Eye Tracking as an Aiming Device in a Computer Game

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Abstract

This paper describes an experiment in the application of eye tracking to facilitate aiming in computer gaming. A simple 3D computer game was run under varying conditions to test the effect of gaze-contingent gaming on a player's performance, measured by accuracy in selecting targets within the game and completion time. The game was run using a traditional mouse and with the Tobii ET-1750 eye tracker as aiming devices in timed and un-timed trials. The results showed that subjects had better performance in completing their objectives when using the mouse instead of the eye-tracker as an aiming device. However, difficulties with the calibration process suggest that the experiment may yield different results if run with a modified calibration process.

1. Introduction

With recent advances in technology, the possibility of using eye tracking in consumer applications continues to grow. In particular, the decreasing cost of components off-the shelf (COTS) present the possibility of eye tracking systems that can be operated by the end user, without the assistance of an expert. However, the application must be designed in a way as to minimize the difficulty of calibration while still maintaining accuracy. [Hansen et al. 2004] In addition to Hansen's study of the feasibility of consumer eye tracker systems, studies have been done on the use of computer vision in computer games. A study conducted in 2003, Hoysniemi et al. [2004], showed that a child's intuition proved to be a stronger tool for interacting with the game avatar, regardless of the avatar's actions on screen. If player movements are more intuitive for interacting with a computer game, would using the eyes as an aiming/pointing device in a computer game be more intuitive as well? If so, the development of a computer game that utilized an eye-tracking based aiming device (ETBAD) could open new avenues of creative development for the gaming community.

This experiment was setup to examine the performance variations in the use of eye tracking as an aiming device versus a traditional mouse in a computer gaming environment. The goal was to show that, like the children's movements in Hoysniemi et al., using the eyes as a pointing device in a computer game would be more intuitive to the user and would improve task completion times when compared to using a mouse for aiming. More specifically, the goal of the experiment was to measure the performance difference between selections with a traditional mouse and with an eye tracking device in a computer gaming environment. It was hypothesized that although task completion times would improve with the use of an eye-tracker as an aiming device, the user's accuracy would be less than it would when using the mouse as an aiming device.

An obstacle in achieving acceptable performance in an eye tracking game is the method of measuring eye movements. Jacob [1990] observed that the most practical method used is when the head does not need to be rigidly fixed. This removes any discomfort experienced by the user and allows them to feel at ease while using the application, which in turn increases the ability to accurately portray a real life situation.

The eye tracking game (ETG) developed utilized the Tobii ET-1750 eye tracker. This allows the user to sit comfortably in front of the monitor in the same fashion they would while using a normal computer. To overcome the problem of the Midas touch, the users were permitted to point with their eyes, but make their selections by clicking with the mouse as per eye-typing studies. The Midas touch problem in eye tracking occurs when the eyes are used as a selection device in addition to being used as a pointing device. When fixating on an object or location, the eyes have a natural tendency to shift back and forth, usually within one degree. This shifting tendency makes it difficult for a computer application to differentiate between a gaze-based selection and normal viewing behavior. Several solutions to this problem have been proposed, such as utilizing a greater fixation length to signal a selection or recognizing blinking as a selection command. For this experiment, a variation of "MAGIC pointing" method was selected. [Jacob 1990; Zhai et al. 1999]

MAGIC (Manual and Gaze Input Cascaded) pointing 'warps' the cursor to the general area of the user's gaze target. After this the user has to make a small adjustment using a traditional input device, such as a mouse, to be directly on target. MAGIC pointing utilizes two different techniques, liberal and conservative pointing. The liberal approach moves the cursor to each new object the user looks at that is at least 120 pixels away from the current position. This approach can pose problems by limiting eye-based selections inside of the 120 pixel range and forcing the user to rely on the mouse for manual selections. The second approach, conservative pointing, will not warp the cursor to a new position until it is signaled to do so by a single mouse click. The user must then move the cursor to the actual target and click the mouse again to make a selection. The conservative approach is more suited to a gaming environment because it prevents inadvertent cursor movements while the user analyzes and views the scene. However, the conservative approach would require more hand-eye coordination to make selections more quickly than with liberal MAGIC pointing. This extra emphasis on hand-eye coordination would not affect most computer games since strong coordination is often necessary to achieve the objectives of the game.

For this experiment, the conservative MAGIC pointing approach was modified to signal a selection when the left mouse button was pressed. When the mouse event is triggered, the user's current gaze point is used as the cursor position on the screen. If the cursor location is over an object (for this experiment, a magenta colored ball) then a selection is made. Otherwise, no action is taken. With this approach, the physical location of the mouse cursor becomes irrelevant and the user can rely solely on their gaze to point to and select objects, thereby avoiding Fitt's law. Adversely, the strict use of the gaze point as a pointing device requires stringent calibration to insure accuracy and responsive controls – a critical requirement in modern computer games. Finally, as observed by Majaranta [2004], the user requires visual feedback for their current gaze-point. To meet this requirement, a green dot, 10x10 pixels large, was drawn on the screen to indicate the current gaze point. This dot was also utilized during the mouse aiming experiments as a replacement for the cursor location.

