# Use of Eye Movements for Video Game Control

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## ABSTRACT

We present a study that explores the use of a commercially available eye tracker as a control device for video games. We examine its use across multiple gaming genres and present games that utilize the eye tracker in a variety of ways. First, we describe a first-person shooter that uses the eyes to control orientation. Second, we study the use of eye movements for more natural interaction with characters in a role playing game. And lastly, we examine the use of eye tracking as a means to control a modified version of the classic action/arcade game Missile Command. Our results indicate that the use of an eye tracker can increase the immersion of a video game and can significantly alter the gameplay experience.

## Categories and Subject Descriptors

H5.2. Information interfaces and presentation (e.g., HCI): User interfaces: Input devices and strategies

## General Terms

Design, Human Factors

## Keywords

Eye Tracking, Video Games.

## 1. INTRODUCTION

A recent trend in the video game industry is toward a more complex controller. Devices such as the Dual Shock 2 controller made popular with the Playstation 2 are designed to satisfy the needs of the avid gamer but can be intimidating for non-gamers to adopt [7]. To answer this problem, the industry has introduced alternative control mechanisms that allow players to interact with video games in simpler, more natural ways. For example, the Sony Eye Toy allows players to use natural gestures and posturing for control [20]. Similarly, the upcoming Nintendo console, codenamed Revolution, will allow players to use a device similar to a familiar television remote augmented with 6 degrees-of-freedom tracking to control games. These devices are designed to make the control of video games less intimidating to inexperienced users, and hence attract new gamers to the market.

Building on this idea, we propose the use of eye tracking technology as a way to simplify video game control. The use of eye tracking has many benefits including:

- **Eye-based input is very natural** – Humans use eye movements extensively to communicate with other humans. For example, we use eye movements to facilitate turn taking in group conversations [25].
- **Eye movements are extremely fast and require little effort** – The muscles controlling the eyes are the fastest in the human body. Humans make thousands of eye movements every day and experience very little fatigue [4].
- **The eyes provide context for other forms of interaction** – Research has shown that eye movements oftentimes precede other modes of communication, and can hence provide context. For example, we typically look at a device before issuing a speech command to it [10] [15]. Therefore, eye tracking can set the context for speech, allowing for a more natural command phrase to be used. For instance, a user could say: "On" rather than: "Lamp on" [19].
- **The technology is mature** – Eye tracking has been used in psychological research and interactive system design for many years. Today's most popular eye tracking technique was developed in the late 1960's and is now being used in many commercial systems [4].
- **Eye tracker components are inexpensive** – Today's most common eye tracking technique requires only an infrared (IR) light source and a camera fitted with an IR filter [4]. Also, recent advancements in the design of eye trackers have yielded a reduction in manufacturing costs [19] [20].

### 1.1 Gaze and Video Games

Many recent commercial games already include a concept of gaze-based interaction. Most obvious is the first-person shooter genre, where the field of view of the player's avatar is explicitly presented to the user. Other games build on the way humans use eye movements to manage social situations as a means for an avatar to communicate with the player. For example, In "The Legend of Zelda: The Wind Waker", the player's avatar indicates that a nearby object might be interesting by looking at it (Figure



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**Figure 1: In the Legend of Zelda: The Wind Waker, the player's avatar points to interesting objects in the environment by looking at them [1].**


**Figure 2: In Madden NFL 06, the quarterback's vision is represented as a cone protruding from the avatar's eyes [5].**

1) [8]. Additionally, some games require the player to explicitly control an avatar's gaze direction. For example, in Madden NFL '06 the quarterback's field of vision is represented as a "vision cone" protruding from the avatar's eyes (Figure 2) [5]. The character's gaze must be directed toward a target before an accurate pass can be made. A natural extension to these games afforded by an eye tracker might allow a user to, for example, reciprocate eye-based pointing with avatars or allow for a natural mapping between the orientation of a quarterback's eyes and the point on the screen at which the player is looking.

### 1.2 Using Eye-based Input

In this paper, we present a study that explores the effects of eye-based input on the experience of playing video games. Our study compared the use of an eye tracker to a desktop mouse for game control. We chose three different games spread across three different genres, utilizing the input modalities in different ways:

1. *Quake 2*: A first-person shooter where the user controls orientation with either the mouse or the eyes [6].
2. *Neverwinter Nights*: A role-playing game in which an avatar is moved through an interactive environment through pointing [1].
3. *Lunar Command*: An action/arcade game in which moving objects are targeted through pointing [9].

