Head Motion Controls for 3D Head Mounted Display Games

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Dedications

I dedicate this thesis to my wonderful wife Kathleen Lyon. You never stopped believing in me, even though I gave you every reason to. I am eternally grateful for your support and the sacrifices you have made. I love you.
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The established methods for 3D interaction with virtual environments in games are not ideally suited for use with consumer level head mounted displays. Research towards more suitable methods for 3D interaction often focuses on the use of highly specialized input devices that are not easily available to consumer audiences. As an alternative, this research examines and explores control schemes that rely primarily on the motion of a user’s head for interaction in virtual environments, requiring no input devices beyond a head mounted display itself. Control schemes for head motion in existing games and technology demonstrations are reviewed. Several head motion control schemes for travel in virtual environments are prototyped and refined through iterative user evaluation. This research shows how head motion controls can be designed to create 3D interfaces with the objectives of comfort and learnability.
1. Introduction

Head mounted displays (HMD) are a recognizable symbol of the futuristic promise of immersive virtual reality (VR) entertainment. While in the past the reality of consumer HMDs has failed to live up to popular expectations, modern technology has rekindled this vision of compelling, affordable HMD devices. With multiple consumer level HMDs projected to come to market within the near future, identifying effective methods for user interaction with virtual environments mediated through HMDs is highly important.

A wide variety of interaction methods for use in virtual reality applications exist, but many of these solutions are impractical or unsuitable for consumer use. Issues of cost and availability make many sophisticated virtual reality input methods and devices, such as proprietary tracking peripherals, problematic for widespread consumer adoption [1]. Traditional input methods are more affordable and available but are also not ideally suited for use with HMDs. Devices like keyboards can be difficult to use because HMDs block the user’s ability to view the device [2].

A distinctive feature of HMDs for virtual reality entertainment applications is the ability to track the motion and orientation of a user’s head. Typically this is
used to dynamically update the view direction to provide the illusion that the user is in a virtual space. However, many other possible uses for head motion tracking in a game context exist, such as object manipulation, user interface navigation, and gestural input [3]. Answering the question ‘How can head motion controls be used to create control schemes that are easy to learn, comfortable, and self-contained for use with 1st person 3D head mounted display games?’ would generate valuable information about how this distinctive HMD input type could be used effectively in the emerging area of 3D HMD games.

1.1. Head Motion Controls for Head Mounted Displays

Head motion controls are important for use with consumer grade HMDs in entertainment for several key reasons. Head motion controls allow for self-contained, accessible, and modular control schemes with HMDs. The self-contained nature of head motion controls means that no additional hardware is required beyond the HMD itself in order to play games that use only this type of control. Accessibility means that users that are not able or are reluctant to play games with traditional manual controls can potentially play games that use head motion controls. Head motion controls are modular in that they are hands free and therefore retain the potential for combination with hand controls.
In order to provide interactive virtual reality experiences with HMDs, the devices must be able to provide orientation tracking. While many other input methods and devices are possible, specialized virtual reality input devices are not guaranteed to be available to a majority of the HMD consumer audience. Relying upon head motion controls means that no members of the potential audience for a VR experience will be excluded due to lack of hardware.

While many individual game developers are currently exploring ways to use head motion tracking for HMDs as an input method independently, no previous studies have focused on cataloging and evaluating its use specifically. The best practices guide for the Oculus Rift HMD suggests that further research is needed to evaluate the comfort and effectiveness of head motion controls, and that orientation and acceleration readings from head motion can be used to create unique control schemes [4]. Additionally, using head motion tracking for game tasks such as navigation is described as a unique problem to which potential solutions are not yet well documented [5].

1.1.1. Comparison with Advanced 3D Input

Specialized input devices designed specifically for VR can provide for compelling 3D input but are often expensive, of limited availability, or require potentially prohibitive amounts of space. These high requirements form a barri-
er to consumer adoption. Furthermore, there is no one specific standard device or set of advanced 3D input devices. For example, the Razer Hydra is a consumer motion controller that is very effective with consumer head mounted displays like the Oculus Rift. However, due to its limited availability, content designed for use with this device excludes a percentage of the possible audience that owns head mounted displays but does not own the Razer Hydra [3]. Similarly, requiring hardware that is more expensive or requires more physical space would also reduce the potential audience. The Virtuix Omni omnidirectional treadmill is one such device. It costs around $400 and occupies a 4 foot diameter circle [6]. These factors limit the potential consumer audience for games and applications that require this device.

1.1.2. Comparisons with Traditional Inputs

Traditional inputs, such as keyboard and mouse or a console videogame controller, are viable for consumer use but have some drawbacks in comparison to head motion controls. Mouse and keyboard suffer from fine registration and rooting problems that occur when users cannot see where their hands are and when the position of the hardware restricts their freedom of motion respectively [2]. Game controllers, similar to ones designed for game consoles, suffer less from these issues. However, Palmer Luckey, inventor of the Oculus Rift head
mounted display, feels that game controllers are not ideal for 3D input because of their high level of abstraction. Furthermore, he states it is difficult for non-gamers to learn the use of dual analog controls [7]. Head motion controls can be explained more easily than those for controllers to non-gamers when their vision is obscured by an immersive head mounted display. Head motion controls may also be used in conjunction with game controllers if the intended audience is already familiar with game controller use.

1.2. Terms

**Head Mounted Display (HMD):** A display device worn on a user’s head that displays an image directly in front of one or both eyes.

**Virtual Reality (VR):** A medium of interactive computer simulations that sense a user’s position and give feedback to generate a feeling of being present in the simulation [2].

**Virtual Environment (VE):** A synthetic, spatial world seen from a first-person point of view under real-time control of a user [8].

**Head Motion Controls:** User input defined by the motion of the user’s head. For consumer HMDs, orientation and acceleration are the primary components.

**Presence:** Illusion of non-mediation. Feeling of being present in a simulation.
**Immersion (Virtual Reality):** The level of sensory coverage. Greater immersion results from quantity and quality of sensory experiences provided by the simulation.

**Immersion (Gaming):** Refers to the level of engrossment or engagement in a simulation.

**Interaction Fidelity:** The degree to which 3D interactions are similar to analogous real world interactions.
1.3. Background

Head mounted displays could potentially bring the medium of virtual reality to a consumer audience in the next several years. Reviewed literature for this research examines what virtual reality is, why it is compelling, and how head mounted displays are able to provide effective virtual reality experiences. A brief history of the origin of head mounted displays and their prior shortcomings as widely adopted consumer devices is discussed.

1.3.1. Virtual Reality

The term ‘virtual reality’ describes a set of techniques and technologies that allow users to experience simulated 3D space. Sherman and Craig define virtual reality as, “A medium composed of interactive computer simulations that sense the participant’s position and actions, providing synthetic feedback to one or more senses, giving the feeling of being immersed or being present in the simulation.” [2] The motion sensors of a head mounted display allow for the computer generated images to respond dynamically to the motion of a user’s head, resulting in a sense of ‘presence’ in the virtual environment.