2. Methodology

The game that was tested was a simple 3D game built with the Qt development toolkit (www.trolltech.com) and the OpenGL API. Twenty-five balls were randomly placed on the screen and given a random velocity vector. The balls then proceeded to travel around inside of the view frustum according to a simple physics simulation. Balls are removed from the screen by clicking the left-mouse button while aiming with the current aiming device.

Four variations of this game were run:

1. No time limit, using a mouse for aiming.
2. No time limit, using an ET for aiming.
3. 10 second time limit, using a mouse for aiming.
4. 10 second time limit, using an ET for aiming.

2.1 Equipment

The computer used for rendering the game was a dual-cpu (Intel Xeon, 2.0 GHz) with 2 GB RAM. The game was displayed on a Tobii ET-1750 eye tracking monitor. The ET-1750 is a 17-inch TFT monitor that runs at a resolution of 1280 x 1024 and uses a pair of near infra-red light-emitting diodes (NIR-LEDs) and cameras for corneal reflection eye tracking. The Tobii 1750 eye-tracker is shown in Figure 1.

Figure 1: *The Tobii 1750 eye tracker.*

The ET-1750 eye tracker operates at a rate of 50Hz with a latency of 25-35ms and is capable of determining the subject's eye position with an accuracy of approximately 1° in a range of +/- 40° above the camera and +/- 10° below the camera. The eye tracker software ran on a Windows XP PC, and communicated with the user application via a TCP/IP connection. This setup is illustrated in Figure 2.

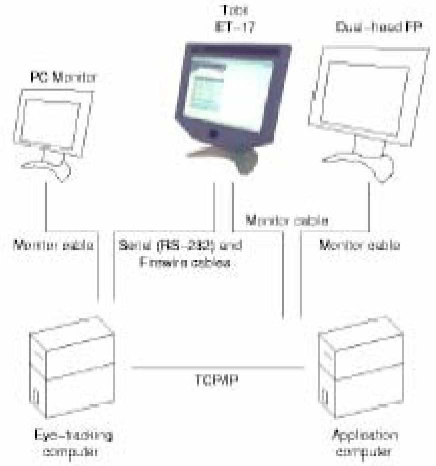


Figure 2: *Tobii ET-1750 computer and application computer configuration*

2.2 Subjects

Thirteen subjects were drawn from a population of graduate and undergraduate students at Clemson University and Furman University, ranging in ages from 20 to 28. Each participant was randomly assigned a unique order in which to play the four different variations of the game according to a Latin Square. The results for one subject had to be discarded, leaving 12 subjects for the final analysis. The final pool of subjects consisted of 7 males and 5 females.

2.3 Design

Each subject was given the opportunity to familiarize themselves with the game environment and screen setup during the experiment phase. During this familiarization run, each subject was allowed to play through the game with 1 ball randomly placed on the screen, using the mouse as an aiming device (Figure 3). The 4 variations of the game used in the experiment included 25 randomly placed balls on the screen.

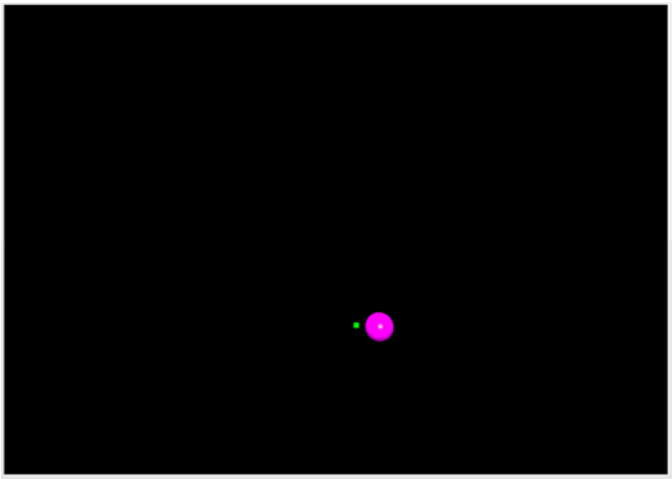


Figure 3: *Familiarization Run in Eye Tracking Game.*

All subjects had to perform the same task in the game, remove all of the balls from the screen. On the monitor the users could see a 1280x1024 black screen with 25 magenta balls moving around the screen. The 25 balls were randomly placed on the screen at initialization and were assigned a random velocity vector (Figure 4). The users had to point to a ball using the current pointing device and click the left mouse button to remove the ball from the screen.

