reality application. These visuals were categorised as

“Near” in which the user is stationary and all objects are within the user’s proximity and the absence of Vection (illusory self-motion) and “Far” which involve distant objects, self-motion through the application and Vection. It is in these applications that vestibular input does not correspond to the visual display. McCauley and Sharkey noted that “Far” applications were more likely to cause Cybersickness.

Additionally, there have been findings regarding factors that affect susceptibility to Cybersickness, irrespective of the type of Virtual Reality method they are using. Biocca (1992) found that women appear to be more susceptible to Cybersickness than men. One of the reasons is that women have a wider field of view. Kolasinski (1995) noted that a wider field of view increases flicker perception which was previously found as a contributing factor to Cybersickness by Pausch et al (1992). Reason and Brand (1975) found that age also plays a factor in the susceptibility to Cybersickness. They stated that susceptibility is greatest between the ages of 2 and 12 years and decreases rapidly from the ages of 12 to 21. They also claimed that around 50 years of age, susceptibility is almost non-existent. Furthermore, Stone (1993) found that eye strain is a common effect of exposure to virtual environments and is more common in children under twelve as their binocular vision is not fully developed. Illness is another factor that increases susceptibility to cybersickness. Frank et al. (1984) stated that in addition to illness, those who are suffering from fatigue, sleep loss, hangover, upset stomach, stress, head colds, flu, ear infection or respiratory illness should avoid virtual environment simulations.

The position of a user when interacting with a virtual environment also plays a role in their susceptibility to Cybersickness. Riccio et al (1993) found that sitting down appears to be a better position than standing up when it comes to reducing Cybersickness. Furthermore, the postural instability theory suggests that by sitting down, the demands on postural control are reduced. Reason and Brand (1975) added that there is a significant reduction in motion sickness symptoms when an individual adopts a supine position. They attributed this to the restricted motion of the head.

Elaborating upon posture when using Virtual Reality headset, Costello (1997) noted that those wearing older headsets were observed propping up the weight of the headset with one hand and interacting with the environment with the other. Di Zio and Lackner (1992) consider the role of headsets in motion sickness experiences, noting that the gravitational force that effects the inner ear also determines the effective weight on the head. Their experiment showed that

wearing a 600g weight on the head increased the susceptibility of motion sickness. Costello also reported that the long-term effect of this unnatural posture was difficult to quantify, but discomfort was often reported when using heavy Virtual Reality headsets. Although this issue will become less significant as headsets become lighter, it is important to realise that the weight of the headset does influence the posture of its user. So (1994) suggested that additional strain could be placed on the neck if the user remains relatively still and that potential issues could be exasperated by poorly fitting and poorly balanced headsets. Ultimately, this issue will cease to be a major drawback of Virtual Reality headsets.

Knight and Baber (2007) stated that weight has a limited, detailed and direct attention regarding head mounted displays. Furthermore, wearing a head mounted display can force wearers to modify their neck posture. As such, the musculoskeletal system may be placed under increased levels of stress. Head mounted displays could dictate modifications in neck posture, which may have a detrimental effect and compound the weight effect of the headset. The results of Knight and Baber's study found that an unloaded head result in no signs of musculoskeletal fatigue after 10 mins, whereas signs of fatigue can be induced after 4 minutes with a load of 0.5 kg attached to the front of the head, and after two minutes with a load of 2kg. Additionally, Abeysekera and Shahnavaz (1988) found that headsets with a weight between 350g and 1450g have a significant effect on the neck of users. In a separate study, Knight and Baber (2004) found that increased neck muscle activity and perceived pain attributable to increased head load was compounded when the neck was flexed and rotated. They concluded that the use of head mounted display presents a risk of detrimental effects to musculoskeletal system and that determining the effect of the added weight to the head required a knowledge of working postures.

Gupta (1996) and Viirre (1994) stated that there is a risk of injury whilst using a head mounted display. Viirre noted that when a user is wearing a head mounted display, they are functionally blind in the real world. This can lead to collision with real world objects or headset cabling. Even if the user has some external vision, the immersive scene may distract attention from the outside world. Both Gupta and Viirre suggest that users be kept within a "safe zone" to minimize injury risk. Additionally, repetitive strain injuries (RSI) are another area of concern. Howarth (1994) argued that head movement within virtual environments be kept as natural as possible to alleviate any potential RSI. Howarth also suggests that interaction techniques that require continual repetitive movement be kept to a minimum, as it would be for a real-world task.

### ***Head Tracking Studies***

After looking at the health concerns of Virtual Reality, the first study was focused on how the headsets effect head movement. Therefore, investigating previous studies on the subject helped to influence its design. McKnight (1995) found that a reduced field of view within a motorcycle helmet resulted in an increase in head movement. Additionally, Venturino (1990) concluded that the smaller the field of view, the greater the displacement and risk of injury. Reduced field of view and head movement is relevant to Virtual Reality headsets as the natural field of view of humans is close to 180 degrees whereas both the Oculus Rift and HTC Vive provide 110 degrees of view (Digital Trends, 2016). The increased movement, in addition to the potential head displacement, corresponds with Knight and Baber (2004) who stated that headsets increased neck muscle activity. Furthermore, the weight of both the Oculus Rift (470g) and HTC Vive (555g) are above the threshold of 350g recorded by Abeysekera and Shahnavaz (1988) where weight of a head mounted display could have a significant effect on the neck.

So (2000) found that most investigations into head tracking have used symmetrically shaped targets. For example, Sirachi et al (1978), Wells and Griffin (1987) and So and Griffin (1996) all used circles in tasks implemented within their studies. Additionally, both So (2000) and Gerhart (1991) stated that the use of predictor displays and previews of future target positions improved manual tracking performance and significantly reduce head tracking errors. So (2000) stated that to provide a direction cue to a circular target moving along a predetermined path, future target positions should be shown in advance in the form of a trace. The length of the trace is determined by the lead time of future target positions. Furthermore, there is an absence of a significant effect of practice with the use of the look-ahead trace. This suggests that a trace provides a natural way to provide direction and movement cues. Additionally, when tracking a circular target, the use of a look-ahead trace can reduce head tracking phase lags, head tracking errors and subjective ratings of task difficulty.

Geri (2002) looked at the effect of head movement in a visual search task using night vision goggles. Geri described night vision goggles as a head mounted display which provide a restricted field of view and have other characteristics that may affect head movements used in a visual search, not unlike a Virtual Reality headset. The study measured head scan patterns in two dimensions (Pitch and Yaw), as participants searched for a target image on a high and low resolution background. The results of this study suggested that the night vision goggles did not significantly affect any of the individual head movement variables. However, Geri did note that

although the results were not statistically significant, both head-scan speed and amplitude were higher when wearing night vision goggles compared to not wearing goggles.

LoPresti (2003) analysed head movements in the context of two computer exercises, an icon selection task and a tracking task using a head mounted display. In the tracking task, a circular target would appear at the centre of the screen. The target would begin to move in one of eight directions, with the participant instructed to track the target circle as close as possible. Once the target had reached the end of its path, it would disappear and a new target would appear in the centre of the screen. Each target moved from the centre to an edge of the screen. The selection task involved a circle that would appear at the centre of the screen. Once the participant's gaze remained at the circle for a short period, the circle would appear elsewhere on the screen, with the user moving their head to that position. Within the virtual environment of these tasks, the participant was sat in a large wire mesh sphere. DeFrate (1999) found this display method helps participants perform standardised movement patterns, therefore assisting in a standardised measure of head movement.

### ***History of Virtual Reality***

To fully embrace the topic of this thesis, it was important to first investigate where Virtual Reality started from and how it has evolved from its early iterations as an “experience” and its transition into a video gaming platform. This section looks at the major progressions within virtual reality from its creation to the headsets of today.

Virtual Reality was defined by Greenbaum (1992) as “An alternate world filled with computer generated images that respond to human movements”. Additionally, Steuer (1993) stated that it is a collection of technological hardware including computers, head-mounted displays, headphones and motion sensing gloves. However, today's headsets do not include motion sensing gloves but a physical controller such as that included with the HTC Vive (HTC and Valve, 2016). Steuer (1993) noted that previous definitions refer to specific technological systems, meaning the application of these definitions is limited to those technologies. This statement is enforced by previous definitions of Virtual Reality which mention the hardware used in various systems over the experience felt by its users. For example, Coates (1992) stated that Virtual Reality is the electronic simulation of environments experienced via head mounted eye goggles and wired clothing, enabling the end user to interact in realistic, three-dimensional situations. Another hardware based definition by Krueger (1991) referred to Virtual Reality as a three-dimensional reality implemented with stereo viewing goggles and reality gloves.

Steuer (1993) suggested that the key to defining Virtual Reality is in terms of human experience rather than hardware, as well as the concept of presence. Gibson (1979) described presence as the experience of one's physical environment; referring not to one's surroundings as mediated by both automatic and controlled mental processes. By employing the concept of "telepresence", which has been used to describe any medium-induced sense of presence, Steuer (1993) created a new definition of Virtual Reality as "A real or simulated environment in which a perceiver experiences telepresence". When referring to the Virtual Reality headsets today, Steuer's definition encompasses experiences the headsets provide above and beyond their hardware.

Wheatstone's (1838) research into viewing side by side images through a stereoscope, giving the perception of depth and immersion started the journey to current Virtual Reality. Morton Heilig then developed the Sensorama (Patented 1962) in 1950 which is defined as a multimodal "Experience Theatre". Kock (2009) described the Sensorama as simulating the odours of a virtual environment as well as vibrations, wind and sound. Heilig then developed the Telesphere Mask (Patented 1960), which was one of the first examples of a head-mounted display, albeit with zero motion tracking. Per its patents, the Telesphere Mask comprises of a hollow casing, a pair of optical units, a pair of television tubes, a pair of earphones and a pair of discharge nozzles, all working together so the user can comfortably see images, hear sound effects and be sensitive to the air discharge. Comparing this description to headsets available today, Heilig's 1960's creation is not too dissimilar.



**Figure 1** - *The Sensorama (Left) and the Telesphere Mask (Right) by Morton Heilig.*

In 1961, the first motion tracking head mounted display was created in 1965 by Comeau and Bryan of the Philco Corporation. Dubbed the Headsight, it was designed to remotely view dangerous situations through closed circuit television. Although this does not necessarily class as Virtual Reality, it is the first instance of viewing tracked images through a head mounted display. It also shares some of the same characteristics as current devices. Regarding these characteristics of Virtual Reality devices, Sutherland (1965) described what he envisaged as the “Ultimate Display” which pertained to the perfect Virtual Reality experience. The ultimate display would be a room within which a computer can control the existence of matter. A chair would be good enough to sit in, handcuffs displayed would be confining, and a bullet displayed would be fatal.

In 1968, Sutherland created what was referred to as the “Sword of Damocles”, which aimed to present its user with a perspective image that changed as they moved. This headset was the first to display a three-dimensional, computer generated image rather than a stereoscopic image. In 1987, the formal term “Virtual Reality” was coined by Jarion Lanier, the founder of the Visual Programming Lab (VPL). In 1989, the VPL became the first company to sell consumer Virtual Reality goggles with the Eyephone. Blanchard et al. (1990) describes the Eyephone as a head-mounted device consisting of twin LCD screens that completely cover the eyes and are offset from each other by six degrees so users get a binocular view of the virtual world. Images on the screens are updated in real-time and correspond to the movement of the user’s head. It also provides earphones that deliver three-dimensional sound to each ear. If we compare the features of the headsets mentioned so far, it would seem then that the overall design of Virtual Reality headsets had mostly been defined by the late 1980’s with influences stretching back to Heilig’s Telesphere Mask in 1960.



**Figure 2** - *The "Sword of Damocles by Sutherland (1968)"*





**Figure 3** - The "Eyphone" by VPL (1989)

Virtual Reality headsets were released in the 1990's with Sega announcing a headset for their "Genesis" console in 1993 and Nintendo releasing the "Virtual Boy" in 1995. However, these headsets were plagued with performance issues and were cancelled and discontinued by their manufactures respectively. In 2013, Oculus released the first development kit of its "Rift" Virtual Reality headset. After multiple iterations, the first consumer version was released in 2016 along with the HTC Vive by HTC and Valve. The consumer Rift features a design similar to the Eyphone by VPL. However, with a OLED display, 2160 x 1200 resolution and a 90Hz refresh rate, it goes far beyond previous Virtual Reality headsets (Digital Trends, 2016). The HTC Vive features the same specifications as the Rift but also includes 15 x 15 feet tracking area which allows its users to walk around a virtual environment when wearing the headset. It also provides motion tracked controllers to interact with the virtual world. Oculus plans to release motion tracked controllers in late 2016.



**Figure 4** - Sega Genesis headset (Left) (Sega, 1990) and the Virtual Boy (Right) (Nintendo, 1993)

Finally, the technology of Virtual Reality has expanded beyond that of headsets attached to computers and have been implemented within mobile phones. Through the usage of a headset peripheral, users can attach their phone in front of their eyes and experience wireless Virtual Reality.

### ***Literature Summary***

This literature review looked at many topics concerning virtual reality, it looked at the history of virtual reality from its inception through to today's advanced headsets to provide a broad overview of how far this technology has advanced and how it has migrated from use as an experience to a video game platform. The health concerns of virtual reality were also looked at to provide direction to the studies presented in this thesis. Without an understanding of the potential effect of the virtual reality headsets on head movement for the first study and how motion sickness is caused and prevented for the second study, the quality of both studies would be diminished. Additionally, previous work into existing virtual reality spectator modes and head tracking studies were also investigated and helped to influence the direction of the studies within this thesis. By looking at what had already been done, the studies could adapt previous work and target new areas of the subject matter, with the aim of providing better understanding of virtual reality spectating and head movement.

Conventional spectator modes were also looked at in the same manner with the aim of trying to see what spectator methods are currently used and if they could be adapted into a virtual reality format. Furthermore, current virtual reality spectator modes were looked at for inspiration for the second study to find successful views that could be implemented or adapted and to investigate the methods that made these current views so successful. Finally, an investigation into how presence influenced virtual reality experience was looked to provide a background for the second study whereby the link between the level of presence felt by spectators and their preferred spectator view was investigated.

### **Chapter 3 – Study 1**

The first study was influenced by previous studies used to investigate the effect of head mounted displays on head movement and apply those methods to a current Virtual Reality headset as well as to provide developers with current information on how conventional head movement when spectating video games is affected by wearing a Virtual Reality Headset. Using an application created in the Unity game engine (Unity, 2016), the purpose of this study was to provide up to date information on the effects of a Virtual Reality headset on head movement. It

also aimed to provide an open source, standardised application that could be used again with other Virtual Reality headsets. Furthermore, this study resulted in the creation of a tailored data analysis script which enabled the automated generation of test results. Both the test and analysis applications including results and graphs can be found in the “Study 1” folder on the memory stick provided with this document.