1.3.2. Presence

Lombard and Ditton define presence as the “the perceptual illusion of non-mediation.” [9] In layman’s terms, presence is the extent to which a person feels
like the VR simulation is real. They identify a variety of potential effects of presence, including enhancing enjoyment, involvement, task performance and training, desensitization, persuasion, and memory. Presence is thought to increase the extent to which users react to virtual stimuli in ways similar to how they might react in the ‘real world’ [10]. Slater and Wilbur state, “The distinguishing feature of immersive VEs [Virtual Environments] (IVEs), compared with exocentric desktop display systems, is that they afford a sense of presence.” [11] Sense of presence is an important factor in making consumer grade HMDs desirable for games and entertainment.

The term ‘presence’ as applied to media is derived from Minsky’s ‘telepresence’, coined in 1980 as a way to describe remote operation of robotic tools with high quality sensory feedback [12]. Sheridan applied the concept to virtual reality as well and began the use of the shortened form of ‘presence’ [13].

Presence is related to but distinct from immersion. Slater argues that immersion should refer to the objectively measurable technological level of media. “The more that a system delivers displays (in all sensory modalities) and tracking that preserves fidelity in relation to their equivalent real-world sensory modalities, the more that it is ‘immersive’.” [14] To avoid confusion, some researchers prefer the term ‘fidelity’ over immersion [15]. This is especially
important in gaming contexts where the term immersion can refer to many aspects of gameplay experience, including tactical immersion, strategic immersion, and narrative immersion [16]. The term ‘spatial immersion’ is used in gaming contexts as a near synonym for presence in virtual reality contexts [17].

1.3.3. Distinctive Properties of Head Mounted Displays

The first computer driven head mounted display was developed by Ivan Sutherland in the 1960s [18]. Since that time, display and rendering technology has advanced greatly, but the core concepts that allow head mounted displays to deliver compelling virtual reality experiences remain the same. Brooks defines virtual reality experiences as “any in which the user is effectively immersed in a responsive virtual world. This implies user dynamic control of viewpoint.” [19] For head mounted displays the orientation of the head is of key importance, especially when the range of positional motion is limited by seated posture or cords [2]. Sheridan states that the ability for head mounted displays to change the display viewpoint based on response to head motion allows them to be principal providers of presence, which is a sense of feeling present in a VR simulation [20]. For HMDs to serve as virtual reality displays, head orientation tracking serves as a functional minimum for user input when the user is seated or stationary. This reasonably assures the availability of this form of input for consumer
HMDs designed for interactive virtual reality. As a consequence, head motion controls are likely to be viable for the majority of consumer targeted HMDs.

Head mounted displays are able to create a sense of being inside a virtual environment by using motion tracking technology to match the view direction that is displayed to the user according to the orientation of their head. This provides an intuitive “look left, see left” interface [2]. This form of viewpoint matching is an extremely important aspect of an interactive virtual reality experience.

Head mounted displays are also able to provide depth cues via stereopsis. Two distinct images, one for each eye, are rendered and displayed to the user simultaneously. This is unlike the temporal multiplexing required for stereoscopy with projection based displays and monitors [8].

An advantage of head mounted displays is their ability to offer a full 360 degree field of regard. The user can always see the virtual world, regardless of where they are looking [8]. This contrasts with traditional displays and even some spatially immersive displays that do not provide 360 degree coverage.

Head mounted displays have traditionally had relatively small fields of view. Many have fields of view that are only 30 to 60 degrees horizontal [8]. However,
with modern display technology, head mounted displays with 90 degrees horizontal field of view or greater are now possible [21].

### 1.3.4. History of the Head Mounted Displays

In 1968, Ivan Sutherland created the first head mounted display in order to effectively display three dimensional images by taking advantage of perspective changes [18]. Called ‘the Sword of Damocles’ because the mechanical tracker’s weight required that it be suspended from the ceiling, Sutherland’s device displayed perspective vector graphics that changed as the user moved. Later iterations included ultrasonic tracking and wand based interaction [22].

By the mid-1980’s, advances in display and computer technology made similar but more powerful head mounted displays and virtual environments possible. NASA's Ames Research Center was the site for development of the Virtual Environment Workstation. The system, developed by Fisher, Humphries, McGreevy, and Robinett, offered greater capabilities with fewer custom built components [23]. Researchers desired to create a portable, low cost alternative to expensive and large projection configurations. Additional interaction modes, such as gesture and speech recognition, were also developed as part of the project. The first dataglove, by which a user could directly control 3D virtual objects
such as an articulated hand, was designed and implemented as part of this project [24].

By the early 1990’s, virtual reality and its associated hardware, such as head mounted displays, had become popular topics and gained widespread media attention. Despite improvements in cost and performance for graphics processing, head mounted displays still struggled to achieve high field of view, acceptable real-time rendering speeds, and low latency tracking [25]. Brooks describes the status of head mounted displays in 1994 as a choice between, “costly and cumbersome CRT HMDs, which had excellent resolution and color, or economical LCDs, which had coarse resolution and poor saturation” [19]. By 1999, Brooks describes available LCDs as more acceptable but notes that the industry median for field of view was still an undesirable 45 degrees at a cost of $5,000.

During the 1990s, several attempts at marketing head mounted displays to consumers for entertainment were made. Noteworthy entries include the Forte Technologies VFX-1 headgear and the VirtualIO I-glasses. These devices, released in 1995, each supported 3DOF orientation head tracking. The VFX-1 was compatible with PCs only but came with a 2DOF input device and retailed for $995. The I-glasses lacked an additional input device but were able to accept NTSC video, which allowed them to be used as a personal media viewer in addi-
tion to a virtual reality display. The PC enabled I-glasses retailed for $799 [26]. Widespread consumer adoption of immersive head mounted displays was inhibited by the high hardware costs, both for the headsets themselves and the required graphics processors for compelling experiences. Industry veteran Paul Mlyniec described the situation as, “a bubble that burst in the late 90s. It looked like there was no stopping Virtual Reality - but what did stop it was the cost of every piece of equipment... There was no possibility of using it at a consumer level - games were out of the question - so it just existed in labs and government. It couldn't break through the barrier” [27].

In the intervening time, advances in technology related to the video game and smartphone industries have enabled affordable head mounted display solutions to become available [28]. Powerful, modern graphics hardware can now compensate for geometric distortions caused by low cost, wide field of view lenses. Components such as motion trackers and compact displays developed for smartphones can now be purchased for use in head mounted displays cheaply and easily [5].

Recently, head mounted displays have begun to generate renewed interest at the consumer level. The most widely known head mounted display targeted at the consumer level is the Oculus Rift. The Rift has garnered strong positive me-
dia exposure through high profile demonstrations and a $2.4 million dollar crowd funding campaign via Kickstarter [5]. Sony has recently begun showing demonstrations of their HMZ personal 3D viewer line of products with a prototype head orientation tracker that allows for virtual reality applications [29]. Numerous other comparable consumer head mounted displays exist in the market including the Silicon MicroDisplay ST1080, the Carl Zeiss Cinemizer OLED, and the Vuzix Wrap 1200VR [30]. Head motion tracking is the most sophisticated form of tracking offered by any of these HMDs.