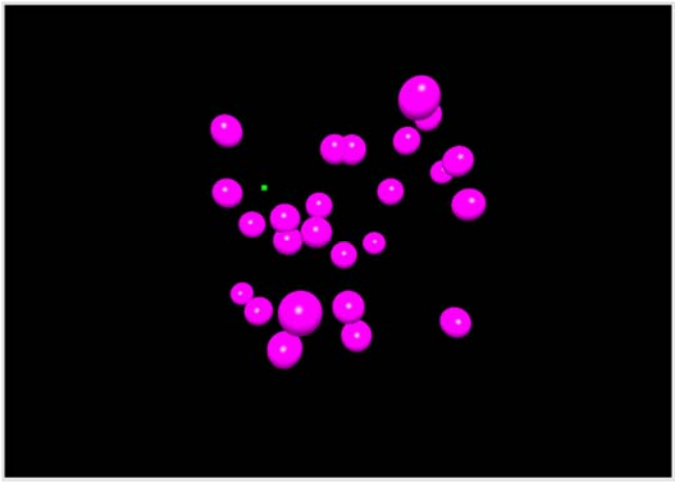


Figure 4: *Eye Tracking game at immediately after initializing game variation 1.*

In the first game, the users had an unlimited amount of time to clear the screen and had to use the mouse as their pointing device.

For the second game, the users still had an unlimited amount of time to complete the task, but had to utilize the ET for aiming. In this variation, users were instructed to look at the ball they wished to target and click on the mouse when they were ready to remove the ball from the screen.

The third variation of the game operated in the same manner as the first, except the users were given a 10 second time limit to complete their task. To maintain uniformity on the display, users were not presented with a countdown timer. The fourth and final variation of the game ran the same as the second, but reduced the time limit to 10 seconds.

2.4 Procedure

1. **Pre-Test:** The subject was asked to read and sign an Informed Consent Form detailing the experiment objectives, benefits and possible risks. Demographic data on age, sex, vision and experience with computer games was also collected for each subject (Table 1). Before the experiment began, the subject was allowed to ask any questions he/she had.

1. Age
2. Gender
3. Do you have 20/20 corrected or uncorrected vision?
4. With respect to your computer gaming experience, on a scale of 1-5 (1 being the lowest), how would you rate your familiarity with computer games?

Table 1: *Pre-Test Questions*

2. **Seating:** Before beginning the testing phase, subjects had to be properly seated in front of the Tobii eye-tracker. Subjects were seated approximately 50-60 cm from the Tobii eye-tracker with their backs straight. The Tobii eye-tracker was used to draw the subjects' eye positions as two grey dots (Figure 5) relative to the screen. The subject's position was adjusted until the grey dots were located in the center of the screen.

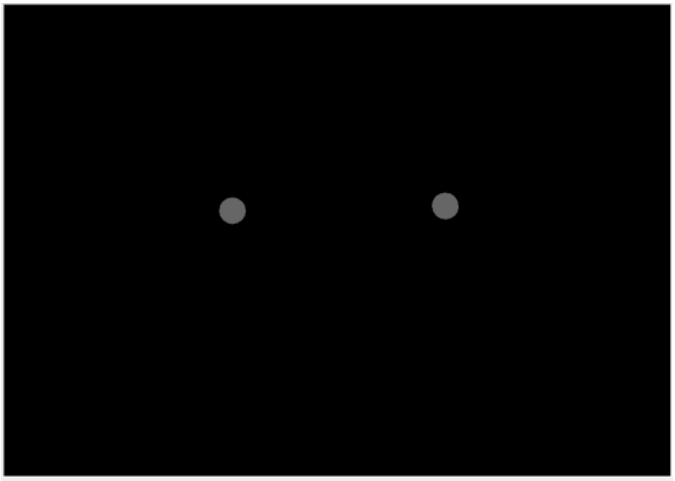


Figure 5: *Eye positions relative to screen, as indicated by the Tobii ET during the Seating Phase of the experiment.*

3. **Test:** The testing phase was divided into two sub-phases:

    a. Calibration: In order to properly calibrate the Tobii eye tracker, the subjects were instructed to look at 16 calibration points on the screen as they shrank in size to a final size of 1x1 pixel. The calibration points were displayed in a left-to-right and top-to-bottom order. During this phase the subject was also instructed on how to initialize each of the 4 game variations for the main testing phase. This was accomplished by selecting the "Run Game" menu from the top menu bar and selecting the appropriate game from the menu. The game would immediately begin execution. All of the subjects were warned that if an incorrect game variation was inadvertently selected, their test results would be deemed invalid.

b. Testing: For the main testing phase, the subject was instructed to play the 4 variations of the game in an unique order according to a Latin Square. For example, the first subject was instructed to play the games in the order 1-2-3-4 (where 1-4 refer to game variation number), the second was instructed to play 1-2-4-3, and so on. Since each variation begins execution immediately after selection, the user was permitted to initialize each game variation autonomously. All subjects were instructed to remove all of the balls from the screen by pointing at a ball with the current pointing device and then clicking on the left mouse button. The game screen is shown in Figure 4. At the end of the game, the game redraws all of the balls that were removed along with the mouse clicks for that game. The mouse clicks are indicated with yellow dots and are connected by white lines. The first and last mouse clicks have blue and red lines, respectively, leading out of or into them to indicate order (Figure 6).