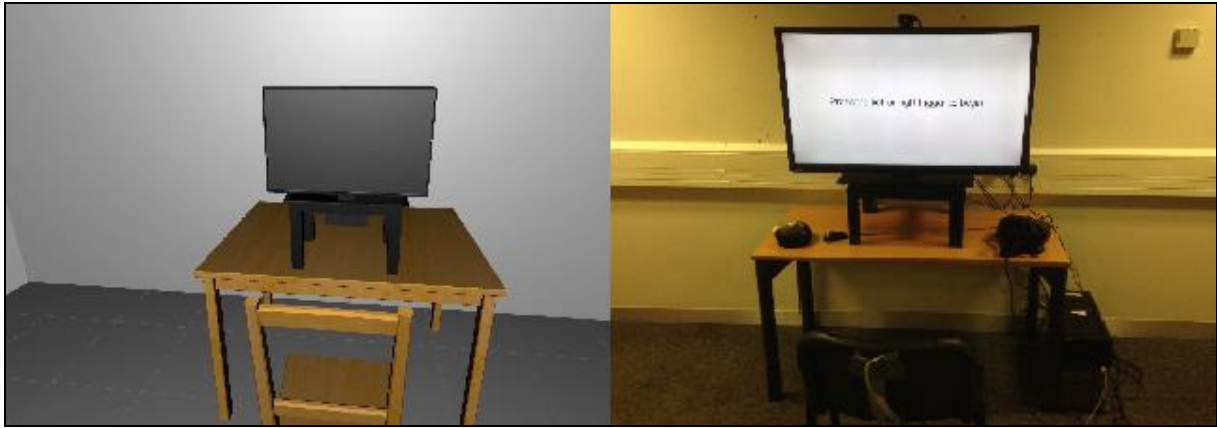
### ***Hypothesis***

It was hypothesised that under the Virtual Reality condition, acceleration of the head would be slower than in the Non-Virtual Reality condition due to the additional weight of the Virtual Reality headset. This hypothesis was based on findings by Regan (1993) who stated that users who had worn virtual reality headsets in the past moved their heads cautiously. Although, these findings were contradicted by Geri (2002) who found no significant effect of head mounted displays on head movement. However, the addition of the virtual environment could affect head movement more than the night vision goggles used by Geri.

### ***Methods***

#### **Conditions**

This study had three conditions which were used to measure the effect of an Oculus Rift Development Kit 2 (DK2) (Oculus, 2015) Virtual Reality headset on head movement. The first condition was classed as “Non-Virtual Reality” (NVR) where the participant viewed the chosen head movement tasks outside the virtual environment. The second condition was called “Non-Virtual Reality Weighted” in which the same tasks as NVR were completed but participants were asked to wear a weighted headset of 440g, the same weight as the DK2. This condition would allow a comparison of head movement outside and inside a virtual environment to see if the weight of the headset contributed to a difference in head movement. The third condition was called “Virtual Reality” (VR), in this condition the real-world setting of the experiment was replicated in a virtual environment so the location and tasks remained as consistent as possible. Participants completed the same tasks as in the other two conditions. Figure 1 shows a comparison between the real-world and virtual iterations of the experiment location.



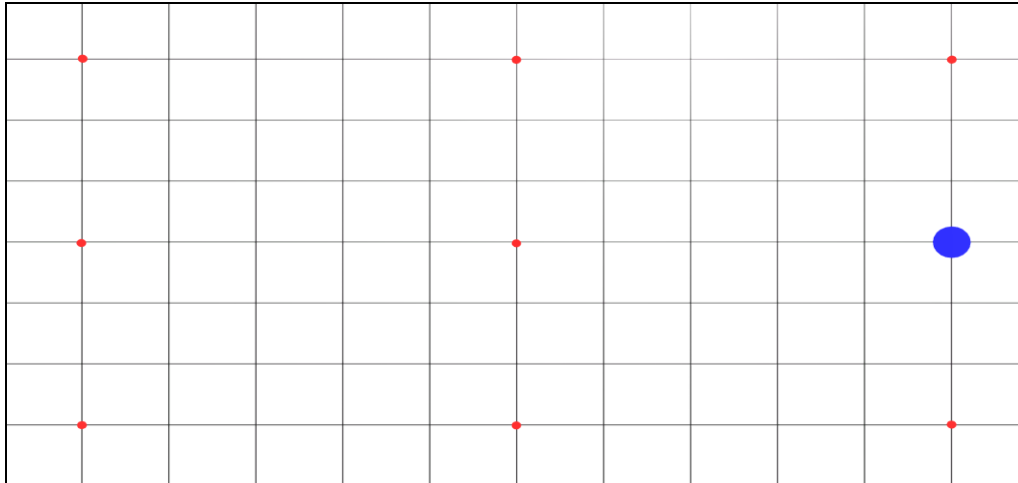
**Figure 5** – *Virtual and Real-World versions of the test environment.*

### Tests Used

This study adapted three methods used by Geri (2002) and LoPresti (2003) to evoke head movement from participants, each study from LoPresti was set on a wire mesh which was shown to aid uniform head movement by DeFrate (1999). Figure 2 displays the first task modelled from the method used by Geri. For this task, the participant searched for a target which became visible over time on a high-resolution background. The target position was randomised to prevent any practice effect as participants had to complete the test for each condition. The random target position allowed for the collection of scanning head movements while participants searched for the target. The second test, shown in Figure 3, is adapted from a task by LoPresti. A circle moved slowly to eight different positions on the screen, up and down, left and right and each diagonal location. This test aimed to evoke slow, deliberate head movements. Finally, the third test was also adapted from LoPresti with the same construction of task two but the target circle jumped instantly to each position to provoke accelerated head movements.



**Figure 6** - *Adaptation of Geri (2002).*



**Figure 7** – Adaptation of LoPresti (2003) for use in task 2 and 3.

### **Data Collection and Analysis**

To collect the data, an Adafruit BNO055 accelerometer (Adafruit, 2016) was attached to a running cap which was worn by participants (Figure 4). The accelerometer recorded the Heading, Roll and Pitch of head movements and was attached to the PC running the test application via a USB cable. Furthermore, the test application also recorded the duration of each task as well as the start time. The data was written to a .csv file for each participant in addition to the update time for each recording. This is specified as every 0.02 seconds due to the speed of the Unity game engine update tick. Data was only recorded to the .csv file when a task had started and stopped recording when the task had finished, ensuring only necessary data was collected. All data was zero normalised and each recording was manually added to nine new .csv files, one for each condition and task combination.



**Figure 8** - Running cap and Accelerometer.

The nine .csv files were loaded into an R script created specifically to work with the structure and types of data collected for the study. The script interpolated each recording to remove duplicate readings so that changes in head movement were easier to observe. Using the interpolated data, the Acceleration, Velocity and Movement of each participant within each condition and task were plotted in a time series graph by the script. The data was then condensed down by the script into an RMS (Root, Mean, Square) value for each participant for each condition and task, creating nine new tables with a single value for the Heading, Roll and Pitch. These RMS tables were then used for an ANOVA analysis comparing the Acceleration, Velocity and Movement of the data from each condition and task, with that of the same type from a different condition. For example, “Non-Virtual Reality Task 1 Pitch” was tested against “Non-Virtual Reality Weighted Task 1 Pitch” to see if there was any significant variation. The ANOVA was repeated for each possible task and condition variation, with the script also producing box plot graphs to better visualise the results. The results data and graphs can be found in the “Study 1” folder on the memory stick provided with this document.

### ***Tools Used***

Several tools were used to create the study application. Firstly, a suitable Virtual Reality headset was selected. While the study was being developed, both the Oculus rift and HTC Vive consumer versions were not yet available. Furthermore, the HTC Vive development kit was unobtainable. Therefore, the Oculus Rift Development Kit 2 (DK2) was selected as it was the highest specification headset available. The Unity game engine (Unity, 2016) was chosen for the development environment as it provided a simple Virtual Reality implementation, where a level could be specified as being within Virtual Reality or not. This allowed switching between Virtual Reality and Non-Virtual Reality while the application was running, streamlining experiment experience for participants. Furthermore, the developer was familiar with C#, the native language of Unity, which reduced the overall development time and enabled faster prototyping.

To implement the weighted condition, a sweatband with rolls of electrical tape attached weighing 440g was used. This is the same as the Oculus Rift DK2. Figure 5 shows the weighted headset. Although not an elegant solution, the weighted headband was a close approximation of the weight load experienced when wearing the DK2. This is one element of the experiment that should be improved upon with a more elegant solution in future iterations. Due to budget constraints, this method was the closest and most feasible to produce that fulfilled the aim of the weighted condition.





**Figure 9** - *Weighted headset used in the first study.*

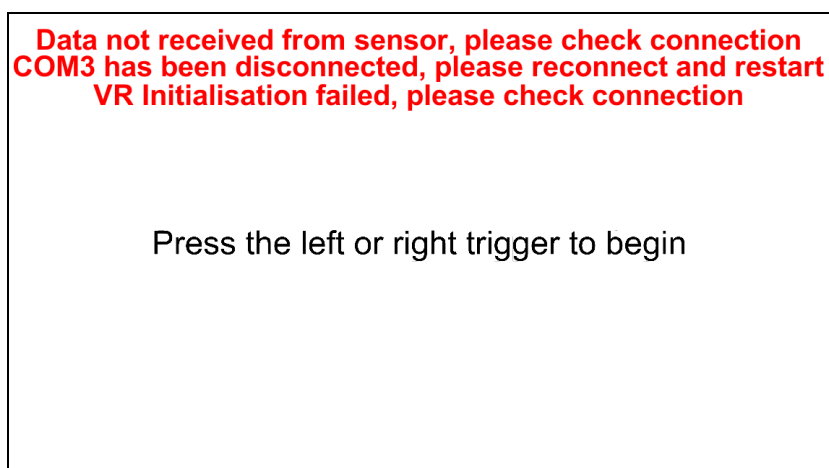
To record the axis movement of the head, an Adafruit BNO055 accelerometer (Adafruit, 2016) was used as it provides large amounts of additional data that could be investigated in future studies. For this study, the absolute orientation (Euler Vector) at 100Hz was used. While the Oculus Rift DK2 contains a built-in accelerometer, using an independent tool was preferred to maintain consistency between each condition. It also provided ability to record only necessary data and structure it within a .csv file suitable for the requirements of this study, rather than work within the confines of the DK2 data stream. However, the accelerometer is programmed in Python. This meant that a stream reader had to be coded within the C# application allowing it to start and stop the Python code used to record Heading, Roll and Pitch. By integrating the Python code of the accelerometer in the application, a single logging script that would output both the application and accelerometer data into a single file for each participant could be created, reducing the work volume. It also meant that the application could be distributed and used by others as a single software package.

For the data analysis, the R programming language along with its development environment R Studio was used. Using R allowed thousands of lines of movement data for each participant to be analysed automatically and accurately, reducing the overall workload and chance of human error due to the repetitive nature of the analysis. Using R was also preferable over other statistic suites as it was code based, meaning that the developer of the application could use their existing programming background to analyse the data instead of having to learn separate statistical software suite. It also allowed for each analysis task including the construction of graphs to be contained in a single script that could be provided alongside the study application.

This meant a complete experiment is available which can be replicated or altered by others as the source code for each aspect of the study is freely available in the “Study 1” folder.

### ***Application Overview***

The application was created in the Unity game engine and was programmed in C#. It contains the replication of three tests by Geri (2002) and LoPresti (2003) in both a two-dimensional and virtual environment. The virtual environment aimed to replicate the layout of the room the study took place in (Shown in Figure 1). The order of these conditions was randomised by the program at launch, with each task being randomised within the condition order. This meant that all conditions were completed in a row, but with a random task order. This reduced the number of times the participant would have to put on and remove the headsets. The only controls needed to interact with the application was the space bar or trigger on a PC compatible controller to begin the current task. This action was completed by the person conducting the study. Another feature added to the application was a persistent connection check for both the accelerometer and Virtual Reality headset when the application was running. This ensured that all elements of the experiment were functioning correctly before each participant. Figure 6 displays a start screen of the application with notifications stating a sensor and headset connection error. The error messages were shown in the two-dimensional and virtual environments so both the participant and experiment conductor were aware of any connection issues and can act accordingly. The error checking persisted throughout the duration of the study. If there was a connection error, the error message would display and the .csv file currently being wrote to was deleted, ensuring no incomplete data existed when the data was analysed.



**Figure 10** – Start screen of the first study application.

The .csv creation was also automated. Each time the test was started, a new .csv file was created and set as the write target for the applications logging script. The naming conventions of each



file was based upon the previous file existing in the “Participant Logs” folder. For example, if “Participant 1” existed within the folder, the next file to be created would be “Participant 2”. In addition to logging data from the accelerometer and Unity, the logging script also formatted the data in an easy to read format. Figure 7 shows an example of this format. This ensured the data was understandable when it came to manually condensing the files into one for each task and condition combination.

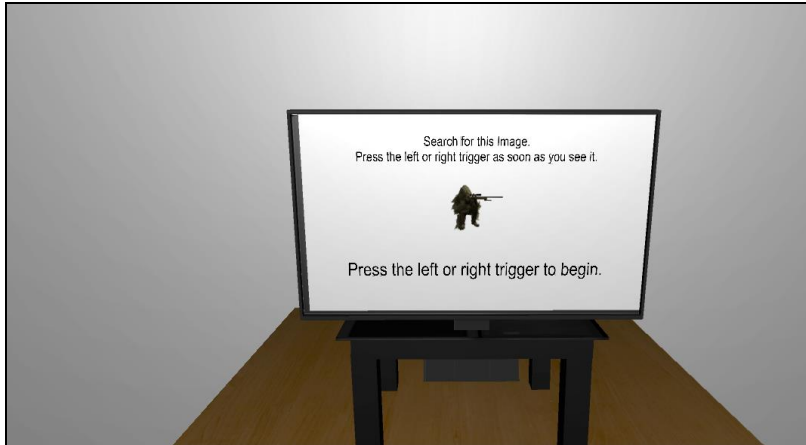
1	Participant Number:	1		
2	Test started on:	04/04/2016 13:14		
3	Current Task:	NVR Task 3		
4	Task Start:	12:16:31 PM		

**Figure 11** – An example of how each participant file was laid out.

To record head movement data from the accelerometer, a Python stream-reader was implemented in the application. The script created new Python process when the test application started and passed a text file containing the Python code including the necessary compile keys. This process then sent the accelerometer data to the logging script and checked to see if the accelerometer was connected every update tick. This script can be found in Appendix 1.

To ensure the experiment instructions were consistent, audio instructions were included between each task that instructed participants of their next action, whether that be to remove or put on a headset or how to complete the next task. Using this method reduced the reliance on a single person conducting the experiment as all the participant instructions were included within the application, with only a single button press required by whoever is conducting the experiment to start a task. The rest of the application was automated with each participant being instructed through each task

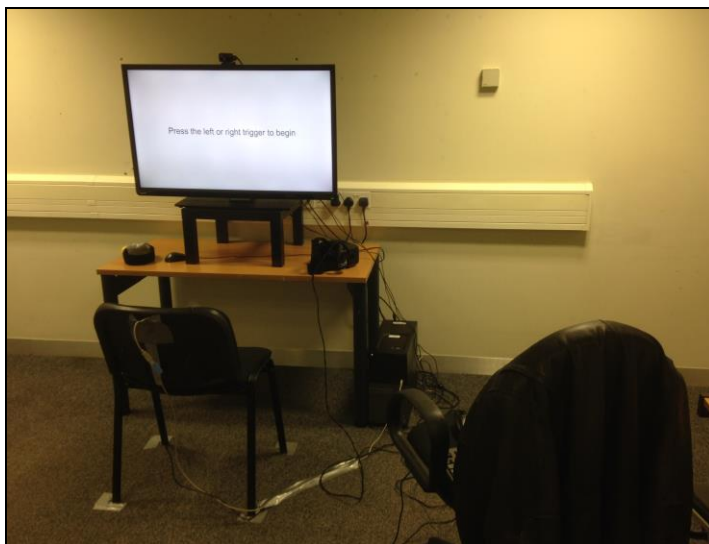
Participants were asked to complete each task outside and inside a virtual environment, requiring them to wear and remove a Virtual Reality headset. To streamline the study, both the Virtual Reality and two-dimensional tasks were implemented in the same application, enabling and disabling the Virtual Reality support depending on the test condition. When inside the virtual environment, the study continued the same as the two-dimensional environment. Each task appeared on a rendered television screen with audio and visual prompts of how to complete each task, as in the two-dimensional condition. Figure 8 displays a task instruction within the Virtual Reality condition.