In the past, virtual reality through head mounted displays was not as widely adopted by consumers as many had predicted. Problems of fidelity, cost, and lack of unified 3D input techniques or devices each contributed to head mounted displays failing to gain traction at the consumer level. This research examines head motion controls as one possible way to create virtual reality experiences that do not rely on costly 3D input hardware.

1.4. Related Work

Several key studies informed this research. First, 3D interaction cataloging surveys helped to generalize and consolidate information about 3D user interfaces in the past. Second, testbeds for 3D interaction tasks have been used previously to analyze various control schemes for a variety of interaction tasks,
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and iterative methods of revision have shown promise. Lastly, prior research on using head motion for controls in virtual reality has suggested that this form of interaction might be viable for a broad audience.

1.4.1. 3D Interaction Techniques Surveys and Classification

In 1997, Chris Hand wrote a report detailing the state of the art in 3D interaction techniques for virtual environments [31]. While the techniques themselves have advanced in the intervening time, the motivation for this work is highly applicable to the state of 3D interaction techniques for HMDs. Hand concludes, "There is a large body of work on 3D interaction techniques, but this is presented in papers or is embodied within a variety of different systems. Consolidation of this information is required so that the various techniques can be easily described, shared and implemented by those interested in advancing the field."

Similarly, there is a growing body of work for 3D game interactivity for virtual environments with HMDs, but it is embedded in independently developed experimental games.

Mine defined several possible types of interactions for virtual environments, including movement, selection, manipulation, and scaling [32]. His report assumes only some form of display, not necessarily a HMD. Furthermore, the interaction techniques described may also require a hand tracker and an addi-
tional input device. Despite these differences, the listed major interaction types of movement, selection, and manipulation are applicable to head motion tracking for HMD games. Furthermore, the consolidation of 3D interaction techniques provides a precedent to show the value of such a research task.

Bowman, Kruijff, LaViola, and Poupyrev also addressed 3D interaction techniques for virtual environments [33]. They identified navigation, selection, manipulation, and system control as major categories of 3D interactions. In a subsequent publication, these authors added symbolic input as an additional major interaction type [8]. A similar classification method for head motion controls types would allow the range of potential interactions to be better understood.

1.4.2. 3D Interaction Testbed

Bowman, Johnson, and Hodges developed a 3D interaction testbed which was used to compare multiple 3D interaction methods in travel tasks [34]. The relevant task type from this study was a naïve search task performed in a virtual environment with multiple hidden areas and obstacles that blocked a user’s sight. The task required users to move in a virtual environment and find flags as quickly as possible. A large number of 3D interaction methods with a variety of hardware requirements were tested in this study. A gaze directed steering technique was found to be the fastest.
1.4.3. Iterative User Interface Design

Jakob Nielsen outlines a method for iterative user interface refinement and evaluation based on user tests [35]. In such a method, a user interface is created, evaluated by users, and refined based on feedback. This iterative method for user interface design has been shown to be capable of making great gains in usability with user groups of around ten individuals. The subjects used for each iteration of the design should be different to avoid transfer effects. Aspects of usability include ease of use and pleasantness.

1.4.4. Head Directed Navigation

Fuhrmann et al. [1] created the ‘head-directed navigation’ technique for navigation in a virtual environment using only head rotation as an input. In this method, users can move forward by tilting their head down, move backward by tilting their head up, and steer by rotating their head in the desired direction. Additionally, users could swap from walking mode to looking mode, where motion would temporarily be suspended, by tilting their head to the side. The ‘head directed navigation technique’ shows how head orientation controls can be used for navigation tasks but does not consider other forms of 3D interaction.
2. **Research Question**

How can head motion controls be used to create control schemes for 3D head mounted display games that are easy to learn, comfortable, and self-contained?

2.1. **Subsidiary Questions**

What control scheme designs currently exist?

How does user variability affect performance and user experience?

2.2. **Project Description**

In order to adequately answer the proposed research question, a two-step research project was carried out. First, a survey of head motion controls was performed. A selection of available games and experiences designed for HMDs was examined for instances of head motion controls for actions beyond simple viewpoint control. Identified uses were categorized and evaluated. Second, a playtest evaluation of selected head motion control methods was performed. A testbed prototype was developed in order to further evaluate head motion controls for a selected 3D interaction task in a gaming context. The prototype was used to compare several head motion control schemes in terms of learnability and comfort through a series of iterative playtest evaluations.
3. **Survey of Head Motion Controls**

A survey of techniques for using head motion controls in 1st person HMD games for actions beyond view direction control was performed. Academic literature has few examples of 3D interactions that rely specifically on head motion, so a survey of published work on head motion controls would be of limited use. However, many examples of head motion controls do exist in the forms of games and demonstrations created experimentally by virtual reality enthusiasts. Because of the active developer community, there exists a large volume of suitable games and demonstrations to explore for instances of head motion controls.

Each game or demonstration was briefly described. A description of each head motion control interaction type and its use were recorded, as well as a subjective evaluation of its effectiveness. Examples of head motion controls were classified based on the 3D interaction tasks as defined by Bowman et al [8]. A screenshot of each game or demonstration was also taken.

3.1. **Game and Demonstration Selection**

The games and demonstration applications were selected for their interesting uses of head motion controls. Many of the selected entries were created as part of the IndieCade VR game jam which took place in August of 2013. This was a three week event where Oculus Rift games were created. This event featured a
total of $50,000 in awards for the top entries [36]. Many of the entrants chose to use head motion controls as a major component of the games and experiences they designed. The large volume of entries provided a sufficient pool from which to draw examples. For individual game and demonstration analyses, see Appendix A.

The survey of head motion controls shows that a wide variety of games and demonstrations use this form of control. A broad range of 3D interaction tasks are possible. Some interactions were easier to learn and more comfortable than others. The survey supports the idea that head motion controls can be easily learned and comfortable, but further playtesting was carried out to evaluate this idea empirically.
4. **Playtest Evaluation of Selected Control Methods**

Head motion control schemes require no additional hardware beyond the head mounted display itself. The survey of head motion controls shows the breadth of their potential applications. Playtest evaluations were designed and performed in order to study how users would react to head motion controls in practice. The design of the playtests, the playtest procedure, and the data collected during playtests are described.

In order to evaluate the potential for head motion controls specifically in a sufficiently structured manner, a series of iterative playtest evaluations were undertaken. This method of research allowed for more flexibility than a more formal user study, while still providing the opportunity to gather empirical data on the potential for head motion controls to be used for HMD gaming. A travel 3D interaction task was selected as the focus for playtest evaluations, and three experimental head motion control schemes for travel were prototyped. These control schemes were evaluated during four discrete playtest periods, and between each period aspects of the control schemes were iteratively revised, with the goal of improving comfort and ease of learning.
4.1. Design

The design of the playtest evaluation is composed of several facets. These include selection of the task, the design of the testbed, and the iterative nature of the playtests, the software, and the hardware. These choices were informed by the background research, the related works, and the overall research goals of assessing comfort and ease of learning.

Three control schemes for the selected task were created and evaluated in the iterative playtests. These control schemes represent possible applications of head motion control to movement of avatar viewpoints in virtual reality.