In each of the games, we recorded player performance with the mouse and eye tracker and collected subjective data comparing the subjects' experiences across the two conditions. Our results indicate that utilizing eye-based input for game control can alter the gaming experience by making the game's virtual environment feel more immersive.

## 2. TRACKING THE EYE

Eye tracking technology has a long history, however most previous work has focused on studying the cognitive processes of the brain or studying the human visual system itself [4]. The use of an eye tracker as an input device for a computer is a much less studied area of research, focusing mainly on how the eyes can be used as a substitute for a mouse as a pointing device. In the following two sections, we look at modern eye tracking techniques and various ways in which this technology has been used in interactive computer systems.

### 2.1 Corneal Reflection Eye Trackers

Today, the most common form of eye tracker is the desktop "corneal reflection" unit (Figure 3). These systems report the location of the user's gaze as a screen coordinate on a monitor. To determine where the user is looking, these systems track one or both eyes by observing them with a camera fitted with an infrared (IR) filter. The system uses computer vision techniques to extract the user's pupil and the reflection on the cornea of an IR light source that is in a fixed position near to the camera. Because the surface of the user's cornea is roughly spherical the location of the corneal reflection will stay fixed as the users' eyes move relative to the head. Thus, the position of the pupil relative to this reflection yields the user's eye position. A calibration sequence is used to map eye movements to screen coordinates. Wearable systems also exist that are useful for ubiquitous computing scenarios. These systems employ the same technique as desktop systems, but report gaze as a coordinate in an on-board camera mounted on the user's head.

Detecting the user's pupil is perhaps the most delicate and error-prone aspect of corneal reflection eye tracking. Hence, several different techniques have been proposed. The simplest is "dark pupil" tracking (Figure 4) [4]. These systems illuminate the users' eyes with an IR light source located somewhere external to the camera's visual axis. This leaves a dark, round pupil in the middle of a bright, illuminated iris, and the pupil can then be thresholded out. Other systems use "bright pupil" tracking (Figure 5) [4]. These systems take advantage of the same phenomenon that produces the "red eye" effect in flash photography. To detect the pupil, these systems use an IR light


**Figure 3: The Polhemus VisionTrak ETL-400 uses a camera and an IR light source situated around the camera lens to track the user's eyes [17].**

source located on the visual axis of the camera. Light rays from this IR light source enter the pupil and are reflected back off the retina in the same direction as they entered. This causes the pupil to appear illuminated relative to the rest of the eye. The Pupil Cam, developed as part of the IBM Blue Eyes project, uses both bright and dark tracking to detect the users' pupil [11]. This system alternates techniques from frame to frame. Each frame is then subtracted from the one before it, leaving only the user's pupil.

### *2.1.1 Eye Contact Sensing*

The Eye Contact Sensor (ECS) is a system that is designed to be embedded in an object and reports when it is receiving visual attention [19]. This technology applies the same pupil detection technique used with IBM's Pupil Cam, but does not relate the location of the user's gaze to a coordinate system, eliminating the need for calibration. In addition, the system can be produced for a fraction of the cost of a commercial eye tracker. The ECS signals eye contact when the corneal reflection appears central to the user's pupil. The sensor can detect eye contact at up to 2-3 meters distance.

ViewPointer is a wearable version of the eye contact sensor that is suited for scenarios where many different objects are to be augmented with eye contact sensing [20]. The user wears a small headset and the eye contact is reported with objects bearing a small IR tag. The system uses dark pupil tracking and reports eye contact when the reflection of the IR tag appears central to the user's pupil. These tags are modulated with a unique binary code used for identification. ViewPointer has a large cost reduction over the ECS when tracking the eyes of a small number of people over a large number of objects.

## 2.2 Estimating Gaze with Head Orientation

Some systems use head orientation as an estimation for the user's gaze direction. TrackIR is a commercial system that uses head orientation as input for many PC video games [13]. This system uses an infrared camera to track the position of IR reflective markers placed on the user's head, and reports head position with six degrees-of-freedom at a sample rate of 120 FPS. Head orientation can then be used as input for "fish tank VR", where a virtual world appears to be 3D because the view changes depending on the angle at which the user looks at it.