**Figure 12** – Instructions for Task 1 in Virtual Reality.

### **Experiment Structure**

The study was conducted in an office containing a desk, widescreen television, chair and computer with other peripherals required for the study including the Oculus Rift headset and weighted headband (Figure 9). Before each participant, the accelerometer was calibrated by holding it stationary until the calibration error (Figure 6) disappeared. In addition to the participant setup, Figure 10 displays the chair in which the experiment coordinator was seated including a keyboard and controller that were used to begin each task. The coordinator was sat behind the participant to ensure they were not a distraction, but remained available to deal with any issues.

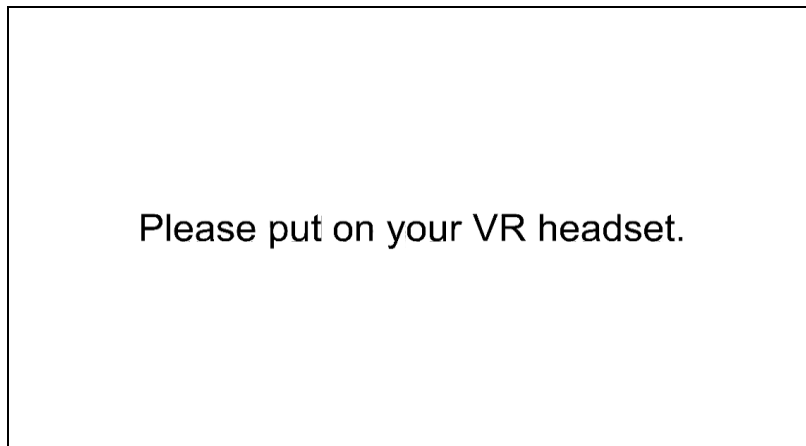


**Figure 13** – The setting and equipment of the first study.

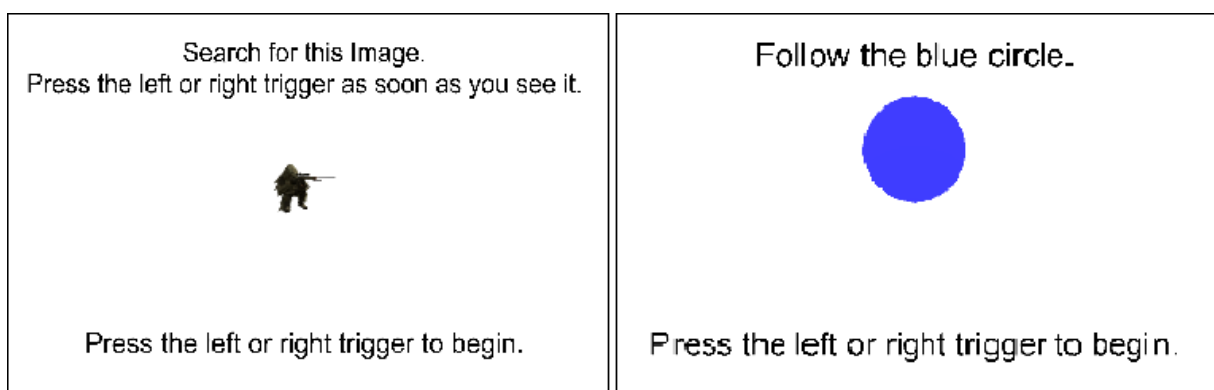


**Figure 14** – *The experiment setting including the coordinator chair.*

At the beginning of each study iteration, participants would enter the room and be asked to fill out a consent form (Appendix 2) agreeing to perform each task in the study. Participants would sit down in the chair and the coordinator would press the spacebar or trigger on a PC controller to begin the tasks. The application would then instruct them as to whether they needed to put on the weighted headset, Virtual Reality or neither (Figure 11). The application then displayed the instructions for the task. Apart from their head movement, the only other thing participants would do was to state if they were ready to begin a task after they had read the instruction screen. Figure 12 displays the instructions for each task. Task two and three have the same instruction screens. If the participant was ready, the coordinator would begin the task. Additionally, when completing searching task by Geri (2002), participants were asked to say when they had found the target image. When the image had been found, the coordinator would progress the application to its next screen. The rest of the study follows the sequence of instructing the participant of what condition and task is next until all nine task and condition combinations have been completed. The participant is then shown the end of test screen and may leave the room. The application is then restarted and the accelerometer is recalibrated ready for the next participant.



**Figure 15** – Headset instruction screen.



**Figure 16** – Instruction screens for each task.

## **Results**

### **Participants**

21 people took part in the study. No gender or age information was recorded as it was not relevant to this initial study. However, participants were asked to confirm they were over the age of 18 to conform with ethics protocol. In future iterations, gender and age could be investigated in addition to head movement. Previous findings by Biocca (1992) stated that females are more susceptible to cyber sickness and Reason and Brand (1975) stated that age effects the likelihood of cybersickness. Therefore, the head movements of different genders and ages may affect their susceptibility to cybersickness and could be measured using this study.

### **ANOVA Findings**

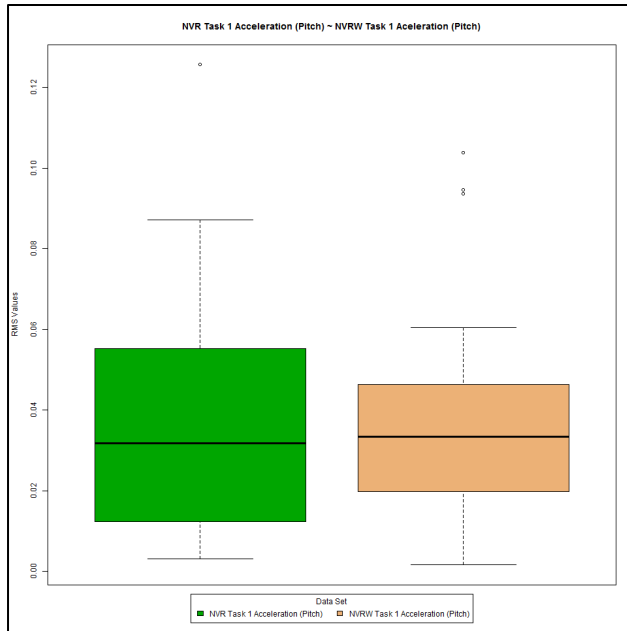
As this study required many ANOVA tests, and provided a large number of results, this section has been broken up into different parts that discuss the significant findings within head

acceleration, velocity and movement. The non-significant ANOVA results as well as box plots of the results can be found in the “Study 1” on the provided memory stick.

#### *Acceleration*

There was some significant difference in head movement acceleration between Non-Virtual Reality and Non-Virtual Reality Weighted conditions in task one and three, with the Pitch movement being significant in task one and Heading and Pitch being significant in task 3 (Figures 24 and 25). Task two had a significant difference in Heading acceleration between Non-Virtual Reality Weighted and Virtual Reality conditions. Task 3 also had a significant difference between Non-Virtual Reality and Virtual Reality conditions in Roll acceleration. The Heading acceleration had no significance across tasks, with Non-Virtual Reality Weighted and Virtual Reality having a significant difference in task 2 (Figure 26). The Heading difference between Non-Virtual Reality and Non-Virtual Reality Weighted conditions were significant in task 3 (Figure 27).

There was no significant difference in heading for task one. Roll was the only significant recording in task three between Non-Virtual Reality and Virtual Reality conditions (Figure 28). However, Pitch was significant between Non-Virtual Reality and Non-Virtual Reality Weighted conditions in task one and task three. Pitch appears to maintain its significance between tasks. Although not significant in task two, the  $Pr(>F)$  value was 0.2 which could point to a close to significant relationship between conditions.



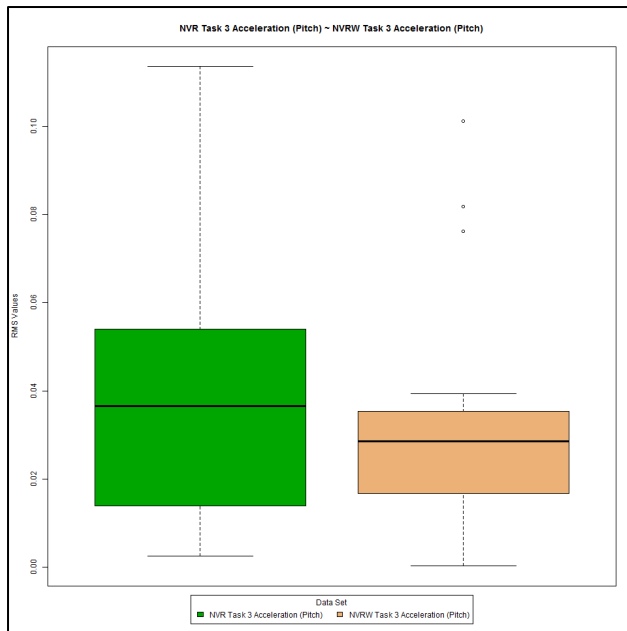
```
[1] "NVR Task 1 Acceleration (Pitch) ~ NVRW Task 1 Acceleration
(Pitch)"
```

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Task1Dataset_NVRW	1	0.003991	0.003991	4.538	0.0464 *
Residuals	19	0.016713	0.000880		

```
---
```

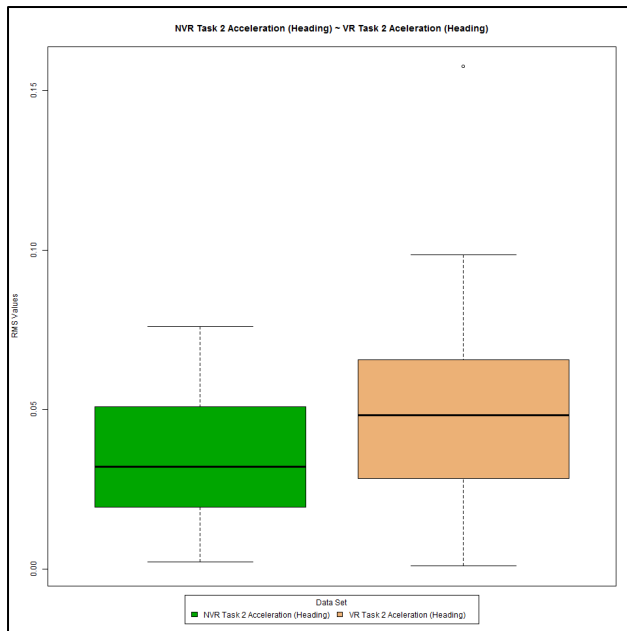
```
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 17** – Significant difference between Non-Virtual Reality Task 1 Pitch and Non-Virtual Reality Weighted Task 1 Pitch.



```
[1] "NVR Task 3 Acceleration (Pitch) ~ NVRW Task 3 Acceleration
(Pitch) "
      Df Sum Sq Mean Sq F value Pr(>F)
Task3Dataset_NVRW  1 0.004159  0.004159    4.698 0.0431 *
Residuals        19 0.016819  0.000885
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

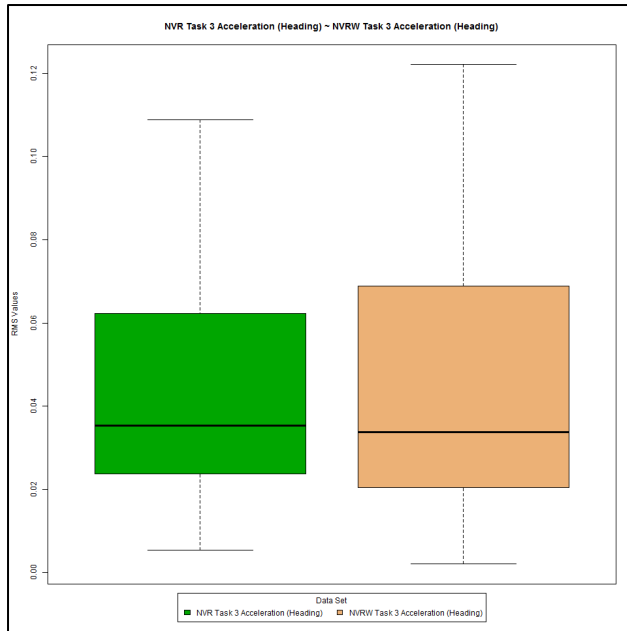
**Figure 18** – Significant difference between Non-Virtual Reality Task 3 Pitch and Non-Virtual Reality Weighted Task 3 Pitch.



```
[1] "NVRW Task 2 Acceleration (Heading) ~ VR Task 2 Acceleration
(Heading) "
      Df Sum Sq Mean Sq F value Pr(>F)
Task2Dataset_VR 1 0.002106 0.0021063    3.965  0.061 .
Residuals      19 0.010094 0.0005312
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

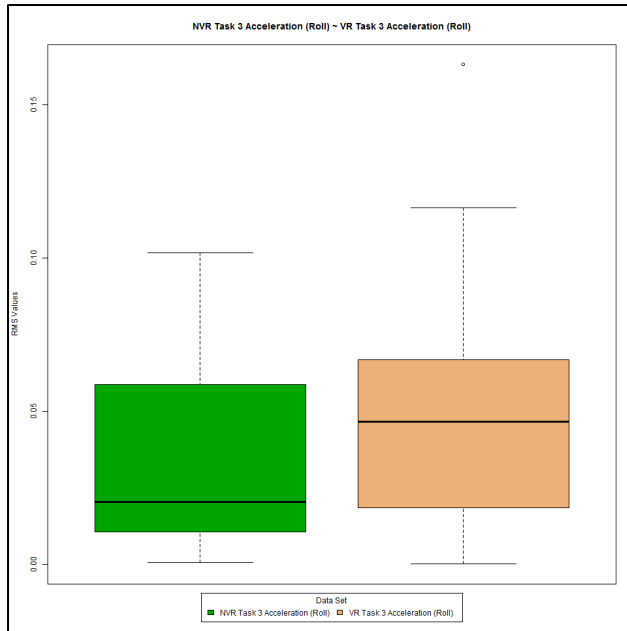
**Figure 19** – Significant different between Non-Virtual Reality Weighted Task 2 Heading and Virtual Reality Task 2 Heading.