4.1.1. Iterative Playtests

Ideally a wide range of head motion controls would be evaluated through user testing. However, due to the scope of the project and limited available resources, a single use of head motion for a specific 3D interaction task was selected as the focus for playtest evaluation. A travel task was selected because travel is considered a fundamentally important and universal task type in virtual reality research [8]. Effective travel is also necessary to increase user comfort and productivity in virtual environments [37]. Additionally, the work of Fuhrmann et al. suggested that a head motion control scheme for travel might be easy to learn and comfortable [1].
The design of the test task and environment is based on experimental work done by Bowman, Johnson, and Hodges in which multiple 3D interaction techniques were compared in travel tasks [34]. While numerous comparative 3D interaction studies have been conducted more recently, this particular study provided a simple but elegant method that focused on a single interaction task. The specific travel task selected for this research was a naïve search task. Naïve search tasks are appropriate in a gaming context because they stipulate that the user has no prior knowledge of the location of the target [38]. In games, players often travel through unfamiliar environments in search of objectives, so a naïve search task was highly appropriate.

Similar to the work of Bowman et al., a testbed environment was created in order to compare three different head motion control schemes for travel. The evaluation prototype was designed to be modular so that it could be reused in the future to evaluate additional kinds of VR control schemes and compare their results to the results of the head motion control schemes.

An iterative research method was selected in order to evaluate the relative merits of the three head motion control schemes for travel in virtual environments. This method was selected for its potential to achieve significant improvements in usability with small numbers of subjects in relatively few iter-
The Oculus Rift was selected as the head mounted display for this research. This choice was made because the Oculus Rift is relatively widely available, affordable, and offers high display and interaction fidelity. Additionally, the Oculus Rift software development kit allows for efficient integration with a variety of 3D engines suitable for rapid development of a playtest testbed environment.

Unity 3D was selected as the development environment for this research for its potential for rapid development and its excellent integration with the Oculus Rift. A fully featured Oculus Rift plugin is available for Unity 3D, that makes integrating the device relatively straightforward. The plugin also ensures that the image warping and camera setup are configured correctly for the unique display properties of the Oculus Rift.

4.1.2. Playtest Environment

The selected naïve search task required subjects to travel through an unfamiliar virtual environment in order to locate and collect flag targets as their objective. A primarily brown and green ‘post apocalypse’ urban theme was chosen for the environment for its relevance to popular gaming genres and the availability of licensable visual assets on the Unity asset store (see fig. 2). Visual assets were placed to create a single introductory level of low complexity and
Subjects were instructed to collect flags in groups of four. Each trial consisted of collecting a group of four flags. Each subject was asked to complete three consecutive trials with each of the three control schemes. For each control scheme, one of the three evaluation levels (A, B, or C) was selected. Between control schemes, subjects were permitted a five minute break during which they were instructed to complete a per scheme post evaluation questionnaire.

4.1.3. Head Motion Control Schemes

Three head motion control schemes for travel were developed and refined as part of the playtest evaluation process. The control schemes were designed to explore the potential range of possible head motion control schemes for travel and to show that unique control schemes were possible and could be made better through iterative playtesting. The three control schemes that were a part of this research were called the aviation control scheme, the motorcycle control scheme, and the stillness control scheme.

All control schemes were restricted to 2D travel along the ground plane, as users were confined to the surface of the environment in a manner consistent with reality. The linear speed for forward travel and the angular speed for rotation were selected based on real world human capabilities, as well as the requirements for a game like context.
The maximum speed for the initial control scheme configurations was approximately 10 meters per second, and the maximum rate of turning was 90 degrees per second. The Oculus Rift best practices guide suggests that speeds above 1.5 meters per second can be a source of discomfort, but a higher maximum speed was desired in order to more fully explore the potential for head motion control as a game input. Additionally, it was felt that subjects would be able to limit their speed using the head motion controls, to mitigate discomfort. The overall maximum speeds for the control schemes were intended to be the same throughout each of the playtests, but as the playtests progressed an overall reduction in speed of 50% was implemented for trial period 3, and a 75% reduction was implemented for trial period 4.

Head motions in this research are primarily described using terminology borrowed from the field of aviation. Pitch refers to neck flexion or extension directly forward or backward. Yaw refers to common head turning to the left or right. Roll refers to a leaning motion of the head to the left or right, also known as lateral flexion (see fig. 5).
Figure 5: Head Rotation Terminology
4.1.3.1. Aviation Control Scheme

The aviation control scheme is based primarily on the head directed navigation of Fuhrman et al. In the aviation control scheme, as in head directed navigation, tilting the head forward, also known as flexion, triggers forward movement. Tilting the head forward is referred to as head pitch. Turning is achieved by rotating the head in the desired direction of travel. Fuhrman’s head directed navigation allowed for backward travel and included the potential to switch between a mobile mode for travel and an immobile mode for viewing [1]. The aviation control scheme does not allow for backward travel or mode switching, to make it easier to learn and decrease chance of discomfort that may be caused by backward travel [4].

The aviation control scheme used minimum and maximum pitch parameters to drive forward velocity. If a subject assumed an orientation with less than the minimum required pitch, they would have no forward velocity. If a subject assumed an orientation between the minimum and maximum pitch, their velocity was interpolated, linearly in earlier iterations and later exponentially. If a subject assumed an orientation with greater than the maximum pitch, they would move at the maximum velocity.
The aviation control scheme also used minimum and maximum yaw parameters to control turning. The subject’s direction of motion always matched the direction that their head was facing with regard to yaw. However, if a subject exceeded the minimum yaw parameter in either direction, they would experience an additional amount of rotation, applied to their viewpoint’s root. This had the effect of allowing subjects to rotate their views a full 360 degrees in simulation space while still maintaining a seated position comfortably. The rate of viewpoint root rotation was interpolated between the minimum and maximum values.

4.1.3.2. Motorcycle Control Scheme

The motorcycle control scheme was inspired by the mechanical metaphor of shifting gears and the ability to control steering of a motorcycle by leaning. Users could cycle through a series of discrete speeds described as ‘gears’ by nodding. Additionally, root viewpoint rotation was possible by leaning the head to the left or right, referred to as roll.

Nodding was detected by sampling the angular velocity of head pitch. When the direction of pitch changed between positive and negative, the time and angle at which this event occurred was recorded. If a subsequent change of direction from negative to positive was detected within a short time, the angle between the
first and second directional change events was compared, and if it exceeded ten degrees, a nod event was interpreted by the control scheme.

Parameters for gear shifting included the total number of gears and the amount of time shifting from one gear to another would take. Presence or absence of an auditory sound effect denoting when shifting was taking place was also treated as a parameter.

The motorcycle control scheme used minimum and maximum roll parameters to control the rate of viewpoint root rotation. Roll below the minimum threshold in either direction resulted in no viewpoint root rotation. However, the direction of travel still matched the yaw of the subject’s head, so small amounts of turning were still possible through yaw as well. This had the unfortunate side effect of causing some subjects to ‘drift’ away from a true forward facing position.

4.1.3.3. Stillness Control Scheme

The stillness control scheme was developed as a potential way to balance desire to move with desire to look around the environment without moving. The velocity of a subject varied inversely with the overall motion of their head, such
that when a subject was looking around they tended to slow down, whereas if
they focused on a specific point they would tend to move toward it.