Eye-R is a system that uses head orientation as estimation for gaze direction, but also detects when the user's eye is fixated [18]. The system was designed to be used as an augmentation for any common pair of glasses that detects eye contact with other wearers in ubiquitous computing scenarios. The system contains an IR transmitter and receiver pointed into the user's environment. This transmitter is fitted with an IR LED with a narrow angle of transmission (17 - 20 degrees) that transmits a unique code. This allows the system to determine when the user's head is oriented towards another user. An IR LED and a phototransistor is pointed inward towards the user's eye. As the user's eye moves, the amount of IR reflected from the eye changes. A fixation is detected when the amount of IR reflected from the wearer's eye remains constant. Eye contact is determined when the user's head is oriented towards another user

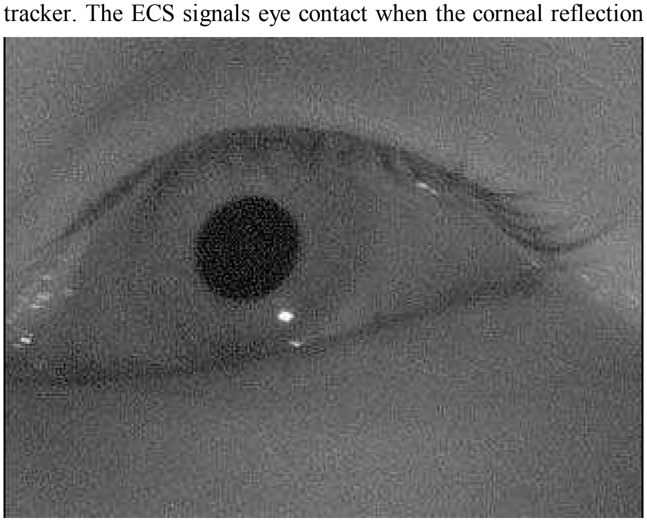


**Figure 4: Dark pupil tracking illuminates the eye with an off-axis IR light source and extracts the black pupil [11].**

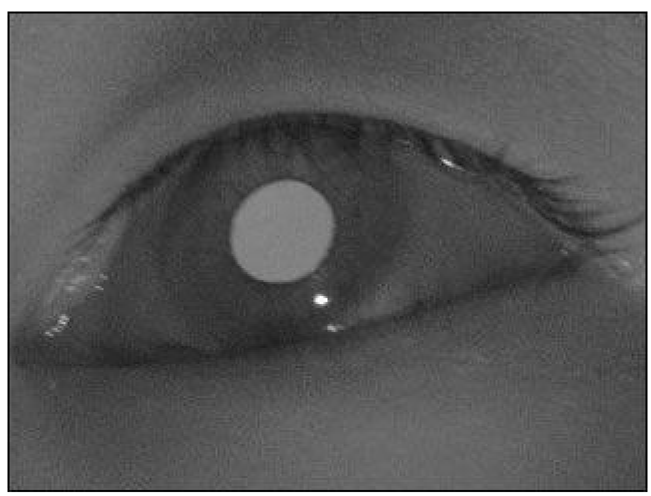


**Figure 5: Bright pupil tracking uses an IR light source located on the visual axis of the camera to induce the "red eye" effect seen in flash photography [11].**

and the user's eye is fixated. The system communicates with a base-station with a wireless transceiver that is connected to a PC with a serial port. A major advantage to this approach is detection speed. A sample-and-hold circuit at 60 Hz is used to detect eye contact, and an onboard PIC micro-controller is used to detect fixations within the signal. However Eye-R assumes that the user's gaze direction is always in the direction the head is oriented, and does not actually track the direction of the eye itself.

## 3. GAZE-BASED INTERACTION

The most obvious means of eye-based interaction is in pointing tasks, where the object the user is looking at is considered to be selected. Jacob studied the effectiveness of the eye movements as a pointing modality where the eyes were used largely as a substitute for the mouse [8]. The most interesting result from this work suggests that simply selecting whatever object the user is looking at is quite undesirable. The problem arises because the user ends up selecting everything they look at, even if they do not wish to select an object. The name given to this problem is the "Midas Touch" effect, and it results from the overloading of an input device to the brain with an explicit output function. To address this problem, Jacob proposed looking behavior should be accompanied by a secondary actuation step, such as pushing a button or fixating of the object for a short time.