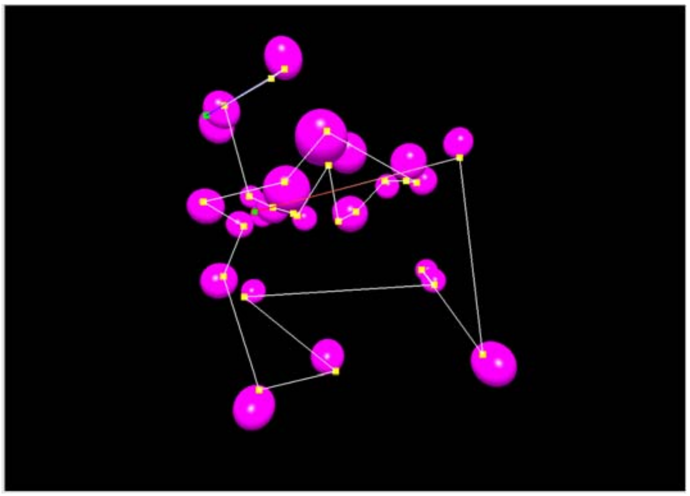


Figure 6: *Post-Game Status Screen*

4. **Post-Test:** Upon successful completion of the experimentation phase the subjects were debriefed on their individual performance in each of the 4 game variations. The subjects were then asked to fill out a post-test questionnaire (Table 2) on their experience with the experiment and were thanked for their time.

1. Which aiming method did you prefer?
2. Which aiming method did you feel was more accurate?
3. Which aiming method do you think you performed better with, i.e., which aiming method do you feel was more responsive?
4. The questions below are all related to the calibration process of the experiment (where the yellow dots sequentially appeared on the screen):
   i. I found the process too long.
   ii. I found the process too difficult.
   iii. I found the process too burdensome.

Table 2: *Post-Test Questions*

3. Results

For each game variation tested, three metrics were tracked: accuracy, completion time, and completion rate. Accuracy was defined as the ratio of balls removed from the screen to total number of mouse clicks. Completion time was the total amount of time taken to complete the task. Finally, the completion rate was defined as the ratio of balls removed from the screen at the end of the trial to the total number of balls on the screen at the beginning of the trial. Each metric was tracked for between and within subject comparisons within the timed and un-timed groups.

3.1 Accuracy

For the timed game variations, the arithmetic mean accuracy was .833 for mouse aiming and .5687 for Tobii ET aiming. For the un-timed games, the arithmetic mean accuracies were .8899 and .5225 for mouse and Tobii ET aiming, respectively.

For the timed games a one-way ANOVA between subjects (Mouse and Tobii Aiming) on mean accuracy (see Figure 7) suggests that the difference in accuracy between using the mouse for aiming and using the Tobii ET for aiming were significant, $F(1, 20) = 19.443$, $p < 0.05$.

The one-way ANOVA between subjects on mean accuracy for the un-timed games also suggests a significant difference between using the mouse and the ET for aiming, $F(1, 20) = 16.573$, $p < 0.05$.

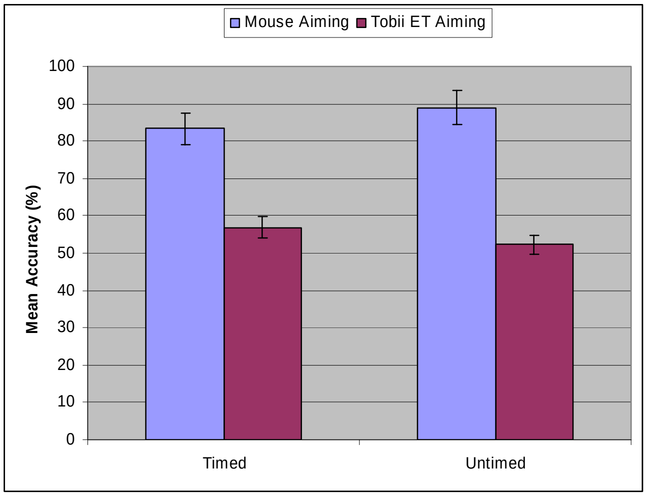


Figure 7: *Mean Accuracy (%)*

3.2 Completion Time

For the timed trials, the subjects had 10 seconds to complete the objective. If the object was completed before the time expired, the timer was cut off. The 10 second time limit was enforced using the QTimer from the Qt toolkit (www.trolltech.com). The Qt documentation states that the QTimer has an accuracy of 20ms, however, for the mouse trials the timer had an average response time of 5.143ms and an average 8.818ms response time for the Tobii ET trials.

For the un-timed trials, the subjects had as much time as they needed to remove all of the balls from the screen. For this task, the average completion times were 12.703 and 62.683 seconds for mouse and Tobii ET aiming, respectively. The timed trials had average completion times of 9.68 and 10.009 seconds for mouse and Tobii ET aiming, respectively.