The stillness scheme took a rolling average of the magnitudes of angular ve-
locity for pitch, yaw, and roll each frame. When the average was less than the
minimum movement parameter, the subject would begin accelerating, up to a
maximum velocity. If the average movement was more than the minimum, the
subject would begin to decelerate at a rate proportional to the amount of move-
ment, up to a maximum rate. The stillness scheme also included multipliers for
the contribution of pitch, yaw, and roll toward the overall movement calculation,
such that the impact of each could be adjusted independently. Other parameters
included the time to take the movement rolling average over and the total mag-
nitude of acceleration. The stillness scheme controlled rotation in the same
manner as the aviation scheme, with yaw causing viewpoint root rotation past a
certain threshold.
Subjects were then informed that the playtest evaluation would require them to play a simple virtual reality game in which their objective was to collect flags, and they would be able control their movement in the game only by the motion of their heads. Subjects were informed that they would be using three distinct control schemes to complete this objective, and that they would be asked to respond to a series of statements about the control scheme after using it. Subjects were then given a brief description of the first control scheme they would be using. This description consisted of the name of the control scheme, a verbal description of the control scheme, and a simple visual example of the required head motions. Subjects then put on the HMD and began the virtual reality game.

For each control scheme, subjects were permitted to spend up to two minutes in a simplified practice area. They were instructed to practice with the control scheme until they felt they understood how it worked. Subjects were informed that their goal would be to collect flags by traveling towards them. When a subject traveled close to a flag, it would disappear and another would appear somewhere else in the level. After the practice time elapsed, or the subject indicated they understood the control scheme, subjects were informed that they would be collecting three sets of four flags each. During play, subjects could only receive the verbal description of the control scheme.
For each scheme, when a subject completed the collection of all flags, they were instructed to remove the HMD and were then given a post scheme questionnaire. They were instructed to consider only the control scheme they just used when responding to the items on the questionnaire. After completing the questionnaire for one scheme, the procedure for each scheme would be repeated until all three schemes had been played and evaluated.

If a subject experienced intense discomfort during the course of using a control scheme, they were instructed to take off the device if they had not already done so. Subjects who experienced intense discomfort were given several minutes to sit quietly and then were asked to complete the post scheme questionnaire. Subjects were then given the option to either completely end their participation or move on to the next control scheme.
4.3. Collected Data

Data collected during the playtest evaluations consists of three different classes of information. The raw gameplay recordings allow for recreation of the subjects’ experiences for future review. Secondly, gameplay metrics were collected in order to analyze several factors, such as motion information and time to task for flag collection. Thirdly, user self-reports were collected for each control scheme used by each user. Self-reports measure how users felt about a variety of factors but focus on comfort and ease of learning.

4.3.1. Gameplay Recordings

A comprehensive record of each subject’s gameplay session was captured by logging gameplay data each frame and writing the data out to a series of local text files in JSON format. Each frame, the simulation time and sensor output from the HMD was recorded. The Oculus Rift SDK makes available linear acceleration, angular velocity, and estimated orientation data, each of which were recorded every frame. Control scheme specific data for the amounts of movement and avatar rotation being generated by the control scheme were also recorded, as well as the absolute position and rotation of the avatar in the game space. Other game events, such as the beginning and ending of each control scheme, trial, and flag capture were also recorded.
From this data, highly detailed replays of playtest sessions can be recreated and reviewed. Compared to capturing the video output of the playtests directly, this method has the advantage of also being able to generate alternate visual representations of the playtest. A playtest replay client was created to review playtest sessions and uses a 3rd person estimation of the subject’s head position, as well as a top down view. Furthermore, the replay client generates a single camera viewpoint with comparable field of view to the HMD binocular view, which is more easily viewed than the raw video output would be. This method also has the advantage of being more effectively anonymized, as compared to video capture of subjects, which adds additional privacy risk and equipment overhead.

4.3.2. Gameplay Metrics

From the gameplay recordings, a variety of gameplay metrics were calculated. Time per flag and overall completion percentage were calculated. In order to account for the random location of flags, if a flag was instantly visible from the position of the previous flag, the adjusted time per flag was tripled. From the recordings of the position of the subjects at each frame, velocity and acceleration were derived. Rotational velocity of subjects’ heads was also recorded. Derived
measures were calculated by sampling per frame data and comparing changes from frame to frame with the amount of time elapsed between frames.

4.3.3. Per Scheme Post Evaluation Questionnaire

For each control scheme used, subjects were asked to respond to a series of 17 Likert items. Subjects were instructed to indicate to what degree they agreed or disagreed with a series of statements. Subjects were asked to select one of seven numerically associated response anchors for each item. The possible responses ranged from 1 (‘Strongly Disagree’) to 7 (‘Strongly Agree’) (see fig. 8).

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<td>Neither</td>
<td>Somewhat Agree</td>
<td>Agree</td>
<td>Strongly Agree</td>
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Figure 8: Likert Item Response Anchors

Response items were selected to gauge comfort, ease of learning, ease of control, and fun of each control scheme. Item 1 was based on the Single Ease Question which was shown to be effective in assessing ease of learning in post evaluation scenarios with small sample sizes [39]. Items 2 and 3 were based on items from the System Usability Scale which have been identified as constituting the learnability component of that scale [40]. Item 4 was originally written for
this research. Items 5-8 were written to attempt to diagnose in which areas users felt they were not able to control their movement efficiently. Item 9 was based on Core Module Item 23 from the Game Experience questionnaire, which was part of the ease of control measure [41]. Item 10 was a reformulation of Item 1 but altered to address comfort. Items 11 and 12 were originally written for this research to cover additional aspects of comfort. Items 13 and 14 were based on questions from the Simulator Sickness Questionnaire [42]. Items 16 and 17 were originally written for this research to gauge overall opinion of the subjects’ experience with the control schemes with regard to fun and desire to use this kind of control again.

Four Likert scales were calculated for each post scheme response set. Items 1-4 were combined to form the ease of learning scale, which was one of the two primary goals of this research. Items 10-15 were combined to form the comfort scale, which was the other major goal. Items 5-9 were combined to form the ease of control scale, and Items 16 and 17 were combined to form the fun scale. See Appendix B: Per Scheme Post-Evaluation Questionnaire. Items 2, 3, 6, and 11-15 where phrased as negative, so the inverse of these values were used in the Likert scales.
5. Results

The playtest evaluations yielded several results. Overall, subject self-reports indicate a moderately positive response to head motion controls. However, a large percentage of subjects experienced high levels of discomfort due to simulation sickness, which reduced the overall level of comfort reported and caused many subjects to end their participation without completing the desired number of playtest trials. Despite this, through the course of iterative playtests improvements can be seen in the aviation control scheme and the motorcycle control scheme.