```
[1] "NVR Task 3 Acceleration (Heading) ~ NVRW Task 3 Acceleration
(Heading) "
      Df    Sum Sq   Mean Sq F value Pr(>F)
Task3Dataset_NVRW  1 0.002532 0.0025315    3.693 0.0698 .
Residuals        19 0.013026 0.0006856
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 20** - Significant different between Non-Virtual Reality Task 3 Heading and Non-Virtual Reality Weighted Task 3 Heading.



```
[1] "NVR Task 3 Acceleration (Roll) ~ VR Task 3 Acceleration (Roll)"
      Df Sum Sq Mean Sq F value Pr(>F)
Task3Dataset_VR 1 0.002492 0.0024924    3.291 0.0855 .
Residuals      19 0.014391 0.0007574
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

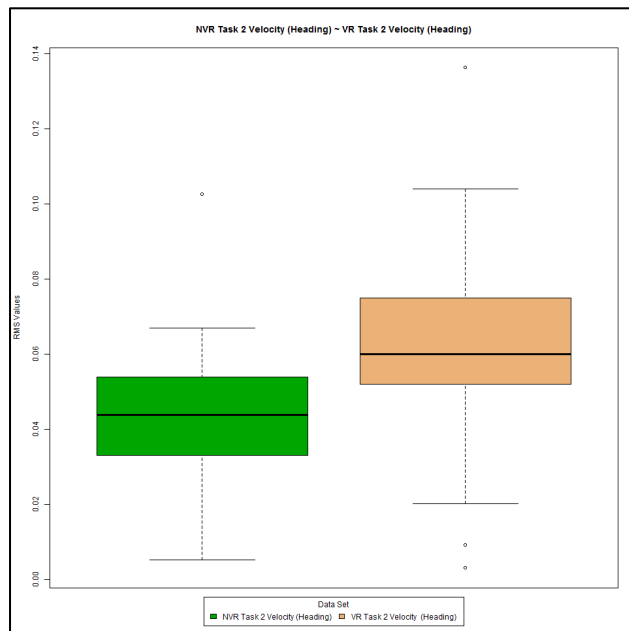
**Figure 21** - Significant different between Non-Virtual Reality Task 3 Roll and Virtual Reality Task 3 Roll.

### Velocity

There was no significant difference in velocity for task one. However, there was a close to significant difference in pitch between Non-Virtual Reality and Non-Virtual Reality Weighted conditions, with a  $Pr(>F)$  value of 0.199. A significant difference was found between Heading in task two between Non-Virtual Reality and Virtual Reality (Figure 29), although this did not persist between tasks. There was also significance in task two and three for Pitch (Figures 30 and 31) and Heading (Figures 32 and 33) velocity between Non-Virtual Reality and Non-Virtual Reality Weighted.

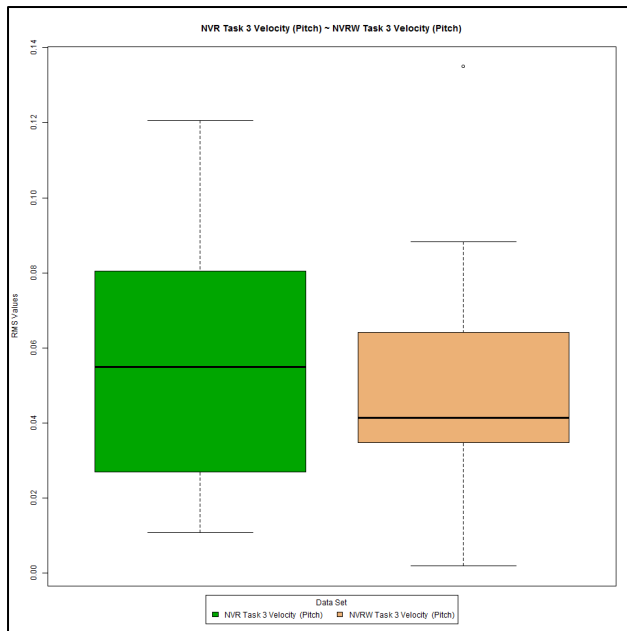
The Heading velocity had a significant difference between Non-Virtual Reality and Virtual Reality for task one, but this relationship did not persist through other tasks. However, between tasks two and three for Non-Virtual Reality and Non-Virtual Reality Weighted, a significant relationship remained. This indicates that participants moved their head quicker when they were not wearing a weighted headset. This again could be because of the front-loaded weight distribution of the weighted headset compared to the Virtual Reality headset which evenly distributes weight. Although there was a velocity difference between Non-Virtual Reality and Virtual Reality in task one, it was an isolated occurrence and if the difference was significant, it

would have persisted between tasks as the head movement were similar for each. Pitch was also significant between each task for Non-Virtual Reality and Non-Virtual Reality Weighted. The theory holds true for Pitch as it does for heading, the front weight load of the Non-Virtual Reality Weighted headset may have affected head movement speed compared to not wearing a headset.



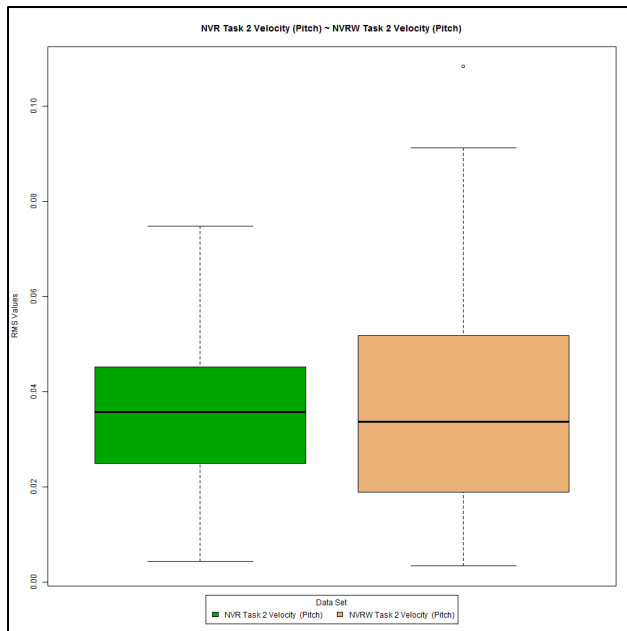
```
[1] "NVR Task 2 Velocity (Heading) ~ VR Task 2 Velocity (Heading)"
      Df Sum Sq Mean Sq F value Pr(>F)
Task2Dataset_VR  1 0.002242  0.0022418    7.1 0.0153 *
Residuals      19 0.005999  0.0003157
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 22** – Significant difference between Non-Virtual Reality Task 2 Heading Velocity and Virtual Reality Task 2 Heading Velocity.



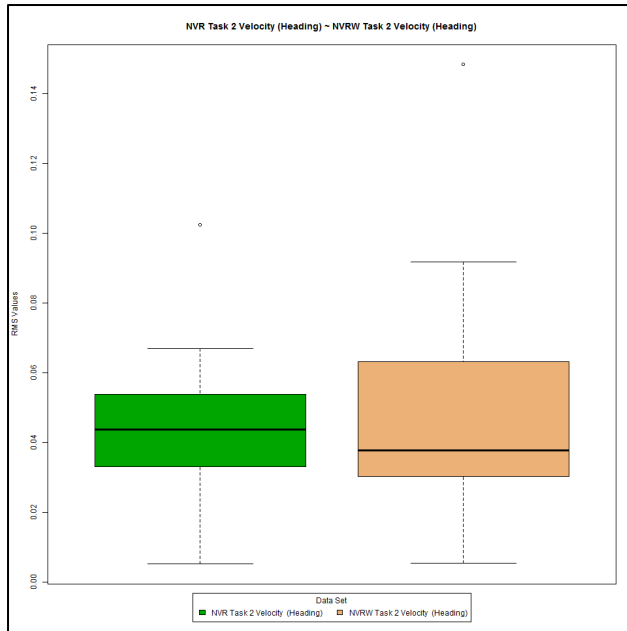
```
[1] "NVR Task 3 Velocity (Pitch) ~ NVRW Task 3 Velocity (Pitch)"
      Df Sum Sq Mean Sq F value Pr(>F)
Task3Dataset_NVRW  1 0.005498  0.005498    5.467 0.0305 *
Residuals        19 0.019107  0.001006
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 23** - Significant difference between Non-Virtual Reality Task 3 Pitch Velocity and Virtual Reality Task 3 Pitch Velocity.



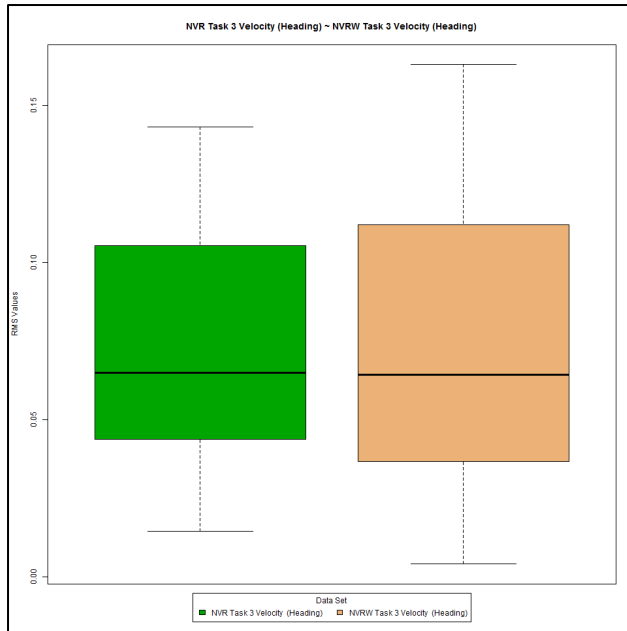
```
[1] "NVR Task 2 Velocity (Pitch) ~ NVRW Task 2 Velocity (Pitch)"
      Df Sum Sq Mean Sq F value Pr(>F)
Task2Dataset_NVRW  1 0.001237 0.0012367    5.481 0.0303 *
Residuals       19 0.004287 0.0002256
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 24** - Significant difference between Non-Virtual Reality Task 3 Pitch Velocity and Virtual Reality Task 3 Pitch Velocity.



```
[1] "NVR Task 2 Velocity (Heading) ~ NVRW Task 2 Velocity (Heading)"
      Df Sum Sq Mean Sq F value Pr(>F)
Task2Dataset_NVRW  1 0.001373 0.0013730   3.799 0.0662 .
Residuals        19 0.006868 0.0003615
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 25** - Significant difference between Non-Virtual Reality Task 2 Heading Velocity and Virtual Reality Task 2 Heading Velocity.

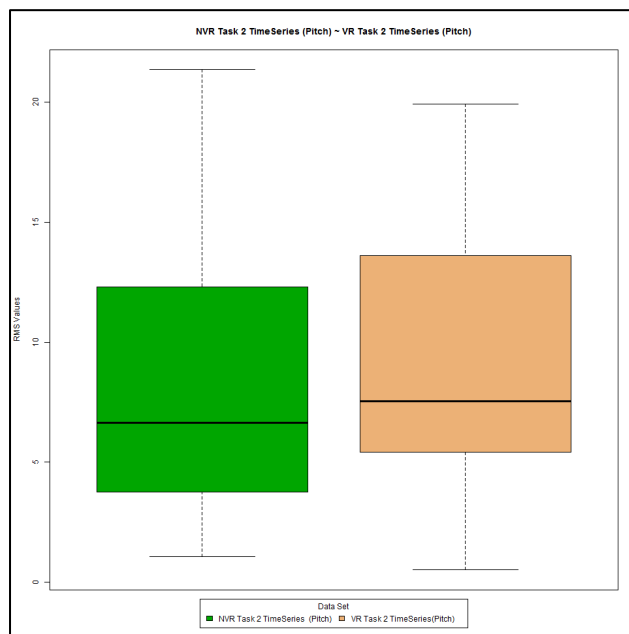


```
[1] "NVR Task 3 Velocity (Heading) ~ NVRW Task 3 Velocity (Heading)"
      Df Sum Sq Mean Sq F value    Pr(>F)
Task3Dataset_NVRW  1 0.01345  0.013450    15.95 0.000777 ***
Residuals        19 0.01602  0.000843
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 26** - Significant difference between Non-Virtual Reality Task 3 Heading Velocity and Virtual Reality Task 3 Heading Velocity.

## Movement

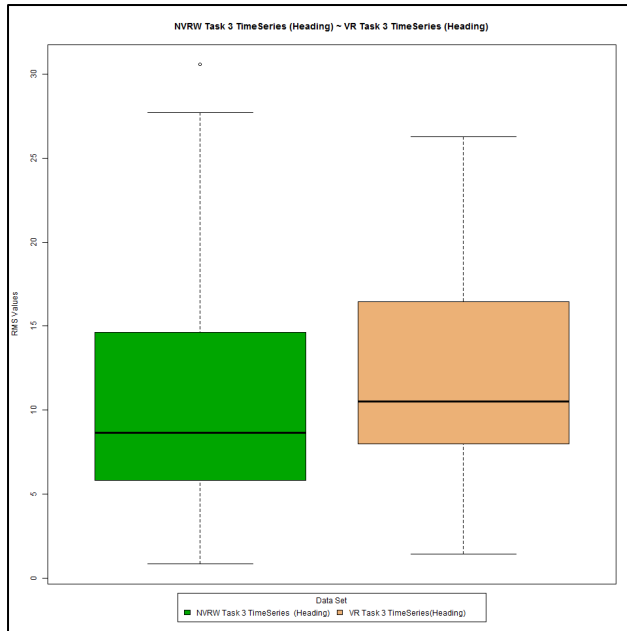
There were no significant trends across tests for movement between each test condition. This suggests that the movement directions of individuals do not change based on if they are wearing a headset or not. Although a significant relationship was found between Non-Virtual Reality Weighted and Virtual Reality in Pitch for task 2 (Figure 34), and Non-Virtual Reality and Virtual Reality for heading in task 3 (Figure 35), these two significant findings did not occur in other tasks.



```
[1] "NVRW Task 2 TimeSeries (Pitch) ~ VR Task 2 TimeSeries (Pitch)"
      Df Sum Sq Mean Sq F value Pr(>F)
Task2Dataset_VR  1  587.2    587.2    6.512 0.0195 *
Residuals      19 1713.2     90.2
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

**Figure 27** - Significant difference between Non-Virtual Reality Weighted Task 2 Pitch Movement and Virtual Reality Task 2 Pitch Movement.





```
[1] "NVR Task 3 TimeSeries (Heading) ~ VR Task 3 TimeSeries (Heading)"
      Df Sum Sq Mean Sq F value Pr(>F)
Task3Dataset_VR 1 312.7 312.69 4.015 0.0596 .
Residuals      19 1479.6 77.88
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

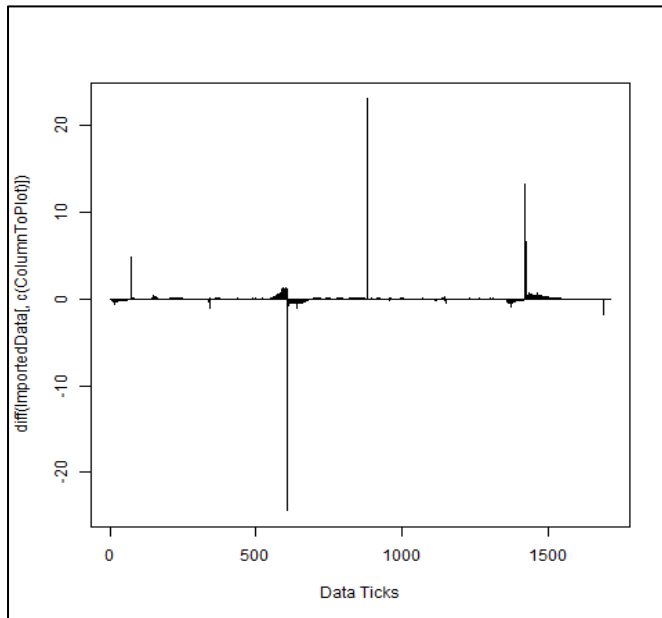
**Figure 28** - Significant difference between Non-Virtual Reality Task 3 Heading Movement and Virtual Reality Task 3 Heading Movement.