Other work has focused on using the eyes to point in more passive ways. These systems seek to reduce the amount of awareness about eye movements the user must have, but still use the eyes for control. Most commonly, the eyes are proposed as an auxiliary input channel to the hands. Manual And Gaze Input

Cascaded (MAGIC) pointing is one such approach [26]. This technique uses the eyes to position the cursor roughly near the object the user is looking at. The hands can then be used to move the cursor to an object local to the user's visual attention. This allows the user to move the cursor long distances with his eye muscles, which are the fastest in the human body, but still retain the fine cursor control afforded by manual input with the mouse. Also, users reported that the "magical" aspect of the technique was that by passively following the user's visual attention, the cursor seemed to follow user intent.

### 3.1 Eye Tracking in Virtual Reality

Eye movements have also been proposed as a modality for pointing within virtual environments. These systems typically correlate the user's gaze into a vector defined by virtual world coordinates. Typically, 2D gaze coordinates are retrieved from the eye tracker and then projected into the world using simple ray casting.

Tanriverdi and Jacob proposed that eye movements could be used as an active pointing device for 3D object selection in virtual environments presented in a head-mounted display (HMD) [22]. The eye was tracked in 2D in screen coordinates in the HMD. Ray casting was used to select the nearest object rendered to the pixel residing at the gaze coordinate, and a dwell time was used to avoid the Midas Touch effect [8]. This work compared eye-based selection to the traditional use of the hands to reach out and touch an object to select it. The study revealed the eyes to be considerably faster than the hands. This work was later extended by Cournia et al. to include a comparison between gaze-based and hand-based pointing where a ray-casting technique was used by the hands [3]. This study revealed that the eyes are not necessarily faster than the hands when the user does not have to reach to touch the target, and instead can point at objects with the hand from a distance.

Eye movements have also been proposed as a means of communication between people in collaborative virtual environments. Since eye movements have been shown to play an important role in group communication, it is thought that adding support for the same types of cues could improve computer mediated communication. With the GAZE groupware system,

**Figure 6: Users controlled the orientation of the view with their eyes. Here, the user is confronted by a monster and looks at it to orient herself towards it.**

Vertegaal et al. studied the effectiveness of including a gaze point in a virtual meeting room [24]. GAZE represents each participant in the video conference as an image, or *personification*, situated around a virtual table. Users' gaze points are represented as spots drawn on the surface of the table. Additionally, the orientation of a user's personification is adjusted based on the user's gaze.

## 3.2 Perceptually Adaptive Graphics

Graphics systems have been proposed that utilize eye tracking to optimize rendering performance [4]. Such systems alter the level of detail rendered to a point on the screen to correspond to the level of detail the user will be able to perceive. For example, the level of detail rendered in the user’s peripheral field of view can be degraded, allowing more resources to be allocated to the user’s fovea [12].

# 4. METHODOLOGY

In our study, we compared a commercial eye tracker to a common desktop mouse for the control of orientation in a first-person shooter, communication with an avatar, and the targeting of moving objects. Data was recorded to indicate player performance when using the two input modalities and also information indicating player preference along a variety of different criteria.

## 4.1 Stimulus

We presented our subjects with three different games that utilize the eye tracker in different ways:

### *4.1.1 Orientation in a First-Person Shooter*

Participants played a first-person shooter where the player’s orientation in the virtual world was controlled with either the eyes or the mouse. The game we chose was an open-source Java port of Quake 2 called Jake2, produced by Bytonic Software [2].

The same task was used for both input modalities. Users were positioned at the end of a long, winding hallway that contained 5 monsters. At the opposite end of the hallway was a door. The players possessed a gun with an unlimited amount of ammunition. Users were asked to navigate down the hallway and through the door, killing the 5 monsters along the way. The time it took to reach the far doorway was recorded.

For the eye based control, participants would look at an object to rotate the view such that the object was in the middle of the screen (Figure 6). With the mouse, the player simply moved the mouse to rotate the view. Moving the mouse forward rotated the view up, while moving the mouse backwards rotated the view down. The speed of the rotation for both conditions was fixed across subjects. Movement was facilitated by the games default keyboard configuration: “A” (left), “S” (backwards), “D” (right), and “W” (forwards). To fire the gun, users clicked the left mouse button in the mouse condition and pressed the right “Ctrl” key in the eye tracking condition. Participants completed one trial with each input device.