A one-way ANOVA between subjects on mean completion time for the un-timed games reveals a significant difference in completion times (Figure 8) between the mouse and Tobii ET aiming game variations, F(1, 20) = 8.451, $p < 0.05$. Contrary to the expected results, however, the Tobii ET was the slower aiming method – requiring, on average, an extra 49.98 seconds to complete the objective.

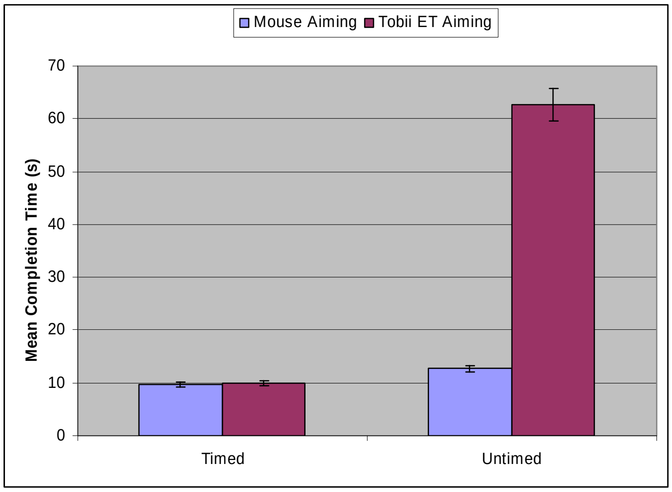


Figure 8: *Mean Game Completion Times (s)*

A one-way ANOVA between subjects for the timed trials also suggested a significant difference between the mouse and Tobii ET aiming game variations, F(1, 20) = 4.822, $p < 0.05$. As with the un-timed game variations, the variations that utilized the Tobii ET for aiming took longer to complete than the mouse aiming variations. One third of the subjects were able to fully complete the game objective within the given time limit when using mouse aiming while no subjects were able to complete the objective when using the Tobii ET for aiming.

3.3 Completion Rate

Completion rate was only tracked for the timed trials (for the un-timed trials the subjects had as long as they needed to complete the task). For the time trials, completion rate was defined as the number of balls removed from the screen in the allotted time (10 seconds) as a percentage of the total amount of balls (25 balls). There was a grand mean completion rate of 0.5736. The mean completion rate for the mouse aiming game variations was 0.8473 and the mean completion rate for the Tobii ET game variations was 0.3000. A one-way ANOVA between subjects for the mouse and Tobii ET game variations (Figure 9) suggests that using the Tobii ET as an aiming device had a significant impact on the subjects' ability to complete the game objective within the given time limit, F(1, 20) = 52.244, $p < 0.05$.

Level of Familiarity with Computer Games	Number of Test Subjects
5	4
4	3
3	2
2	3
1	0

Table 3: *Subject Self-Indicated Familiarity Level with Computer Games (1 is the least familiar)*

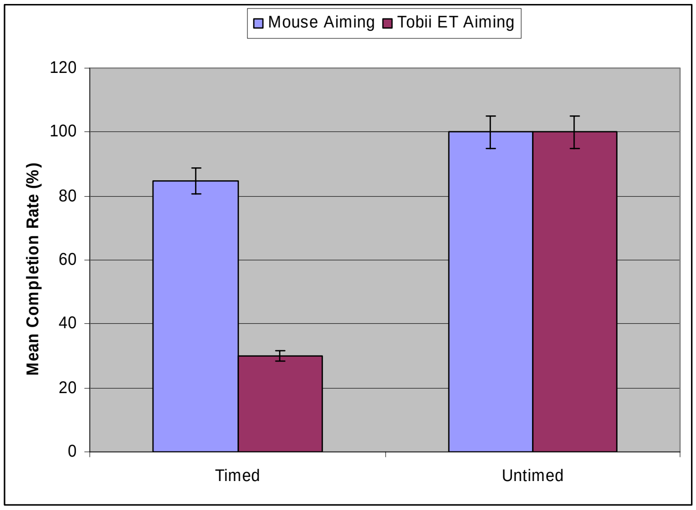


Figure 9: *Mean Completion Rates (%)*

3.4 Subjective Results

Table 3 shows the subjects' self-indicated familiarity with video games. All five female subjects ranked themselves towards the lower end of the scale with a rating of 3 or less. This data was collected from the pre-test questionnaire.

Only one subject preferred the use of the Tobii ET over the mouse as an aiming device, but the subjects unanimously stated that they felt the mouse was a more accurate aiming device while two of the test subjects felt the eye tracker was more responsive than the mouse (see Table 4). It is interesting to note that the subject that preferred the mouse over the eye-tracker was not one of the subjects to say the eye-tracker was more responsive. In regards to the calibration process itself, the majority of the test subjects were satisfied, however, 25% found the process too long, difficult, or burdensome. A more robust and automated calibration process, which was hidden from the user, should be developed for future use.