This study found that there is no significant difference in head movement acceleration or velocity when wearing a virtual reality headset. This differs from the initial hypothesis where a significant difference in acceleration was predicated based on previous findings by Regan (1993). This may be due to the effective weight distribution that current headsets provide. This theory is supported by findings that there was a significant difference in head movement when wearing a weighted headset which was front loaded with reduced weight distribution.

Although this study found instances of significant differences in head movement when wearing a Virtual Reality headset, it could be assumed that with a practice effect applied, the significant findings may vanish. Therefore, this study suggests that current Virtual Reality headsets distribute weight effectively enough that users can move their heads in a realistic manner, with no effect on their head movement. This means that Virtual Reality developers should not have to significantly consider the effect of the headset on head movement when developing applications, but should still focus on how their applications effect motion/cybersickness.

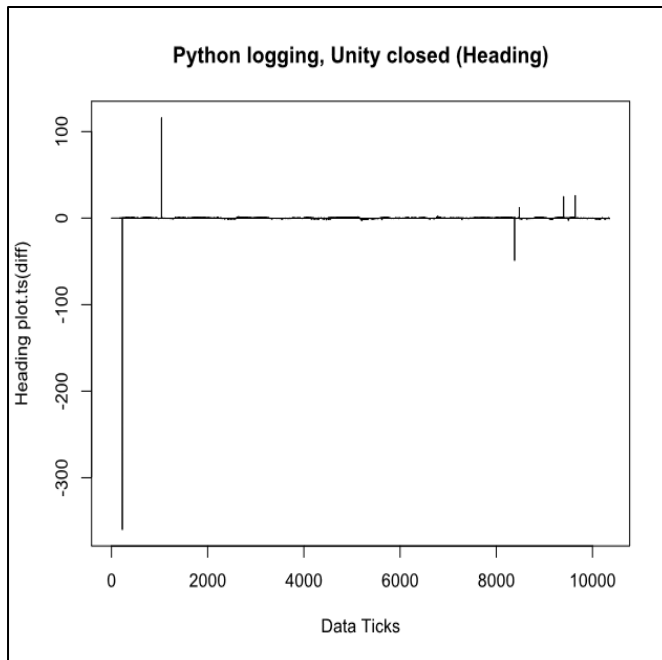
### ***Data Spike Troubleshooting***

During the analysis of the accelerometer data, spikes at regular time intervals were observed in the data plots for each participant. Shown in Figure 13, spikes were observed to occur every 5.5 seconds on average. Further examples can be found in the “Study 1” folder on the provided memory stick. To identify the cause of this issue, several scenarios were investigated and are discussed below. A separate script was created using R to remove the spikes whereby data that was above a threshold of 3 degree’s difference was either added (positive spike) to or subtracted from (negative spike) the previous recording to bring it into the range of the other records and avoid altering overall trend in movement data.

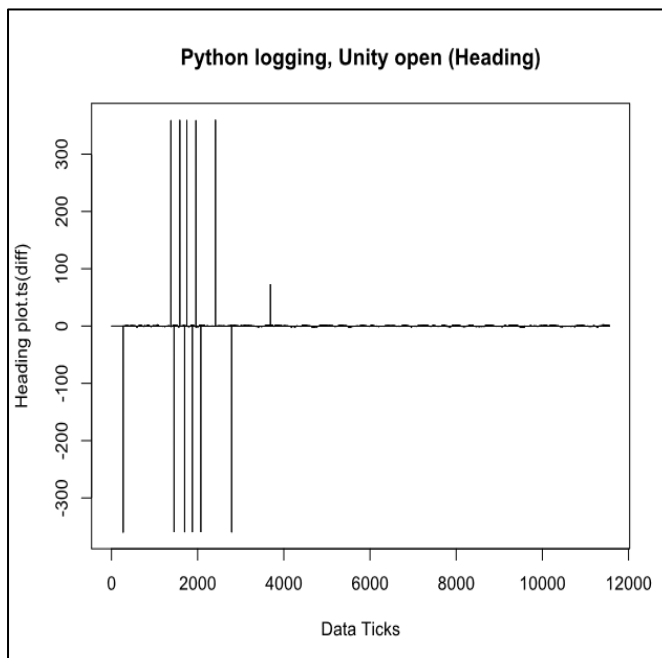


**Figure 29** – *Data spikes occurring in a Velocity plot of a participant.*

Firstly, accelerometer and its Python script was run with the Unity engine closed and a basic logging script added. This was to see if there was a problem with either the accelerometer or its script. Figure 14 shows that the only data spikes that occurred were 0 to 360-degree orientation changes. The test was then repeated, but this time the Unity engine was open but test application was not running. This was to see if just running the engine caused data spikes. However, the same result occurred and only 0 to 360 degree spikes were observed (Figure 15). This suggested that the problem was based within the application created with the engine, not the Unity program itself.

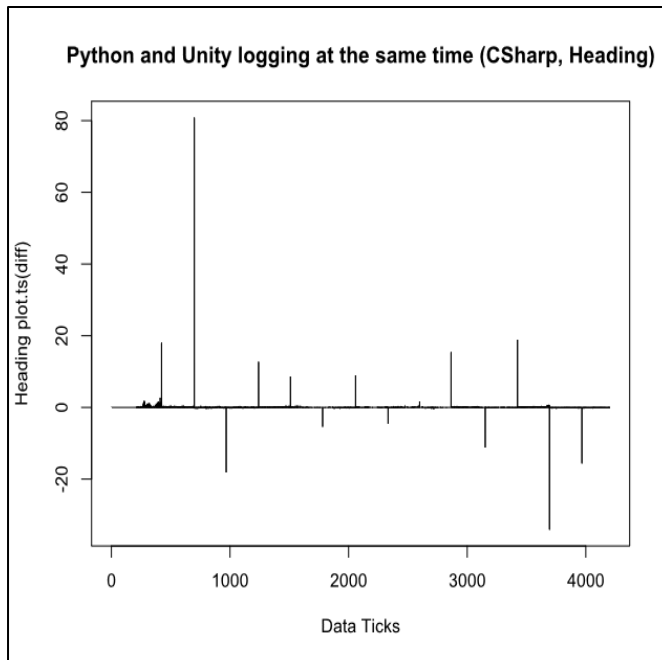


**Figure 30** – Running the accelerometer and its logging script outside of Unity.

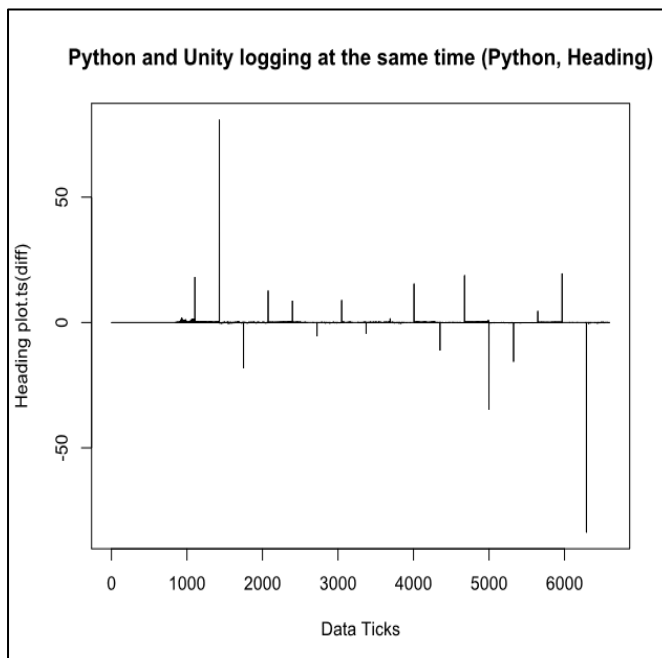


**Figure 31** – Running the accelerometer and its logging script with Unity open.

As running the accelerometer using a separate logging script caused no data spikes, the next troubleshooting method involved using the logging script in the test application. Additionally, the stream-reader script which read the data from the accelerometer had a basic logging method implemented to run at the same time as the logging script to check if it was causing data spikes. Figure 16 and 17 display the results of the logging script and stream-reader logging.



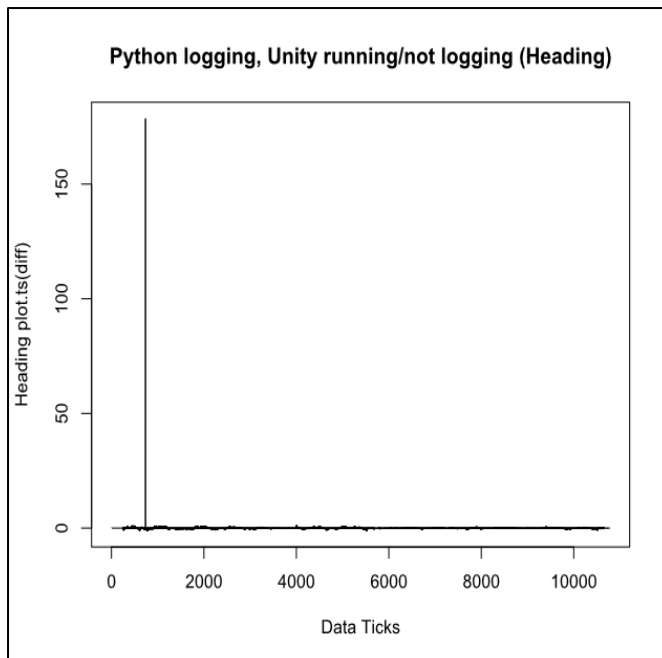
**Figure 32** – Results of the logging script.



**Figure 33** – Results of the stream-reader script.

Both the primary and stream-reader logging methods recorded the same data spikes even when the accelerometer data was logged directly from the stream-reader script. Figure 17 shows the stream-reader script logged data for a longer period. This was because its logging was not controlled by the application start and stop times. As no data spikes occurred when logging outside the application and the logging script just formats data parsed from the stream-reader, it was assumed that the data spikes were being caused by the stream-reader script.

To confirm the theory of the spikes being caused by the stream-reader, the test application was executed with the logging script disabled and using the basic logging script in the accelerometer code to record data. This was to see if just the windows process of the application running interfered within the accelerometer and caused it to produce data spikes. If there were no spikes within this recorded data, it could be assumed that only something within the application could be causing the data spikes as the accelerometer would be running independently of the application. Figure 18 displays the results of this test.

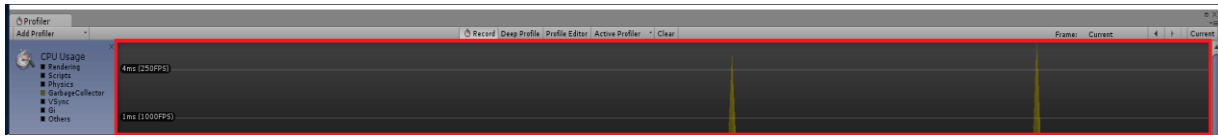


**Figure 34** – Running the accelerometer code with the logging script disabled.

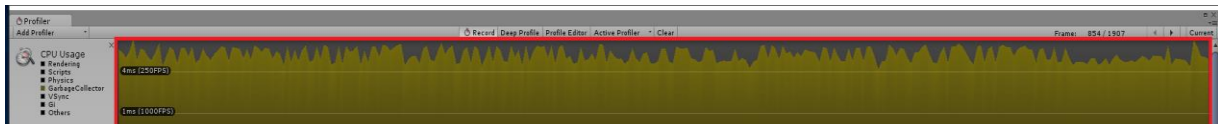
The logging for this test was completed outside of the application and no data spikes occurred, this suggested that data spikes were caused by the stream-reader. The only reason to doubt this assumption is that the test application was not logging at the same time. This was unable to be completed as the accelerometer could not be accessed by two scripts at the same time.

As the issue had been attributed to the application, the next investigation involved checking various performance data whilst the application was running. It was here that spikes in the garbage collector at the same frequency as the accelerometer spikes were observed (see Figure 19). In consulting the Unity Documentation (Unity 2016), it was stated that the constant appending of strings, as done in this application to create the .csv file, increased “garbage” and reduced performance. Therefore, the next test involved manually increasing the rate of garbage collection (see Figure 20) with the intention of reducing the accumulation of garbage to see if the spikes in garbage collection were behind the data spikes. I was also implemented to see if

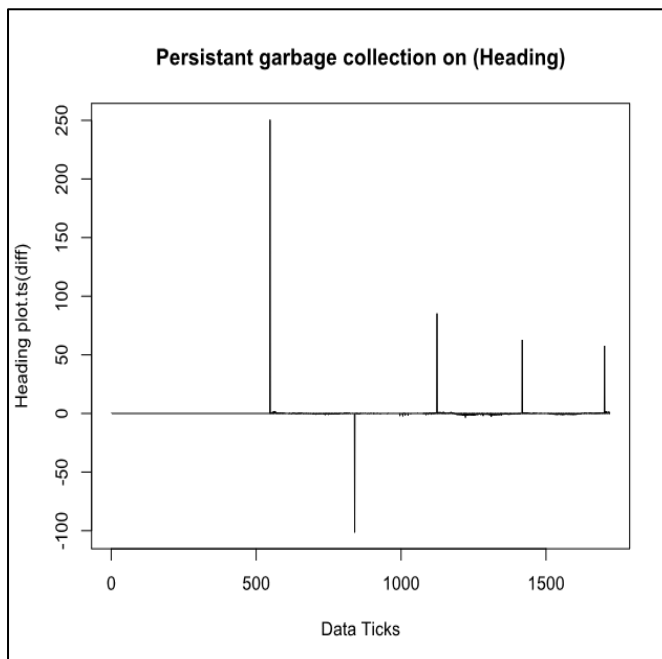
the “little and often” garbage collection method could provide a solution. However, Figure 21 shows that despite having the garbage collection on every frame tick, it had no effect on reducing data spikes.