### *4.1.2 Communicating with an Avatar*

The second game allowed the user to communicate with an avatar through pointing. For this task, we used *Neverwinter Nights* (Figure 7) [1].

Participants were positioned in front of a door that opened to a large room. The player traveled through the door, opened and closed two chests at known locations, and then exited out of a door at the opposite end of the room. The time it took for the player to complete the task was recorded. Participants completed three trials with each input device.

Interaction with the avatar was facilitated only through pointing. To move the avatar, the player simply clicked on a point in the environment and the character would walk there. To open a chest, the player clicked on the lid. In the mouse condition, players simply moved the mouse and clicked with the left mouse button. In the eye tracking condition, players looked at

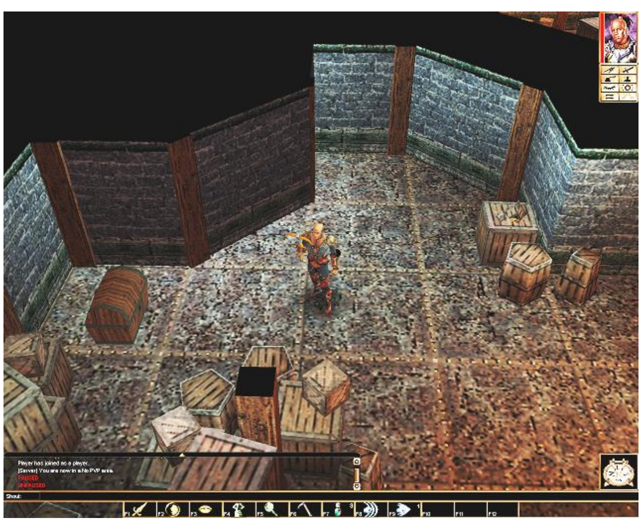


**Figure 7: In *Neverwinter Nights*, players communicated with their avatar through eye-based pointing.**

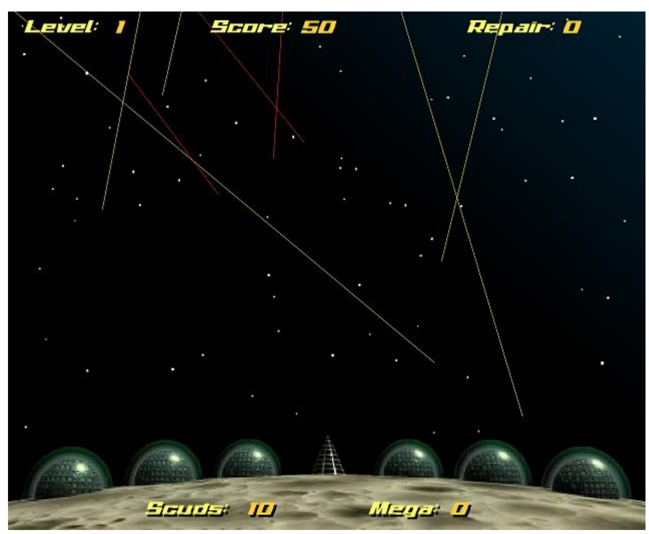
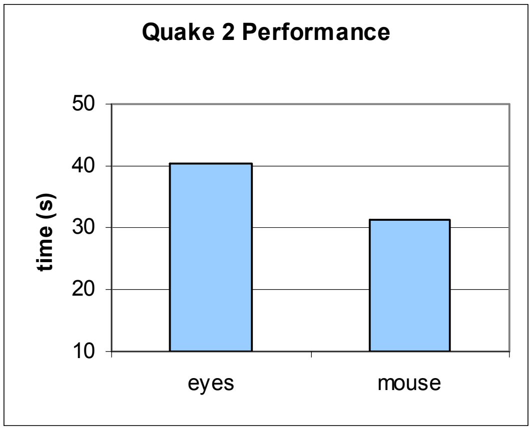
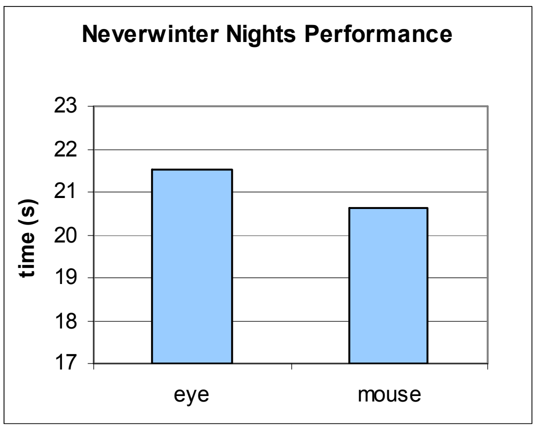