	Mouse	Tobii Eye-Tracker
Preferred Aiming Device.	11	1
More Accurate Aiming Device.	12	0
More Responsive Aiming Device.	10	2

	SD	D	N	A	SA
Process was too long.	8	1	2	1	0
Process was too difficult	8	2	1	0	1
Process was too burdensome	7	4	0	1	0

Table 4: *Subject Subjective Responses to post-test questions. Bottom half uses five-point Likert scale (Strongly Disagree … Strongly Agree)*

3.5 Mouse Click Analysis

Throughout the testing, many of the subjects complained that the feedback from the ET indicated that they were aiming at a different location than which they were looking. These complaints were most often voiced when the subjects would target a ball towards the lower portion of the screen. To further investigate these complaints, the screen coordinates of the targeting reticule (mouse position while using the mouse and gaze point while using ETBAD) were analyzed for all mouse clicks.

Traditional scan path analyses could not be derived from the data due to the interactive nature of the experiment. Participants would follow their targets in smooth pursuits before making an attempt at removing the target from the screen. The off-line analysis program, which was implemented a 7-tap velocity filter, was unable to differentiate between the fixations and saccades within the smooth pursuits. However, when users would indicate that they have made a selection by clicking the left mouse button, an event was triggered to test the attempted selection for success. The coordinates for these selections, and their order of occurrence, were recorded for each game-trail. This data was displayed on the screen at end of each game trial and created a pseudo scan path which indicated the participants' progress throughout the game (refer to Figure 10). Visual comparisons of these images suggested that subjects were able to make mouse clicks near the bottom of the screen more often when utilizing mouse aiming. In order to draw a conclusion for the group as a whole, the coordinates for all mouse clicks were examined on an aggregate level.

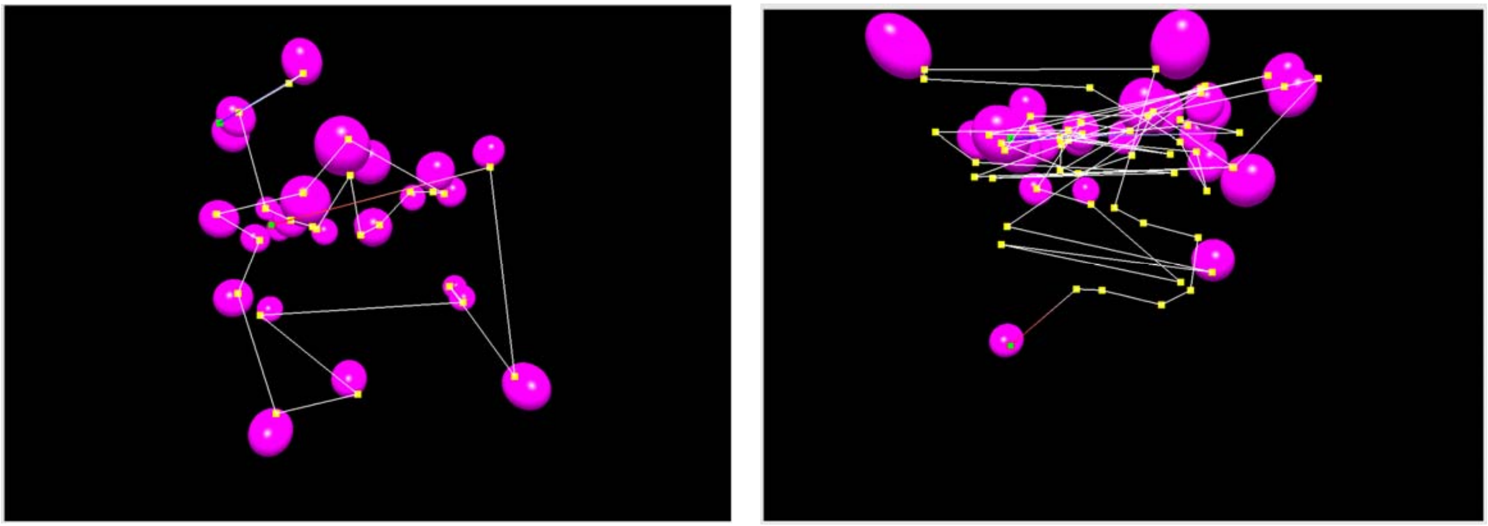
Figure 11 shows the location of the targeting reticule on the screen for mouse clicks (across the entire subject pool) for the game variations utilizing the mouse and the Tobii ET for aiming. Since screen coordinates have the origin, (0, 0), in the upper left corner, the data for the graph is displayed in the same manner. The mean coordinate was (581.039, 402.024) for mouse aiming and (546.977, 319.393) for the Tobii ET.

A visual inspection of the graphs shows that for the Tobii ET, there seems to be a significant decrease in the number of mouse clicks below 500 units along the y-axis. Comparatively speaking, 26.892% of all mouse clicks for the mouse aiming game variations occurred below the 500 unit threshold, compared to only 9.388% for the Tobii ET mouse clicks.