**Figure 35** – regular spikes occurring within garbage collection.

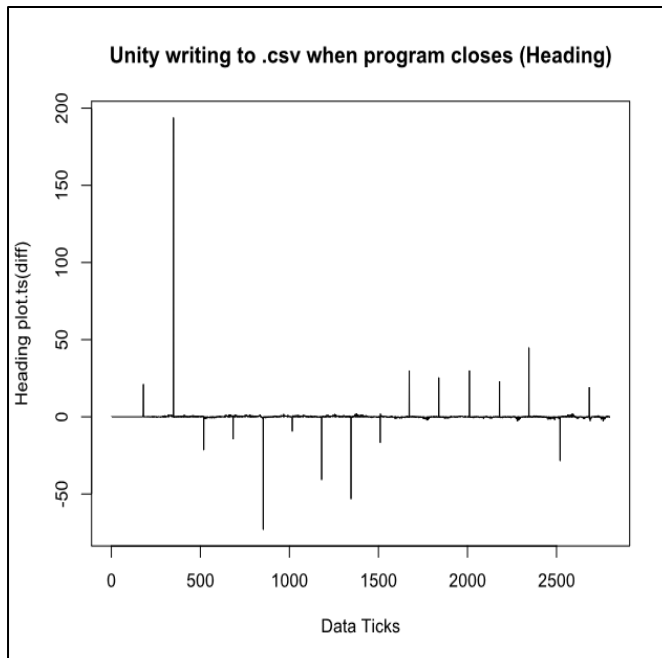


**Figure 36** – “Always On” garbage collection.



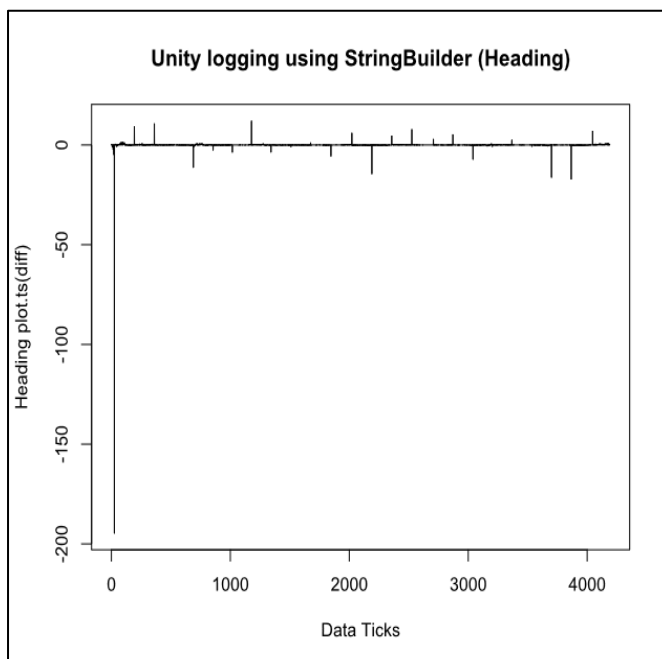
**Figure 37** – Data spikes with persistent garbage collection.

Instead of appending to a .csv file each update tick, the primary method of the test application was changed to write to a .csv file when the application was closed. This meant that the program was only dealing with an external file after all the data had been recorded. This checked if accessing a file every 0.2 milliseconds was a cause of the data spikes. Figure 22 shows that even when writing to a .csv after the data had been recorded, the spikes still occurred. This suggests that it is not an issue with writing to an external file every update tick or even logging to a file at all. It does support the theory of the issue being contained within the stream-reader script of the test application as the change in logging had no effect.



**Figure 38** – Writing to a .csv file when the application is closed.

The final test involved using a `StringBuilder` (Microsoft, 2016) instead of appending to a file to see if it had a positive effect on performance and remove the data spikes. However, as Figure 23 shows, there was no effect on the data spikes and caused 0 to 360 degree spikes which had not occurred with the regular appending method.



**Figure 39** – Using the `StringBuilder` instead of appending to csv.

Troubleshooting focused on the potential causes of the data spikes. The cause of the spikes seemed to stem from the stream-reader script as there were no data spikes when the sensor recorded data outside of the application. Only when the Python process output was sent to the stream-reader did the data spikes occur. Multiple logging methods were also tried as it was found that constant string appending affected performance. However even with these new methods, the data spikes still occurred.

As to why the stream-reader caused data spikes, a potential issue may involve the standard output not being redirected quick enough from the accelerometer to the stream-reader meaning that data could be missed causing a spike. It could also be an interface problem between C# and Python when C# begins a Python process. Another explanation could be that the rate of data being passed from the accelerometer to the stream-reader buffer was too high so when the buffer is cleared at regular intervals, the spikes occur. It could also be an issue with how Unity applications handle external processes being started from within its code. However, it seems the problem has been isolated to the stream-reader method of retrieving data meaning that in the future, a new method should be implemented. If the study was to be completed again, the logging of the accelerometer data should be independent of the application.

## ***Discussion***

### **Improvements**

The quality of the weighted headset used could be improved due to the lack of weight distribution compared to the Virtual Reality headset used. While the weighted headset was the same weight as the Virtual Reality headset, the distribution of that weight was front loaded whereas the weight distribution of the Virtual Reality headset is even. If an evenly distributed headset was used, the results observed could be different and a closer representation of the effect of pure weight on the head of a user could be fully investigated.

Another improvement would be the logging of accelerometer data. At present, when data is recorded from the accelerometer, the logging script in the application rounds it up to nearest 10 before it writes it to a .csv file. While this does not change the highly significant differences found, it could have possibly removed the differences that were just above significant and those that were found to be insignificant such as those observed in the acceleration ANOVA could have been significant findings.



As detailed by the data spikes section, by trying to integrate a stream-reader in the application, issues occurred with the data that significantly extended development time as a separate script had to be created to remove data spikes. In future iterations, the recording of accelerometer data should be completed outside of the application as it was shown that no spikes occurred in the accelerometer data when this was the case.

### **Future work**

Recording gender and age as variables could provide a broader insight into how head movement varies across demographics. It could also provide more compelling findings should a significant difference in head movement be found. Including these variables also tie in to findings by Biocca (1992) who stated that females are more susceptible to cyber sickness, this could also mean that females potentially move their head in different ways compared to men as a difference in head movement could reduce the likelihood of cybersickness. Furthermore, as discussed by Reason and Brand (1975) age effects the likelihood of cybersickness so the same principle could be applied to different age groups to see if people move their heads differently as they get older and if that contributes to an increase or decrease in cybersickness.

Increasing the sample size of participants in a future study would provide a greater observation of general head movements and would improve the validity of this study through the increased sample size. Adapting this study to test the difference between different Virtual Reality headsets could also provide an interesting dynamic. The weighted conditions could be replaced by another brand of headset and the different types of movement could be looked at and compared to see which headset has the greatest effect on head movement.

### **Conclusion**

This study has investigated how a current generation Virtual Reality headset effects the head movement of its users. By implementing tests that have been successfully used in the past to measure head movement, a bespoke application and analysis tool were created that will be freely available for others to improve and alter to their specifications. Although this study found that there was no significant difference in head movement between wearing a headset and not, there are enough improvements that could be made as well as some significant differences between conditions that suggest a trend is there. Furthermore, this study is the first structured experiment into how these headsets effect how we move and it provides a firm starting point for the next iterations of studies surrounding this topic.

This study has provided knowledge that implementing a stream-reader of Python into a Unity application can cause data spikes at regular intervals. While the root cause was not discovered and solved, this study has shed light on an area of the Unity engine which could be investigated in the future. By finding these spikes, an additional script was created to remove them, meaning if this study was to be run again, the freely available script could be used to remove the spikes without those who are running the experiment having to solve this issue before they continue.

In addition to providing the test application, providing the script used to analyse the collected data ensures that those wishing to replicate the study or investigate how it was constructed can do so without having to solve the development problems faced during its construction. Finally, while this study looks at the basic relationship between headset, no headset and weighted headset, the improvements and additions mentioned previously would improve the validity and depth of this study structure. Although, this study does provide a solid base to build upon.

## **Chapter 4 – Study 2**

After first investigating how Virtual Reality headsets altered head movement, it was found that there was no significant effect. This allowed the development of the second study to progress without considering the reduced head movement of the user when implementing spectator modes. As there had been no studies that formally measure the success of Virtual Reality spectator modes, this study aimed to fill a gap in that knowledge by building upon the link of Virtual Reality and presence by investigating if the level of presence felt in a virtual environment effected viewing preference. As well as this, a general opinion regarding the preferred spectator methods and transitions modes was gathered allowing empirical evidence to be provided when recommending spectator methods to be used within a Virtual Reality game.

To gather the data for this study, a mock game was created that put the participant as a viewer within a game as it was being “played” by a scripted character. Using the HTC Vive headset by HTC and Valve (2016), a greater range of views including walking around the game level could be used compared to the traditional sitting Virtual Reality experience also on offer. As with the first study, this application was created with the idea of making it freely available as a base application which can be used to implement and test new Virtual Reality spectator views as well as replicate this study again. An analysis script is also provided alongside the application. However, it performs no special task compared to the script used in the first study as the data it is analysing is non-complex. Therefore, those wishing to replicate or improve upon this study

can use their own analysis method without having to rely on the provided script. This application and results can be found in the “Study 2” folder on the provided memory stick.

### ***Hypothesis***

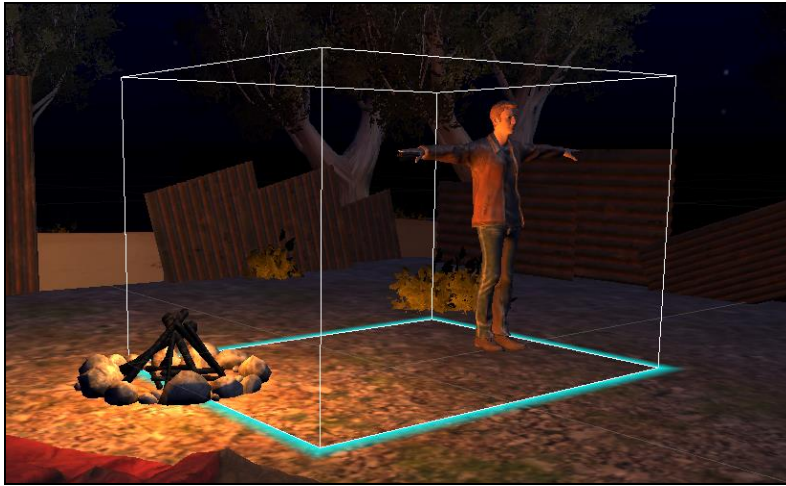
It was hypothesised that the first-person view would be the least preferred view and score the lowest average SPES total. This was due to the opinion that the view included elements that caused motion sickness such as a forced view and forced movement. The free roam view was hypothesised as being the most preferred and the most presence inducing view with the highest SPES score. This was due to the free roam view allowing the participant to walk around the play area and interact with the environment as they choose, not being forced to watch the gameplay from a fixed perspective.

### ***Methods***

#### **Camera Views Used**

The camera views used in this study were a combination of dynamic and static views that cover each angle of the game level. While other angles could have been used that are used in film and television, the views chosen for this study were found to work the best within a virtual environment. This provided the viewer with enough variety to make an informed choice about their most preferred and least preferred camera view.

The application contained five camera views, the first had the participant situated within the middle of the level allowing them to walk around within the designated play area (Shown in Figure 36). This view was chosen as it is the conventional mode for viewing applications using the HTC Vive headset. As the intention of this study was to provide views that could generate presence, by putting users in the middle of the level with the ability to walk around and view the objects up close, it was hoped that this method would fulfil the aim.



**Figure 40** – *The free-roam play area.*

Four cameras, one placed within each corner of the level were also used. As shown in Figure 37, each camera is raised up, giving the impression of “floating” above the play area. This gave spectators a view of the entire layout of the level. When viewing this condition during the experiment, the cameras were switched between each other, following the action of the scripted character. This attempted to mimic spectator methods often used in sports broadcasts where the camera view switches to different locations of the play area based upon where the action is occurring. This viewing method was also used within the study to gather opinions between two different transition modes. The first was an instant jump transition to the next camera location and the second was a slow deliberate pan between locations. While this study is predominantly about camera views within Virtual Reality, a comparison between these two transition modes was also implemented as they both give the corner camera view a different feel when either is being used. Also, a knowledge of preferred transitions between cameras could prove to be as valuable as knowing which camera view is the most preferred and this application provided the suitable platform to show these modes to spectators.

A third-person view was also implemented as it is a common view within conventional video games such as *Gears of War* (Epic Games, 2006) and *the Witcher* (CD Projekt RED, 2007). Shown in Figure 38, it provided spectators with a close-up view of the scripted character as they followed it around looking over their shoulder. While not considered a conventional view for Virtual Reality due to its forced view and in this applications case, forced movement, including it in this study, could confirm a general opinion about the success of the view.



**Figure 41** – *The view from a corner camera within the game level.*



**Figure 42** – *The third-person view from the application.*

Finally, a first-person view (Shown in Figure 39) was implemented as without experiencing this view, it could be considered the most immersive spectator method. This is because spectators see exactly what the player of the game is observing, putting them in their position and mimicking the experience of the player. However, forcing a view within virtual reality increases the likelihood of motion/cybersickness. Including this view in the study application ensures that a variety of camera views were observed and an informed choice of preferred spectator mode could be made.



**Figure 43** – *The first-person view in the study.*

### **Data collection and Analysis**

To gather data, participants viewed each spectator view once and filled out a Spatial Presence Experience Scale (SPES) questionnaire after each playthrough to calculate the level of presence experienced for each view. Participants did not fill out a SPES when they were shown the transition modes in what was the final task of the experiment. As well as filling out the SPES questionnaires, participants were asked to state their “Most Preferred” and “Least Preferred” spectator mode in addition to which transition mode they favoured. They were also asked to provide reasoning for their decisions which could be used in the non-empirical results of the study.

After this data was collected, the average SPES (Presence) score was calculated for each participant within each view. This showed the views in which the participants felt most and least present in. It also allowed for a total average to be calculated showing which view of the four provided participants with the greatest and least sense of presence. This data was then used in an ANOVA to check for statistical significance in presence felt between views as well as check to see if a participants most and least preferred view matched up with their highest/lowest SPES score, linking presence to preference of a spectator view.

### **Tools Used**

To create the study, the HTC Vive Virtual Reality headset (HTC and Valve, 2016) was chosen as it was readily available for use and was considerably more powerful than the Oculus Rift Development Kit 2 (Oculus, 2015) used in the previous study. To develop the application, the Unity game engine (Unity, 2016) was chosen due to the developer’s familiarity with the development environment and the ready-made plugin by Valve (Valve, 2016) which implements

the HTC Vive play area, reducing development time through not having to implement the play area from scratch.

As this application required the three-dimensional models to represent characters within the game, Adobe Fuse (Adobe, 2016) was used as no three-dimensional modelling skills are required to generate the character models. This reduced development time and cost significantly. Additionally, sound assets for the level were sourced from freesound.org (Freesound, 2016) who provide free to use sound assets.

To calculate the presence felt by each participant, the SPES (Spatial Presence Experience Scale) developed by Hartmann et al (2015) was used. The SPES is a short, eight question survey which assesses spatial presence as a two-dimensional construct that comprises a user's self-location and perceived possible actions in a media environment. It asks questions such as *"I felt like I was actually in the environment of the presentation"* and *"The objects in the presentation gave me the feeling that I could do things with them"*. The full SPES questionnaire used in this study can be found in Appendix 3. To analyse the SPES scores using an ANOVA, the R programming language as well as R studio was used. As with the first study, a custom script was created allowing ANOVA analysis and graph creation to be automated.

### ***Application Overview***

As with the application created for first study, this application was built with the Unity game engine and was programmed in C#. Figure 40 displays a view of the entire game level. Each camera view was implemented within the same scene and could be switched between using the number keys on the keyboard. The transition modes between the corner cameras were implemented by pressing the control key and the "1", "2", "3" or "4" key to pan switch between the chosen corner camera. Although the order of the views observed by each participant is randomised, learning from the first study, the randomisation order was done outside of code. This reduced development time as a randomisation script did not have to be created.

The setting of the game is based during a Zombie apocalypse with the scripted character running around the level shooting the approaching Zombies. At the start of the spectator experience the character (Figure 41) is standing stationary in the middle of the level with the sound of crackling of a fire setting a calm atmosphere and attempting to increase the presence felt. During this period, the camera angle for the next condition is switched to by one of the number keys on the keyboard. The gameplay of the level is started using the spacebar and when

it is pressed the Zombies begin to spawn and the character runs around its scripted path, shooting zombies at designated positions. The character moves around the level returning to its start position at the end of its path. The game then reverts to its calm atmosphere with Zombies despawning. When the player starts to run around the level, the sound of the game is also changed to set a tense atmosphere by playing Zombie sounds and a gunshot sound when the character's gun is fired.