5.1. Population

Playtest evaluations were performed on a population of 22 subjects. Demographic data was collected in a pre-evaluation questionnaire. See Appendix B: Pre-Evaluation Questionnaire for full text. The population consisted of 14 males and 8 females (see fig. 9). The subjects’ ages ranged from 19-64 (45 year range) with a mean age of 27.86 ($\sigma = 9.44$). The subjects’ heights ranged from 5.17 feet to 6.33 feet (1.17 foot range) with a mean of 5.68 feet ($\sigma = 0.26$ feet).
A weighted average for combined relevant experience was calculated by weighing computer and gaming experience values at a weight of one, 3D computer and 3D gaming experience at as weight of two, and VR and VR gaming experience at a weight of three. The weights for each aspect of experience were estimated based on the perceived relevance of each category of experience. The combined score was calculated by taking the sum of each score component multiplied by its associated weight and dividing by the sum of the weights (see fig. 14). The combined experience scores ranged from 0.25 to 2.5 (2.25 range) with a mean of 1.48 ($\sigma = 0.70$).

$$\left( \frac{1 \times \text{Computer} + 1 \times \text{Gaming} + 2 \times 3D \text{ Computer} + 2 \times 3D \text{ Gaming} + 3 \times \text{VR} + 3 \times \text{VR Gaming}}{1 + 1 + 2 + 2 + 3 + 3} \right)$$

Figure 14: Weighted Average for Combined Experience

5.2. Analysis

Data analysis was used to compare collected data in several ways. Comparing means of various measures across the periods shows how the performance of
control schemes changed in response to the iterative revisions. Comparing the means of the various control schemes against each other shows the various strengths and weaknesses of each. Comparing the means of different demographic groups allows for determinations to be made about how different groups of people respond to head motion control schemes.

Data analysis was conducted with IBM SPSS Statistics software. Analysis of variance (ANOVA) was conducted in order to compare the mean values of different subgroups. A significance threshold of 0.05 was used to determine whether or not means differed significantly between subgroups. If ANOVA calculations showed a significance value (p-value) of less than 0.05, the null hypothesis was rejected, and the difference was classified as significant. In order to provide a more complete picture of the results, graphs were also generated. Error bars on graphs represent the standard error of the mean.

5.2.1. Overall

Data was gathered from 22 subjects during 4 discrete playtest periods. A total of 66 expected subject control scheme pairs with post scheme questionnaire data was expected, however only 52 such data sets were collected due to a subject withdraw rate that was higher than anticipated. The reason for subjects’
withdraw was high levels of discomfort, commonly referred to as simulation sickness.

The mean completion percentage for each subject was calculated based on the total number of flags collected, divided by the number of flags in a complete session with three trials of four flags each with three different control schemes, 36 in total. Subjects ranged between collecting a single flag before withdrawing, to collecting all 36 flags. Eight subjects completed the full 36 flag objective. The mean completion percentage for all subjects was 57.32% (σ = 38.16%).

For all collected post scheme questionnaire data, the mean ease of learning score was 5.34 (σ = 1.04). The mean comfort scale score was 4.24 (σ =1.29). The mean ease of control scale score was 4.96 (σ =1.06), and the mean fun scale score was 4.64 (σ =1.10). Overall this indicates that the selected head motion control schemes for travel were considered positively by subjects, especially in ease of learning (see fig. 15).
5.2.2. Individual Control Scheme Iterations

As per the iterative evaluation strategy, revisions were made to each control scheme between playtest periods. Revisions were made primarily on the basis of researcher review of recorded game replays. The Likert items that comprise the ease of control subscale of the post-scheme questionnaire were designed to guide revisions but were not sufficiently expressive to accomplish this.

5.2.2.1. Aviation Scheme

Between playtest periods 1 and 2 the aviation control scheme reduced the minimum pitch threshold from 5 to 3, and increased the maximum pitch limit from 20 to 30. This change was made to give users a greater degree of control over their velocities, as it was perceived that subjects had to tilt their heads forward too severely. Minimum yaw threshold for turning was increased from 3 to 6 in order to give users more room to adjust their viewpoints without rotating their viewpoints unintentionally, which was also observed. Maximum yaw was increased from 20 to 30 to increase control.

Between playtest periods 2 and 3 overall speed was reduced to 50% of the original. Additionally, maximum pitch limit was changed back to 20 from 30. The reason for this change was that subjects were observed spending prolonged periods of time with their heads at the maximum angle, which seemed uncom-
5.2.2.2. Motorcycle Scheme

Between playtest periods 1 and 2 the motorcycle scheme had the number of possible ‘gears’ reduced from 5 to 4 (including stopped). This was done to allow subjects a better opportunity to remember which gear they were in and to reduce the number of nods required in general. This was guided by observations of users shifting past the fastest speed multiple times in short succession. Also, the minimum roll threshold was reduced from 20 to 5, as it was observed that subjects appeared uncomfortable in the degree to which they had to lean their heads.

Between playtest periods 2 and 3 overall speed was reduced to 50% of the original. The amount of time that the gear shifting process took was reduced from 0.5 seconds to 0.2 seconds. A lockout time period of 0.7 seconds was added to prevent unintentional over shifting caused by rapid nodding, which was observed. Gear shifting sound effects were added to better communicate when the shift was recognized by the system. These changes were made due to observations of unintended shifting. The maximum roll was reduced from 20 to 40 to reduce the angle to which subjects were required to lean in order to turn sharply, and the interpolation was changed from linear to exponential in order to provide smoother starting and stopping of turning. Between periods 3 and 4 overall speed was reduced to 25% of the original.
5.2.2.1. Stillness Scheme

Between playtest periods 1 and 2, the minimum movement threshold was reduced from 0.2 to 0.1 to increase sensitivity to the motion of subject’s heads. Additionally, the maximum movement threshold was increased from 5 to 3 to reduce the overall amount of head motion required to stop effectively. Subjects were observed to intentionally reduce speed very infrequently, due to the amount of motion that was required to do so. Minimum yaw threshold for turning was increased from 3 to 6 in order to give users more room to adjust their viewpoints without rotating their viewpoints unintentionally. Maximum yaw was increased from 20 to 30 to increase control.

Between playtest periods 2 and 3 overall speed was reduced to 50% of the original. The amount of time over which the rolling average of head motion was taken was reduced from 0.2 to 0.1 for better responsiveness. Additionally, the overall magnitude of acceleration experienced in this control scheme was increased from 0.2 to 0.5, and the contribution of yaw to the overall head motion detection was reduced to allow better potential for turning without slowing down unintentionally. These changes were guided by review of playtest replays in which subjects did not appear to vary their speed frequently. Between periods 3 and 4 overall speed was reduced to 25% of the original.
5.2.3. Flag Collection Time to Task

Analysis of the average time for subjects to complete a single flag collection yielded several significant results. Most interestingly, as the total speed of the control schemes was reduced, the corresponding mean time for flag collection did not increase proportionately. The mean for full speed periods 1 and 2 was approximately 26 seconds per flag. For period 3, the maximum speed for all control schemes was reduced by 50%, but the time per flag increased only by 38%. For period 4, the speed compared to the original speeds was 25%, but the time per flag only doubled, rather than quadruple as might be expected. This suggests that subjects were more efficient with the control schemes in periods 3 and 4. Time per flag is calculated as the mean number of seconds between flag collection events. If a flag was immediately visible from the previous flag position, this value was tripled. The mean of all visible flag captures was about 1/3 of the mean of all non-visible flag captures. Normalized time is normalized based on the speed multiplier for each period. For period 3, the speed of each control scheme was 50% of the base speeds for periods 1 & 2, so the normalized time is 50% of the time. For period 4, the speed of each control scheme was 25% of the base speeds for period 1 & 2, so the normalized time is 25% of the time (see fig. 21).
5.2.5. Simulation Sickness

Throughout the course of this research, high levels of discomfort caused by simulation sickness were a major factor. Interestingly few significant correlations between incidence of sickness, estimated by comfort scale rating and completion percentage and other demographic or gameplay factors, were supported by this research. Factors of age, combined experience level, and currently worn lenses were not observed to significantly impact either completion percentage or comfort scale.