A one-way ANOVA between subjects (mouse and Tobii ET) for the data along the x-axis suggests a significant difference between the clustering of the points with $F(1, 1599) = 15.511$, $p < 0.05$. Along the y-axis, a one-way ANOVA also shows a significant difference with $F(1, 1599) = 128.031$, $p < 0.05$.

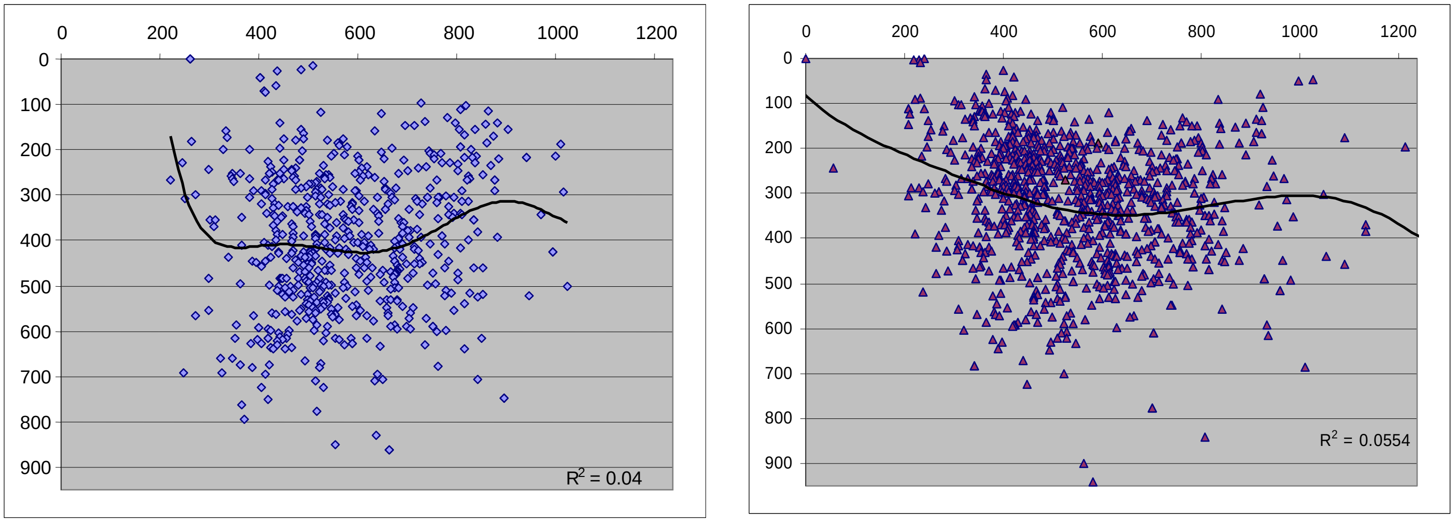
On the aggregate level, there 57% more data points were recorded for the game variations using the Tobii ET compared to the mouse aiming trials. For the un-timed trials, there were 145% more mouse clicks for the Tobii ET than the mouse variations, but for the timed trials, there were 61% more mouse clicks for the mouse variations than the Tobii ET. These differences can be accounted for by means in which the subjects approached completing their tasks. It was observed that during the un-timed trials, the subjects were more likely to take their time and click with the mouse when the visual feedback indicated they were aiming at a ball. This approach highlighted the difficulty many subjects had with targeting balls along the lower portion of the screen (approximately 500 pixels from the origin along the y-axis). Subjects would click on the mouse, but the targeting reticule would move and the click would be recorded as a "miss." Alternatively, during the timed-trials, subjects would repeatedly click the mouse when using mouse and not spend much time aiming – they would then slow down to aim more when using the eye-tracker.

The clustering of mouse clicks towards the center of the screen can be attributed to the generation of ball spawning coordinates. Even though the balls would be randomly placed on the screen with a random path each game, they would still spawn closer to the center of the screen.



(a) Mouse Aiming (Figure 6 reproduced from above) *(b) Tobii ET Aiming*

Figure 10: *Examples of pseudo scan paths derived by recording ordering of mouse click events*



(a) Mouse Aiming *(b) Tobii ET Aiming*

Figure 11: *Aggregate Targeting Reticule Screen Coordinates After a Mouse Click – With Polynomial Regression Lines*

4. Discussion

All subjects had better performances completing their objectives when using the mouse as an aiming device instead of the Tobii eye-tracker.

During the timed trials, subjects would immediately click on the mouse very rapidly, increasing their possibility of hitting a ball instead of relying on their current aiming device. Using this tactic, several subjects were able to complete the objective using the mouse for aiming before time expired. Subjects were less likely to take this approach when they were using the eye-tracker for aiming. The subjects had an apparent lack of trust with the eye-tracker and were hesitant to click on the mouse, even when the visual feedback indicated they were correctly aiming at a target. This hesitance would last for a second or two before users would adopt the tactic utilized with the mouse aiming.