*Figure 44 – A view of the entire game level.*

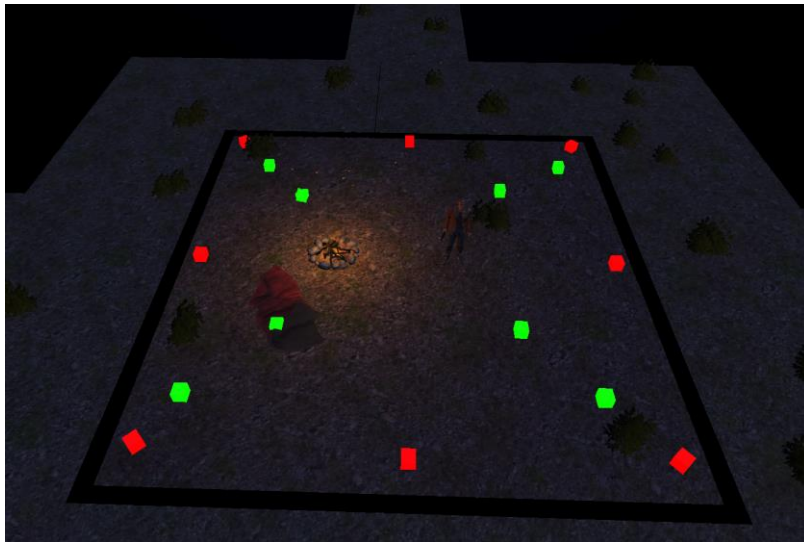


*Figure 45 – The character used for the study.*

The pathfinding of the character was completed by positioning waypoints at locations in the level and using the built-in Unity AI module to make the character move between them. Figure 42 displays the waypoints in green positioned within the level. To make the character shoot the approaching zombies, separate waypoints, shown as red in figure 42 were placed. When touched by the character, the characters shooting animation was played and a ray cast in front of the



character was triggered. If the ray cast passed through a Zombie, their death animation was played and they were removed from the level.



**Figure 46** – The various waypoints for the character in the level.

### **Experiment Structure**

The experiment was conducted within a room providing each participant with the recommended play area size of 1.5m x 2m for the HTC Vive. This play area size enabled participants to have enough room to walk around the level and fully immerse themselves within the virtual environment. Figure 43 displays a participant in the play area. Before each participant, the application was started and the headset was placed in the middle of the play area ready for the participant to put on. This ensured that the participant was placed directly into the test environment and became immersed within their setting immediately. The experiment coordinator was situated just behind the play area, sitting at the computer running the application allowing them to control the camera angles displayed.



**Figure 47** – A participant taking in the study wearing the HTC Vive headset.

At the start of each study iteration, the participant was asked to fill out a consent form that explained what would happen during the study and what would be expected of them during their participation (See Appendix 4). The participant would then be told which camera angle they would be experiencing first and was asked to put on the headset. When they were ready, the coordinator would press the space bar and the character in the game would run around its scripted path with the participant watching the gameplay unfold. After the gameplay finished, the participant would be asked to take off their headset and fill out a SPES questionnaire for that view.

After the participant filled out the questionnaire, the process would be repeated until each camera view had been observed and a SPES questionnaire had been completed for each. After all camera views were observed, the participant was asked to state their most preferred and least preferred spectator view as well as their reasons behind their choice. This was recorded for future reference and can be found in the “Study 2” folder.

The final stage involved showing the participant the transitions between the corner cameras. While the default transition between the corner cameras in the first part of the test were jump cuts, this section incorporated panning transitions into the switching methods, allowing for a preference to be chosen. To display the different transition method, the test application was run again, but incorporated the new transitions into the corner camera switching as the character ran around the level. After the gameplay, had finished, the participant was asked which transition mode they preferred and their reasons behind that choice. These recordings can be found in the “Study 2” folder.

## ***Results***

### **Participants**

There were 20 participants in the study. No other demographic was used apart from the confirmation that each participant was over the age of 18 to fulfil ethics protocol. Although, if gender and age were used, some correlations could be investigated between level of presence felt and demographic information. However, looking at these correlations was not the focus of the study.

### **Non-Statistical Findings**

This section looks at the non-statistical finding of this study, outlining the opinions of participants about each camera view as well as observations of their actions. This section has

been split up into different parts that discuss findings of each camera view and transition modes. To view the full participant transcripts as well as recordings of them observing the test application, they can be found in “Study 2” folder on the provided memory stick.

The results of the study showed that the most preferred camera view was the free roam view with six preferred selections, this matched with the hypothesis. Second was the third person view with five, tied third was the corner camera view and the first person view with four and with one participant preferred none of the views. The least preferred camera view was the first person view with 11 participants choosing it, matching with the hypothesis. Second least preferred was the corner camera with six, third least was the third person view with three votes and the free roam view had only one choice. In terms of transition mode, the panning transition was the most preferred with 15 participants preferring it. The jump transition had three preferences with two participants stating they did not prefer one over the other.

The view with the highest recorded presence (SPES Score) was the third person view, with an average of 4.03/5. The lowest presence recorded was the Corner Camera view with 3.71/5. Free Roam and First Person scored 3.97 and 3.87 respectively. The SPES scores differed from the hypothesis which predicted that the first-person view would have the lowest presence score and the free roam view would have the highest presence score. This points to a lack of correlation between SPES score and preferred/least preferred camera view in the case of this study.

It is worth noting that in 10 cases, their most preferred view correlated with the most presence felt by them in that view (Figure 48). This also occurred in 10 participants least preferred view with 7 of the 20 participants having matching preferences with the most/least presence felt. This suggests that with a larger sample group, a significant correlation between the most or least preferred view and SPES score could be observed.

Participant	Most Preferred	Least Preferred	Most Presence	Least Presence
1	Third Person	Corner Cameras	First Person - 4.0	Corner Cameras - 2.75
2	Third Person	Corner Cameras	First Person - 5.0	Corner Cameras - 3.25
3	Free Roam	First Person	Free, Corners, Third - 4.63	First Person - 4.25
4	Third Person	First Person	Third Person - 4.13	Corner Camera - 3.25
5	Third Person	First Person	Third Person - 5.0	Free, Corner, First - 4.0
6	Third Person	Corner Cameras	Third Person - 5.0	First Person - 3.25
7	Corner Cameras	First Person	First Person - 4.75	Free Roam - 4.13
8	Corner Cameras	Third Person	Corner Cameras - 3.50	Third Person - 2.75
9	First Person	Corner Cameras	Free Roam - 4.75	Corner Cameras - 2.75
10	Free Roam	Corner Cameras	All - 4.0	All - 4.0
11	Free Roam	First Person	Free Roam - 3.75	Corner Cameras - 2.75
12	Corner Cameras	First Person	Third Person - 5.0	Free Roam - 4.50
13	First Person	Corner Cameras	Free, First - 4.88	Corner - 3.50
14	None	First Person	Third Person - 4.50	Free Roam - 3.50
15	Corner Cameras	First Person	Third Person - 5.0	Free Roam - 4.0
16	Free Roam	First Person	Free Roam - 4.0	Third, First - 2.88
17	Free Roam	Third Person	Corner Cameras - 3.50	Free, Third - 3.13
18	Free Roam	First Person	Free Roam - 4.50	First Person - 1.50
19	First Person	Free Roam	First Person - 4.75	Free Roam - 3.63
20	First Person	Third Person	Third, First - 5.0	Free, Corner - 4.25
	Matches With Most Preferred			
	Matches With Least Preferred			

**Figure 48** - Table displaying the links between most and least preferred view and level of presence felt

### Free Roam

The free roam camera was the most preferred view with six participants choosing it as their most preferred and only one choosing it as their least preferred. The average SPES score was 3.97 putting it as the second most effective spectator view. In contrast to the other modes which had complaints about disorientation and lack of immersion in the scene, the qualitative feedback from participants has been predominantly positive with comments about freedom of movement and immersion in the scene. For example; *“I felt more involved compared to the other camera angles and I could move about wherever I wanted to go”* and *“It felt very immersive because I could walk around and do whatever I wanted”* being two examples of how participants felt about this view. Overall, the free roam camera can be viewed as the least controversial view as it presents the generic Virtual Reality spectator experience compared to the others in this study which impose some form of view or movement alteration.

### **Corner Cameras**

The corner camera view was the most preferred by 4 participants and least preferred by 6 making it the second most disliked view. The SPES score of this view was 3.71 making it the lowest scorer. The predominant complaints about this mode was the perceived lack of involvement in the level as well as amplifying participants fear of being up high. This supports claims made by Chandler (2001) who found that high angle views cause detachment between the spectator and the scene. For example, one user commented *"I was up in the tree and I felt very unstable and I felt as if I was going to fall and I didn't feel very comfortable"*. One participant also stated that they felt like they were falling through the floor and became visibly distressed when the camera switched and placed them amongst the trees. However, there were some positive reviews of this mode with one participant saying *"I felt like I had an advantage over the player in that I could see more of the level even though I couldn't interact with the level"*. Although, the general opinion of this view was that of being forced into an uncomfortable position with no real idea of your current position due to the camera switching position. This was evidenced by one participant who said *"I didn't really feel like I was in the scene and it was disorientating when I was being switched between each camera"*.

### **Third Person**

The third person view was the most preferred by 5 participants and least preferred by 3 participants. It had the highest average SPES score with 4.03 although reviews of the mode were very mixed. Whereas the other views had a majority decision in preference or dislike for it, the third person view received praise from participants who felt the moving aspect enhanced the experience such as *"I actually felt like I was there. It felt as If I could actually reach over his shoulder and help him out"*. Or took away from it by saying *"I kept moving around with the character and it made my head hurt"*. This view also made some participants visibly disorientated, some had to hold onto a chair to steady themselves as they followed the character around the level. The third person view could be the view for those who are not effected by motion sickness and can handle forced movement. If viewers can avoid feeling disorientated, this view would place them in the middle of the action with a potentially greater viewing experience but with a less severe view compared to the first-person camera.

### **First Person**

The first-person view was the least preferred view in this experiment with 10 participants choosing it and 4 people choosing it as their most preferred camera view. It has a SPES score of 3.87. While 4 people preferred this view, most of them also admitted that this view, although

immersive, made them disorientated due to the fixed camera angle. One participant said: *"I felt I was more involved within the scene although it did make me feel a bit disorientated"*. The general view of this spectator view was that it made the user disorientated. In several cases, participants were visibly disorientated and held their hands out to try and balance themselves while the character was moving. Some participants had to hold onto a chair to steady themselves when viewing in first person. One participant remarked, *"It totally disorientated me, it made me feel physically sick and losing my balance"*. This view is the most disorientating view of the 4 used in this study with many participants becoming visibly disorientated when viewing it, therefore its inclusion as a standard Virtual Reality spectator mode should come under careful consideration if not dismissed entirely.

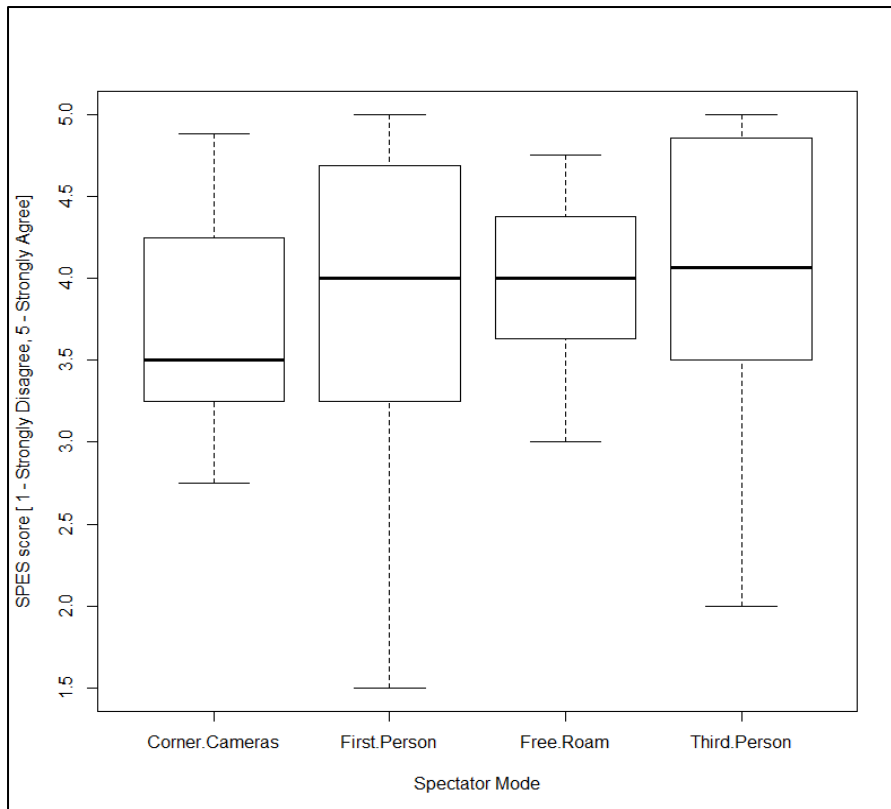
One participant reported that they felt disorientated well after using the headset. This supports findings by Kellog (1980) who suggested that Cybersickness can also develop in the hours following Virtual Reality usage and Gower (1989) who found that Cybersickness can linger for hours and in some extreme cases, for days after experiencing Virtual Reality.

### **Transition Mode**

The transition mode investigation was a choice between instantly switching between corner camera views or slowly panning between them. Out of the 20 participants, 15 preferred the panning transition, 3 preferred the instant transition and 2 had no preference as to the transition mode. In terms of reasons why the panning transition was preferred, the opinion of the participants was that the panning movement gave them a better idea of where they were within the level as evidenced by one participant saying, *"It was less disorientating, I had more of an idea of where I was when I moved compared to the jumping where I had no idea where I was so I to look around to find my position"*.

### **ANOVA Findings**

There was no statistically significant differences between the mean SPES scores for each camera view as determined by an ANOVA analysis ( $F(3, 76) = 0.691, p > .51$ ). Figure 46 shows the Box-Plot distribution of SPES score for each camera view. It can be assumed that the level of presence experienced does not correlate with the most or least preferred spectator view whereby the lowest SPES scoring camera angle is significantly different to the highest SPES score camera angle. Therefore, a more opinion based preference of spectator modes should be considered compared to the statistical levels of presence felt when deciding on which spectator mode to use within a Virtual Reality spectator experience.



**Figure 49** – Box Plot of the SPES score distribution results for each camera view.

## Discussion

### Improvements

One improvement that could alter the results of this study would be to create a game setting that is less horror focused. The reason for suggesting this improvement is due to some participants commenting about fearing the game environment which detracted their focus from observing the camera views. The reasoning behind creating a Zombie themed application was that the assets were readily available and implementing them within the game logic would reduce development time. However, should a different theme be chosen, the game logic would still work as the Zombie theme was a cosmetic choice.

Another significant improvement would be to implement a more dynamic gameplay situation for the scripted character by adding more tasks for it to complete, giving a better impression that a game is being played instead of being scripted. Furthermore, the movement of the character could be improved through tools such as motion capture where an individual could be recorded acting as though they are playing the game. That motion could then be applied to the character and the movements would look more human. While actual gameplay could be used with a player's movements streamed to the spectator view, this would sacrifice the continuity within the experiment application as the character's movements would differ in each

iteration of the study. It would also require the actual implementation of game logic of which this test application does not currently have.