Gender was observed to have a significant impact on reported comfort scale levels. Males reported a mean comfort score of 4.49 across all post scheme questionnaire responses, where females reported a mean score of 3.68. ANOVA shows a significance value of 0.036 which is less than 0.05, allowing for the rejection of the null hypothesis, suggesting that females report significantly lower comfort scale responses (see fig. 25).
experiencing discomfort may have altered their gameplay to reduce accelerations.

Subjects that reported a higher comfort level generally had completed a greater percentage of the intended playtest. For all subject scheme pairs, a Pearson correlation (R) value of 0.441 was calculated, indicating two-tailed significance at the 0.01 level (see fig. 27).

When comparing mean Likert scale values between subjects who completed 100% of the intended playtest against subjects who withdrew due to simulation sickness, several differences can be noted. Ease of control and comfort levels both varied significantly between groups (see fig. 28). Comfort was expected to be higher for the 100% completion group, but ease of control was also higher. This could indicate that feeling in control of a control scheme leads to better completion or could indicate that factors that lead to subjects withdrawing also lead to reduced feelings of control. Fun level was higher for subjects that had greater completion percentages, but not significantly so.
appropriate uses for this type of control scheme, especially in travel or viewpoint manipulation tasks.

6. Limitations

The primary limitation of this research was the incidences of subject withdraw due to high levels of discomfort caused by simulation sickness. While the possibility for discomfort of this type was known, the degree to which the study was impacted was not anticipated. Based on anecdotal responses freely given by subjects who experienced the most extreme discomfort, subjects that are affected by motion sickness in cars, boats, or on amusement park rides may be at especially high risk for simulation sickness. Addressing a history of motion sickness on the pre-evaluation questionnaire would help to account for this issue, in that such propensities could be factored in to the results.

The overall size of the playtest subject population was also a limitation to this study. Additional analysis of improvements over repeated iterations of using a control scheme was planned, however the small sample size combined with the withdraw rate resulted in too few samples. Improvement over time would be another valuable learnability measure.
Several other playtest evaluation design decisions limited the strength of the research results and could be improved upon for future research. An alternative design could anticipate the potential for subjects to withdraw by shortening the amount of time the subjects are being asked to stay in the virtual environment. Additionally, subjects could freely choose the duration of their participation as part of the study, which could serve as an additional data measure. Rather than using completely random selection for flag locations for each subject, a randomly generated set of flag locations could be used for all subjects in order to reduce the effects of chance on playtest results. Additional tasks could be added to the testbed to examine other factors like accuracy of motion or maneuverability rather than just speed.

Lastly, the hardware used for this research can potentially cause feelings of discomfort in some people regardless of the virtual reality content. However, it may also be the case that use of head motion specifically for travel tasks intensifies the risk for simulation sickness to occur. Based on anecdotal evidence from some subjects who have small levels of virtual reality experience, the playtest environment and associated control schemes for this research may be more likely to cause discomfort than other VR experiences.
7. **Future Work**

In order to better understand if head motion controls can be a useful tool in creating virtual reality content for a broad audience, the circumstances around the onset of simulation sickness must be addressed. Research to determine how strongly the head motion controls contributed to simulation sickness, compared to other control schemes or 3D interaction methods, will be critical in assessing the viability of such control schemes. Testing the head motion control schemes from this research or other similar control schemes with new and upcoming hardware will shed light on this issue.

Exploring other 3D interaction tasks for use with head motion controls will also be an important step in determining the appropriate uses for head motion controls. Pointing and selection tasks have great potential in terms of both usability and comfort, and advances in head mounted display technology may also allow for the use of eye tracking in combination with head motion. This would lead to 3D interfaces that are even more easily learned and comfortable.

8. **Implications and Significance**

The significance of this research lies in several key areas. First, this research has highlighted the potential of head motion controls in creating virtual reality
content that targets a wide potential audience. Secondly, this research has collected and consolidated information about existing uses of head motion controls. The design of the iterative playtest experiments provides a case study of how VR research may be carried out with consumer level head mounted displays and shows both strengths and weaknesses that can inform future study. Lastly, this research has provided empirical evidence for the strong impact of individual subject factors in the incidence and intensity of simulation sickness with consumer level HMDs.

This research asserts that head motion controls would be accessible to a wide audience of consumer HMD owners. Head mounted displays need to be able to sense head orientation to provide VR experiences. Accelerometers and gyroimeters capable of measuring head motion are small, lightweight, and very affordable electronic components, so their inclusion in HMDs is highly likely.

The results of the iterative playtesting suggest that subjects found the selected head motion control schemes to be easy to learn. Despite the experience of simulation sickness, subjects also responded positively with regard to comfort, ease of control, and fun as well. This suggests that while head motion controls may not be suitable for everyone, the subset of individuals who do not experience high
levels of simulation sickness may find head motion controls to be a compelling method of 3D user input for consumer virtual reality.

This research highlights several potential uses for head motion controls, including travel, selection, and manipulation tasks in virtual reality. While many more potential uses exist, the uses of head motion control listed provide concrete examples of how head motion controls can be used. Future VR game makers can use the information about existing head motion control schemes to draw inspiration from. This research also provides a link between the vibrant experimental VR enthusiast community and the realm of academic 3D interaction research.

The implementation of the test bed environment for iterative playtesting and the design of the iterative playtests have value for future researchers. The methods of capturing and replaying full session data can be considered as an alternative to other means of subject recordings. The results of this research indicate that greater focus should be placed upon addressing simulation sickness in the design of future research. The results suggest that continuation desire should be built in to a study design more explicitly and that a high withdraw percentage should be anticipated.
Lastly, the results of this research with regard to simulation sickness indicate that unknown individual subject factors strongly impact overall comfort level. While it is possible that the high speed of motion is a contributing factor, users in both the fast speed and later slow speed trials exhibited a range of simulation sickness responses. Some subjects experienced very little discomfort even at high speeds, whereas some subjects experienced very high levels of discomfort even at very low speeds. Some subjects with high levels of relevant experience became very uncomfortable, while some subjects with very low levels of relevant experience did not. This research suggests that some other factor inherent to individual subjects is the major factor in determining level of discomfort when using head motion controls.

Head mounted display gaming has the potential to be an extremely important feature of the consumer entertainment landscape in the coming years. Head motion controls are a nearly ubiquitous form of potential input for consumer HMDs. This research has shown that there is a strong potential for head motion controls to be both easy to learn and comfortable, but that with the currently available consumer HMD prototypes, simulation sickness is a major concern. The knowledge of how head motion controls have been used and what
potential issues they may have allows for more well informed design and development choices for consumer HMD game controls.
List of References


Appendix A: Observed Applications of Head Motion Controls
ly mapped to a navigation control, which allows the user to look around as they travel without altering their path. Instead, rotation of the player’s avatar is mapped to their head roll, and a more extreme roll will result in a faster avatar rotation, which rotates the viewpoint simultaneously.