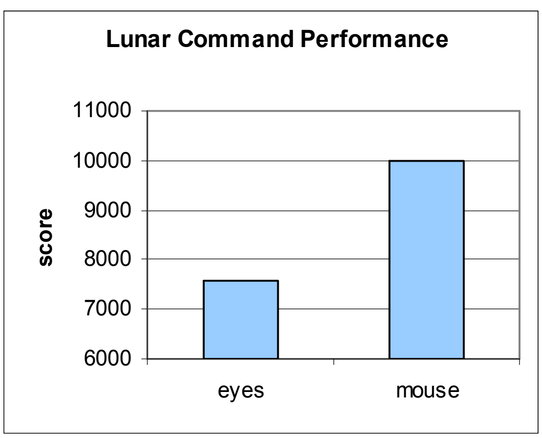

**Figure 8: Players fired at missiles descending from the top of the screen by looking at them and pressing a button.**




**(a)**




**(b)**




**(c)**

**Figure 9: Performance measures for each game. (a) and (b) indicate the mean time taken to complete the tasks in Quake 2 and Neverwinter Nights, respectively. (c) indicates the mean score achieved in Lunar Command.**

the desired point, chest, or door in the environment and clicked the left mouse button.

### 4.1.3 Targeting Moving Objects

The third game used the eye tracker for targeting of moving objects. Participants played *Lunar Command* (Figure 8), which is a modified version of the 80's arcade classic *Missile Command* [9].

Users were presented with six "cities" at the bottom of the screen along with a turret. Missiles would descend from the top of the screen toward the cities. The player's task was to destroy the missiles before they reached the cities. However the shots fired from the turret took j second to reach their target. Players earned points by successfully destroying missiles and lost points by letting missiles reach the cities, or by firing and missing their target. Players completed 3 levels of the game, each of which consisted of approximately 30 missiles that traveled at increasingly fast speeds. The player's score was recorded for each condition. Control for the game was facilitated in the same way as with *Neverwinter Nights*, where players simply click on the point where they wish to fire.

## 4.2 Equipment

We used a Tobii 1750 eye tracker for our study [23]. The Tobii 1750 is a commercial system that uses dark pupil detection and tracks both of the user's eyes. The system consists of a 17" TFT monitor with the eye tracker built into the case. The Tobii is accurate to within 0.5 degrees of visual angle, is insensitive to normal head movements, and reports gaze coordinates at a rate of 50 Hz. A standard USB keyboard and optical mouse were used. The sensitivity of the mouse was fixed across all mouse conditions.

## 4.3 Participants

A sample population of 12 subjects (8 male, 4 female) participated in the study. The age of participants ranged from 19 to 34 with a mean of 25. Participants were screened for visual acuity (20/20 vision: 7 natural, 5 corrected with glasses or contact lenses). All participants had experience playing video games, but only 42% had experience with eye tracking. No subjects were rejected because of calibration problems with the eye tracker.

## 4.4 Experimental Design

We used a within subjects design for our study. Our experiment had one independent variable: mouse or eye tracker. All three games were presented to every participant with both input devices. The order in which the games were presented was rotated about a Latin square. The order in which the subjects used the input devices for each game was randomly assigned.

## 4.5 Procedure

Participants were first presented with an information sheet with a description of our project, asked to sign a consent form, and completed a demographic questionnaire. Then subjects were calibrated on the eye tracker and given a short training period where they controlled a small cursor on the screen to familiarize themselves with the eye tracker's performance. When the participant indicated they were satisfied with the calibration and

| Question | Quake2 | | Neverwinter Nights | | Lunar Command | |
|---|---|---|---|---|---|---|
| | **Eyes (%)** | **Mouse (%)** | **Eyes (%)** | **Mouse (%)** | **Eyes (%)** | **Mouse (%)** |
| Which did you enjoy playing with more? | 42 | 58 | 83 | 17 | 42 | 58 |
| Which was easier to learn? | 33 | 67 | 67 | 33 | 33 | 67 |
| Which was easier to use? | 8 | 92 | 50 | 50 | 8 | 92 |
| With which did you feel more immersed in the gaming world? | 83 | 17 | 83 | 17 | 92 | 8 |
| For which did the controls feel more natural? | 25 | 75 | 67 | 33 | 42 | 58 |
| Which would you prefer to use in the future? | 33 | 67 | 67 | 33 | 42 | 58 |

**Table 1: Analysis of subjective measures. Subjects were asked to indicate which modality they preferred along 6 different criteria.**

familiar with the eye tracker, they were presented with the three games.