### **Future work**

Although there was no significant difference between the SPES score of each spectator mode, this study did find that in 10 out of the 20 participants, either their most or least preferred spectator mode correlated with their lowest or highest SPES score. In 7 instances, both the highest and lowest score matched with the most or least preferred spectator mode. While it was found to be non-significant in this case, a wider study with an increased number of participants may find a correlation.

A more directed version of this study could be developed with different camera angles being mixed together to present the gameplay like a film or current esports presentations. While it would mean that the study theme would stray from looking at specific camera angles, the future study could focus on these viewing methods as the test application provides a ready-made gameplay scenario in which to implement them.

Giving participants control over what spectator views they watch the gameplay in could be implemented. This method would provide a natural way to measure preferred spectator mode as they should naturally navigate to their favourite view. The method of switching between tasks was already implemented on the HTC Vive controller as it was needed for testing the application. Therefore, integrating this feature into another experiment iteration would not require any additional development time.

### **Conclusion**

This study aimed to see which type of spectator mode is preferred when viewing a Virtual Reality game. It also aimed to see if there was a link between the level of presence felt within the spectator experience and the preferred view of participants. This was completed by creating an application that provided users with multiple camera angles to observe a scripted gameplay sequence. It gathered the level of presence felt through a SPES questionnaire and asked them to state their most and least preferred spectator view. A comparison between transition modes was also included as the application provided a suitable platform in which to compare the methods.

The results of this study found no correlation between the participant choices of most/least preferred and presence felt within each view. The SPES results show the most immersive view



was the third person view and the least immersive being the corner camera view. Compared to the participant choices of most preferred being free roam and the least preferred being first person. Based on these findings, it can be suggested that presence alone does not decide which view a spectator prefers. As well as comparing the numerical results with the participant's choices, an ANOVA was also completed and found no significant difference in the presence felt between each of the views, ruling out any empirical evidence that a certain mode is significantly more or less effective at creating presence for the spectator.

Although a significant correlation was not found, it is worth noting however that in 10 participant's cases, their most preferred view correlated with the most presence felt by them in that view. This also occurred in 10 participants least preferred view with 7 of the 20 participants having matching preferences with the most/least presence felt. This suggests that with a larger study, a significant result could be obtained as the correlations somewhat emerge.

This experiment also provided participants with a choice between instant switching between cameras and a smooth panning transition. In this case, the switching was done within the corner camera view scenario but treated as a separate section of the experiment. With an overwhelming majority of 15 to 3, the panning mode was picked as the preferred mode of camera switching. Qualitative answers suggested that the greater sense of location provided by the slow movement to a new position made the panning transition preferable to the instant cut switches.

There was no empirical evidence to suggest which camera views are the most successful as presence scores had no effect. However, the replies to the qualitative questions provide a useful insight into which modes are likely to be successful with a wider audience. For example, the first-person view was the least preferred with over half of the participants naming it with most participants noting how disorientated this view made them feel. Therefore, it can be suggested that this view should not be used in future Virtual Reality applications. In contrast, the free roam view was the most preferred choice with 6 participants selecting it and only one participant selecting it as their least preferred. Although not as decisive a result as the first-person view, the comments about this view are more about the positive experience when using it rather than feelings of disorientation. The other two modes, corner cameras and the third person view have mixed review from participants with some stating them as their preferred view and others their least preferred. This could be because these views contain potentially

disorientating factors such as forced movement and height compared to the free roam where nothing is forced onto the user's position and movement.

This experiment found no significant link between presence felt within a Virtual Reality scene and a user's preferred view of a Virtual Reality scene although there is evidence to suggest that a larger study may confirm these links. As such, the test application used in this study is freely available for those who wish to replicate or adapt this study for their own uses. This experiment did find, through qualitative interviews, that most participants dislike forced movement and viewpoints and prefer an experience which allows them the freedom to choose where they look and when they do it. In addition, the preferred method of switching between camera views is that of a panning transition over that of a jump cut as participants noted a greater sense of location when being moved to a new position over time rather than instantly.

## **Chapter 5 – Discussion and Conclusion**

### ***Real-World Application***

The results of both studies have provided us with a better understanding of how a virtual reality headset affects head movement and what type of view spectators prefer when observing virtual reality gameplay. This section outlines some “real-world” advice of the results of each study and how they could potentially be used to improve current or future virtual reality spectator practices.

### **First study**

Whilst the results of the first study found no significant difference in head movement between wearing a Virtual Reality headset and not, it should be noted that significant results were found in some of the tests. While a practice effect could eliminate the significant results, or the significant results could be attributed to outliers, the significant results suggest that there may still be improvement with regards to the weight distribution and overall weight of virtual reality headsets. Improving these aspects of virtual reality headsets is a common goal amongst hardware developers, but one that is emphasised as important by the results of the first study.

Furthermore, the significant results should be considered when developing new virtual reality spectator modes where extreme head movement is required, such as placing the spectator close to a large virtual screen. While wearing a virtual reality headset has been shown to have no real negative effect on head movement, fast paced, extreme movement across an axis could have an impact due to the increased weight load on the head.

## **Second study**

The results of the second study found that spectators of a virtual reality game prefer to be in control of their movement within the virtual environment and negatively viewed forced perspective, especially within a first person view as it contributed to feelings on motion sickness and loss of control. This suggests that developers should look to more of a free movement situation when developing spectator experiences to avoid the potential discomfort forced view and movement can have within a virtual environment. Furthermore, there was reason to believe a link between presence felt and preference of view would emerge if a larger scale study was conducted. This suggests that developers should endeavour to make their virtual environments as engaging as possible and promote free movement to produce an optimal virtual reality experience.

## ***Thesis Conclusion***

This thesis investigated two subjects that have not been looked at within an experiment setting regarding the speciation of Virtual Reality games. The first investigation stemmed from the question of how current generation headsets would affect its users as the time spent watching Virtual Reality games through these headsets increases. The second study was a study on how different camera angles could be implemented within a virtual environment and if they provided an enjoyable spectator experience. The second study also saw if a significant link could be made between the level of presence felt within a spectator view and the spectators favourite and least favourite view.

Although the first study found that there was no significant difference in head movement when wearing a Virtual Reality headset, a ready-made test application and data analysis tool was created that is freely available for others to improve upon or use as a platform for another head movement test. Lessons were learnt during the development of this study. For example, trying to implement a stream-reader of Python output within a Unity application results in data spikes from the accelerometer readings. In troubleshooting this issue, it was discovered that the best way to gather the accelerometer data was to record it separately in the first place. Additionally, by automatically rounding the data recordings, some slightly significant results may have been lost. This should be changed if the study was conducted again. The quality of the weighted headset used in this study should also be improved as its weight distribution was different from that of the Virtual Reality headset used. This could mean a different result could be found if both headsets were closer in design. However, this study has investigated an important subject

area that has not been explored with current Virtual Reality headsets and has provided a large application and analysis script which others can use to further research in the topic of virtual reality head movement.

The second study found that participants preferred having the ability to walk around a virtual environment and spectate gameplay without being forced into a specific view. It also found that the least preferred view was having a first-person perspective of the character in the game, with multiple reports of motion sickness during this view. The second objective of the study, which tried to find a link between presence (measured using the SPES questionnaire) and preferred spectator views, did not find a significant link. However, half of the participants had a link between either their most preferred or least preferred view and their highest or lowest presence score. As the application used for this study will be made available for anybody to replicate, a link between SPES score and preferred spectator view may yet be found either through a direct replication or an adaptation.

While both studies detailed in this thesis may not have discovered ground breaking new knowledge, it has investigated two critical factors emerging within Virtual Reality video game spectating, how the headset effects its users and which spectator modes people prefer. Additionally, it has found issues within the Unity game engine which caused data spikes and led to the creation of a tool that eliminates these spikes. It has also spawned a tool built specifically for automating the analysis of accelerometer data, as well as the applications used for the experiments which will be made freely available for others to replicate, adapt or build upon.

**End of thesis, thank you for reading**

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## Appendix

### Appendix 1 – stream-reader script.

```
using UnityEngine;
using System;
using System.IO;
using System.IO.Ports;
using System.Diagnostics;

public class Python : MonoBehaviour
{
    private ProcessStartInfo PythonInfo;
    private Process PythonProcess;
    private StreamReader PythonStreamReader;
    private string PythonExe;
    private string PythonScript;
    public string PythonOutput;

    //This is used to display the "sensor not connected" text from ConnectionStatus.cs
    public bool SensorConnected = false;
    public bool StreamData = false; //This is enabled and disabled in the
    TestManager.cs script, allowing data to only be read when the participants are
    completing the tasks.
    public bool COMConnected = false; //This is toggled true and false depending on if
    the accelerometer is connected to the correct COM port. In this case, it needs to be
    connected to COM3.

    private string[] Ports; //This array will save all COM connected devices, allowing
    us to scan through it and find out device.
    private string Port = "COM3";

    private TextAsset Sensor; //This is what we will save our Python script into, as a
    .txt file.

    void Start ()
    {
        StreamData = false;
        PythonExe = "python";

        //Loads in the text file containing the python code.
        Sensor = (TextAsset)Resources.Load("sensor", typeof(TextAsset));
        PythonScript = "-c \"" + Sensor.text + "\""; //Adds the Python compile keys.

        PythonInfo = new ProcessStartInfo(PythonExe);
        //Stops the Python shell being opened.
        PythonInfo.UseShellExecute = false;
        //Redirects the output to Unity so it can be logged.
        PythonInfo.RedirectStandardOutput = true;
        PythonInfo.CreateNoWindow = true; //Stop a window being opened to show output.
        PythonInfo.Arguments = PythonScript; //Passes our script to our Python process.

        PythonProcess = new Process();
        PythonProcess.StartInfo = PythonInfo;
        PythonProcess.Start();

        PythonStreamReader = PythonProcess.StandardOutput;
        PythonOutput = PythonStreamReader.ReadLine();

        Ports = SerialPort.GetPortNames();
    }
}
```

```

//Initial check to see if data is being streamed from the sensor.
if (String.IsNullOrEmpty(PythonOutput) == true)
{
    SensorConnected = false;
}
else
{
    SensorConnected = true;
}
//Initial check to see if our sensor is connected to the correct COM port.
if (Array.IndexOf(Ports, Port) < 0)
{
    SensorConnected = false;
    COMConnected = false;
}
else
{
    COMConnected = true;
}
}
//Constantly checks to see if the connection to the sensor is still there.
void check_connection()
{
    Ports = SerialPort.GetPortNames();
    if (String.IsNullOrEmpty(PythonOutput) == true)
    {
        SensorConnected = false;
    }
    else
    {
        SensorConnected = true;
    }
    if(Array.IndexOf(Ports, Port) < 0)
    {
        SensorConnected = false;
        COMConnected = false;
    }
    else
    {
        COMConnected = true;
    }
}
void get_data()
{
    //Send the sensor output to the stream reader, then assigns it to our string.
    PythonStreamreader = PythonProcess.StandardOutput;
    PythonOutput = PythonStreamreader.ReadLine();
}
void Update ()
{
    check_connection();//We always check the connection to the sensor.
    get_data();//We are always getting the data.
}
//When the program closes, we stop the Python process.
void OnApplicationQuit()
{
    PythonProcess.Close();
}
}

```



## ***Appendix 2 – Head movement study consent form***

### A Comparison of Head Movement with and Without a Virtual Reality Headset

Thank you for agreeing to participate in this study. This study aims to see if there is a difference in head movement when wearing a Virtual Reality headset. This document is intended to provide you with all the relevant information regarding the study. If you agree to continue your participation, please sign at the bottom of the page and proceed with the study. This document will also act as a debrief with relevant contact information should you wish to withdraw from the study.

#### **Method**

You will be sitting for the entire experiment facing the television screen. Instructions will appear on the screen asking you to complete various visual tasks which will involve moving your head. The study includes two tracking tasks where you will follow a circle around the screen, and one searching task where you will look for a target image. In order for us to collect your head movement data, you will wear a hat that has an accelerometer attached.

Firstly, if you wish to, you can spend some time in the Oculus demo scene to get used to being in a virtual reality environment. If you do not wish to do so and feel comfortable within virtual reality, we may begin the test immediately.

For this study you will complete each task 3 times in three separate conditions; wearing a VR headset, not wearing a VR headset and wearing a weighted headset. The order of tasks and conditions are randomised. There are audio instructions for each step of the experiment telling you what to do. Feel free to ask any questions during the study.

#### **Data Collected**

Apart from your name which is used for withdrawal purposes, no personal information is collected. The only data we collect is from the accelerometer that is attached to the hat you will wear during the study.

#### **Withdrawing**

If you wish to withdraw your data, you can for anytime up until 7 days after you have completed the study. To do so please send an email to [jgallacher@lincoln.ac.uk](mailto:jgallacher@lincoln.ac.uk) with your name and statement of withdrawal.

After reading the brief, I agree to participate in this study:

**X**

---

Name:

## Appendix 3 – SPES Questionnaire

### SPES Questions

*Please put a tick in your chosen answer.*

#### Self-Location

1- I felt like I was actually in the environment of the presentation.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

2- It seemed as though I actually took part in the action of the presentation.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

3- It was as though my true location had shifted into the environment in the presentation.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

4- I felt as though I was physically present in the environment of the presentation.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

#### Possible Actions

1- The objects in the presentation gave me the feeling that I could do things with them.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

2- I had the impression that I could be active in the environment of the presentation.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

3- I felt like I could move around the objects in the presentation.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

4- It seemed to me that I could do whatever I wanted in the environment of the presentation.

I do not agree at all	I do not agree	Neither	I agree	I fully agree

## **Appendix 4 – Virtual Reality spectator study consent form**

### Consent Form

Thank you for taking the time to agree to take part in this study. Before we can continue please read and sign this consent form to formally agree of your participation in this short study.

#### Purpose

The purpose of this study is to investigate the emerging capabilities of VR as an entertainment platform through exposing users to various spectator view points of a video game.

#### Study Overview

You will be using a HTC Vive Virtual Reality headset to view some recorded gameplay. You will view this gameplay multiple times with various camera angles. After each camera angle, you will remove the headset and fill out a short questionnaire aimed at recording how engaged you were with the scene using that particular camera angle, there are 4 viewing methods in total. After you have viewed all 4 modes, you will be given the HTC Vive controllers which allow you to switch between each of the camera modes you have previously experienced as a final look at which one is your favourite/least favourite.

After you have done this, you will be asked to state which spectator mode is your favourite as well as provide reasoning as to why this is the case. You will also be asked to state which spectator mode is your least favourite and state reasons why this is the case.

#### What Data do you need to provide?

In signing this form, you agree to have the data provided on the questionnaire used for analysis as well as video recording of your experience using the headset as well as an audio recording of your answers to the questions asked as the end of the study. No other data will be required for this study. The data you provide will also be fully anonymous.

#### Withdrawing

If you wish to withdraw your consent after you have taken part in this study, please email [jackleslie.gallacher@gmail.com](mailto:jackleslie.gallacher@gmail.com) stating your participant number and intention to withdraw from the study. You may withdraw from the study at any time.

#### Contact Information

If you have any questions after the study has been completed, please email [jackleslie.gallacher@gmail.com](mailto:jackleslie.gallacher@gmail.com).

**I Agree to take part in this study and confirm to the requirements stated above.**

**Name:**

**Signature:**