This mapping, combined with the environment which lacked strong reference features, lead to motion which was not easily observed. Sources of discomfort included disorientation from the mapping of roll to rotation and extended head flexion and extension due to not knowing exactly how fast the vertical motion was.

**Head Motion Control: System Control**

View Direction: Highlight menu item.

‘Nod’ Gesture: Select currently highlighted menu item.

This set of head motion controls is used in the pre-game menu. Players can select from several options including ‘start’ and ‘exit’ by directing their view toward the items, which then become highlighted. To confirm selection of a highlighted item, the player must perform a ‘nod’ gesture, defined as a fairly rapid motion of head pitch from a neutral position to a downward position.
The use of view direction for highlighting was effective. The use of the nodding gesture was functional, but uncertainty about whether or not the game had properly interpreted the gesture could lead to confusion.
the lean controls is so subtle, using the keyboard or gamepad steering controls is necessary to make any quick maneuvers, such as avoiding obstacles on the course.
of a pecking motion, the player is unable to see other relevant game elements as their gaze is directed toward the ground. Other objectives or enemies, like the fox, are more difficult to view when facing downward as part of the pecking motion. This incentivizes the player to return their head pitch to a more neutral level after the desired resource has been collected, rather than leaving the head downward at all times.

The motion of pecking feels like it would potentially become tiresome over longer periods of time since a large amount of rotation is required in order to activate resource collection.
and be brought into a mini-game view. Additional rotation of view is possible with arrow keys or gamepad joystick.

**Head Motion Control: Aiming/Selection**

In the mini-game view, players shoot hacks to disable programs and take control of the node they are in. View direction controls the path in which the hack will be fired. Fire activation is controlled by button press. Auto-targeting ensures that the hack will hit the closest program to the direction in which the player was looking.

The use of abstract imagery allows Ciess to create a sense of presence in its cyber themed environment. The combination of view direction for selection control and button presses for selection confirmation allows for good combinations of head motion and traditional controls. Restricting travel to only forward motion and only at specific times allows for the sensation of moving within the environment, without introducing movement possibilities that can cause disorientation or discomfort.
item will appear and require a subsequent selection. This is used for the main menu and other menus for which an inadvertent selection would be problematic. Symbolic input occurs in a similar fashion for menus such as the one where you enter your initials upon achieving a high score selection but does not require the subsequent “OK” activation.

**Head Motion Control: Aiming / Manipulation**

The primary gameplay mode allows the player to control a space ship that continuously fires projectiles at a fixed rate. The ship is constrained to a spherical shell at a fixed distance from the player’s viewpoint in 3D space. The player is able to control the motion and direction of the space ship by looking at different parts of the screen. The space ship will rotate in order to aim in the direction of the player’s view, and the ship will move toward the position of the player’s view.

Both the menu systems and the core gameplay are intuitive. The gameplay control scheme often results in the ship shooting exactly what the player is looking at, but the motion of the ship adds an additional layer of challenge in later levels where asteroids need to be avoided.
to activate by looking in the direction of the item. The item that the player is looking at moves forward, toward the player. The selection becomes active via button press.

The viewing map control is very effective in this style of game. Looking downward at a map is both thematically appropriate and a way to add tension to the already scary atmosphere. Looking down at a map becomes much more of a strategic choice, as a player may not see unfriendly spirits approaching them if they are looking down at the map.

The inventory system is clean and intuitive and helps to preserve the crucial sense of presence by grounding a typically disconnected inventory system directly in the virtual world.
Appendix B: Playtest Evaluation Instruments
Pre-Evaluation Questionnaire

Age__________

Gender__________

Height__________

Vision: Please Check One

☐ Nearsighted ☐ Farsighted ☐ Normal Vision

Vision Correction Currently Worn: Please Check One

☐ No Corrective Lenses ☐ Glasses ☐ Contact Lenses

Computer Experience: Please Check One

☐ None ☐ Small Amount ☐ Moderate Amount ☐ Large Amount

Gaming Experience: Please Check One

☐ None ☐ Small Amount ☐ Moderate Amount ☐ Large Amount

Computer Experience with 3D Programs: Please Check One

☐ None ☐ Small Amount ☐ Moderate Amount ☐ Large Amount

3D Gaming Experience: Please Check One

☐ None ☐ Small Amount ☐ Moderate Amount ☐ Large Amount

Immersive Virtual Reality Experience: Please Check One

☐ None ☐ Small Amount ☐ Moderate Amount ☐ Large Amount

Immersive Virtual Reality Gaming Experience: Please Check One

☐ None ☐ Small Amount ☐ Moderate Amount ☐ Large Amount
**Per Scheme Post-Evaluation Questionnaire**

Please fill in the number that represents how you feel about the game you have been just playing.

1. Learning the controls was easy.
   - 1 Strongly Disagree
   - 2 Disagree
   - 3 Somewhat Disagree
   - 4 Neither
   - 5 Somewhat Agree
   - 6 Agree
   - 7 Strongly Agree

2. I would need outside help to be able to play this game.
   - 1 Strongly Disagree
   - 2 Disagree
   - 3 Somewhat Disagree
   - 4 Neither
   - 5 Somewhat Agree
   - 6 Agree
   - 7 Strongly Agree

3. I would need to learn a lot before I would be able to enjoy this game.
   - 1 Strongly Disagree
   - 2 Disagree
   - 3 Somewhat Disagree
   - 4 Neither
   - 5 Somewhat Agree
   - 6 Agree
   - 7 Strongly Agree

4. Controlling the game was intuitive.
   - 1 Strongly Disagree
   - 2 Disagree
   - 3 Somewhat Disagree
   - 4 Neither
   - 5 Somewhat Agree
   - 6 Agree
   - 7 Strongly Agree

5. I was able to start and stop moving whenever I wanted to.
   - 1 Strongly Disagree
   - 2 Disagree
   - 3 Somewhat Disagree
   - 4 Neither
   - 5 Somewhat Agree
   - 6 Agree
   - 7 Strongly Agree
6. I often turned in a direction that I didn’t intend to.

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<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Somewhat Disagree</td>
<td>Neither</td>
<td>Somewhat Agree</td>
<td>Agree</td>
<td>Strongly Agree</td>
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7. I was able to move quickly from place to place.

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8. I was able to move to the locations I wanted to.

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9. I was fast at reaching the game’s targets.

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10. Controlling the game was comfortable.

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11. I had to move my head in awkward ways.

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</table>
12. I felt dizzy when playing the game.
   ![Survey Rating Scale]

13. I felt disoriented when playing the game.
   ![Survey Rating Scale]

14. I felt nauseous when playing the game.
   ![Survey Rating Scale]

15. Playing the game was tiring.
   ![Survey Rating Scale]

16. This game was fun.
   ![Survey Rating Scale]

17. I would like to play this game again.
   ![Survey Rating Scale]