For each of the three games, participants were first given instructions on how to complete the task and given a demonstration. Subjects were then given a training period to familiarize themselves with the game controls and to ensure understanding of the specific gaming task. Participants were given as much time as they wished in the training period and indicated when they felt ready for the trial. The participant then completed the task with the first input device and their performance was recorded. The training and task was then repeated with the second device. Once the game had been played in both conditions, the subject was asked to complete a short questionnaire in which they compared their experiences with the two devices across several criteria. After each game, the eye tracker calibration was re-evaluated and adjusted if necessary.

# 5. RESULTS

Results from our study are classified into two types:

- **Performance measures** – These measures describe how well users performed when playing the games. These measures are specific to each game (Figure 9).
- **Subjective measures** – These measures are intrinsically comparative and are designed to capture the participants' opinions of the input modalities (Table 1). Subjects were asked to indicate a preference across 6 different criteria. These measures are not game specific, although they were collected separately for each game.

A single-factor ANOVA analysis was performed on the performance measures for each game to detect any significant differences between the two input modalities. Users performed significantly better with the mouse in Lunar Command: $F(1, 22) = 18.959$, $p < 0.01$. However no significant performance difference was found for Quake 2 or Neverwinter Nights.

## 5.1 Discussion

Our subjective results indicate that a large majority of participants felt more immersed in the game's virtual environment when using the eye tracker. We believe this is due to the continuous nature of eye-based control. When using the mouse for pointing tasks, for example, the user will oftentimes look at the target and then move the cursor only when he/she decides to select a target. However with the eye tracker, the cursor moves every time the user moves his/her eyes. This results in a considerable increase in the amount of feedback the user receives from the game, even when the user isn't consciously performing an explicit action.

Users also showed a strong preference toward the eye tracker when playing *Neverwinter Nights*. We believe this is due to the reduced amount of effort required to move the character when using the eyes. To complete the task, users were required to perform many cursor movements that traversed the entire screen. When using the mouse, the user typically would look at the desired target and then perform an explicit action with the mouse to move the cursor. However with the eye tracker, just looking at the desired destination moved the cursor, removing the need for any hand motion. One participant commented that, "I could explore with sight freely and only clicked the mouse when needed". Additionally, humans naturally use eye movements to point when communicating with other humans, and eye tracking allows for the extension of the same visual cues into the virtual world.

Our results also indicate that participants felt the mouse was easier to use with the first-person shooter. We suggest this is related to the "Midas Touch" problem [8]. When a user performed an eye movement their orientation changed, and consequently the direction in which they were traveling changed. A common problem occurred when participants walked past an interesting object, such as a small box on the floor. The player would look at the box while intending to continue down the hall, but by doing so would inadvertently change the direction in which they were walking. To avoid this, users had to fixate in the direction they wished to travel when moving through the environment. The mouse, however, allowed players to look freely at any point in the viewport without affecting the direction in which they traveled.

We believe the difference in performance between the eye tracker and mouse when playing *Lunar Command* is due to the latency that occurred when shooting at a target. Recall that it took almost a second for a shot to reach the point at which it was fired. Participants were almost uniformly observed firing behind the missiles. Users appeared to have a difficult time making themselves “lead” the missiles by looking out into empty space in front of the moving target.

## 6. SUMMARY

We presented a study on the effectiveness of an eye tracker as a control device for video games. Eye tracking has been used for many years in psychology and interactive system design. Eye movements are a common means of communication, as humans naturally use eye movements to communicate with other humans.

We compared the eye tracker to a mouse for game control. Three commercial games were played with both input devices, and subjects were asked to compare the experience afforded by the two modalities. Our results indicate that the eye tracker can increase the amount of immersion experienced when playing a video game. Additionally, we found that users found the eye tracker more enjoyable to use when playing a game that required the user to direct an avatar around a screen by pointing.

## 7. ACKNOWLEDGMENTS

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