During the un-timed trials, subjects would take almost the opposite approach from the timed-trials. With the mouse aiming they would leisurely complete their task with 90% accuracy rates. When using the eye-tracker, subjects seemed to strive for pinpoint accuracy. Several subjects made the comment that they found themselves aiming at the green targeting reticule instead of the balls on screen. They would watch the visual feedback waiting for it to land on a ball before making their mouse click. It was also during these trials that the difficulty aiming with the eye-tracker near the bottom of the screen became apparent.

Subjects complained that when they were looking in the bottom third of the screen, the targeting reticule would hover two-thirds of the way down the screen, and would intermittently jump towards their intended target only to jump away again. Efforts to identify the source of this problem with hopes of restarting the experiment with a more accurate eye-tracker aiming device were unsuccessful. The decision was made to continue the experiment and attempt to identify the problem with the recorded data.

An initial attempt was made to develop scan paths for the subjects from using the Tobii eye-tracker; due to the interactive nature of the program, no scan paths could be derived from the data. Fixations and saccades could not be extracted from the data because the subjects would engage in a smooth pursuit of each target before jumping to the next. The visual feedback utilized in this experiment (the green targeting reticule), was placed at the location of the mouse cursor when using the mouse as an aiming device. When using the eye-tracker, the targeting reticule received its coordinates from the subjects' gaze point, according to the eye-tracker. By recording the coordinates of the targeting reticule for each mouse click, a pseudo scan-path for each game variation could be inferred by the order of the subjects' mouse clicks. An example of such a scan path was shown in Figure 10.

The scan paths for the ET aiming trials suggested that there was a trend for a smaller portion of mouse clicks on the bottom half of the screen in comparison to mouse aiming trials, however it was not until the aggregate recordings for all mouse clicks were examined that this became apparent. The analysis of the aggregate group of mouse clicks showed the clear majority of the mouse clicks (successful and unsuccessful attempts at selection) for the eye-tracker trials to be located in the upper left quadrant of the screen. The small cluster of mouse clicks along the borders of that region correspond to the subjects who were trying to click on balls that were at the bottom of the screen, despite the visual feedback indicating they were looking else where.

It was finally determined that the source of this aiming problem rests in the calibration process for the Tobii ET-1750 eye-tracker. At the end of the calibration process, the ET-1750 returns the calibration errors for 200 calibration samples. For this experiment, 16 calibration points consisting of 20 samples each were used in the calibration process. The resulting 320 calibration samples are way above what the ET-1750 reports errors for, suggesting the extra 120 samples are ignored. The calibration points are drawn on the screen sequentially beginning in the upper left-hand corner and proceeding to form a 4x4 matrix on the screen. Under this procedure the 200th calibration sample would be taken by the ET-1750 at the matrix entry (3, 4), or ¾ of the way down the screen. This cut-off point has a strong correlation to the region on the screen where the vast majority of mouse clicks with the eye-tracker were recorded. This suggests the difficulty experienced by the subjects when aiming near the bottom of the screen was a result of the eye-tracker not being fully calibrated for that portion of the screen.

The calibration process was adjusted to record 12 samples per calibration point, bringing the total number of samples to 192. The immediate effect of such a change was to noticeably decrease the time required for calibration. A preliminary test demonstrated a more responsive and accurate aiming device. Comparison of the preliminary test of an un-timed game using the ETBAD for the original and for the modified calibration process showed an improvement in both accuracy and completion rate. These results are shown in Table 5.

	Original Calibration	Modified Calibration
Completion Time	33.581 s	23.2483 s
Accuracy	55.55 %	69.44 %

Table 5: *Results from Preliminary Testing with Original and Modified Calibration Processes*

Unfortunately, by the time this solution was developed, there was not enough time to fully investigate its implications and run the experiment with a new pool of participants.

5. Future Work

More research is needed to accurately determine the affect of an ETBAD in a computer game. An overarching limitation in this experiment was the limit on calibration samples, which wasn't fully realized until the eleventh hour.

Beyond rerunning the trials presented in this paper, it would be interesting to study the affects of an ETBAD on player performance when introduced along with other standard gaming factors. For instance, how the GUI overlay on the game screen would affect a player's eye movements. Is the GUI too distracting for the action on screen? For this particular experiment, it would be interesting to see how an onscreen timer showing the elapsed (or remaining) time would affect each player's performance.

Another aspect that was not examined in this experiment are the colors and complexity of the onscreen components. Magenta colored balls, RGB(1,0,1), and a green targeting reticule, RGB(0,10), were chosen for their stark contrast to the black background. Increasing the complexity of the scene or decreasing the contrast of the onscreen elements could require players to focus more on what they are aiming at. It would very interesting to see how the users eye movements, or aiming patterns with an ETBAD, adapted to new computer simulated situations.

The affects of different implementations of ETBAD on such situations should also be explored. The variation on MAGIC pointing implemented in this experiment may very well not be best solution. For instance, in first-person-shooter (FPS) games, the eyes do not have to make a selection, merely aim at the target. Alternatively, using a longer fixation period to indicate a selection in some games may produce better performances than the MAGIC pointing uses in this experiment. Analyzing the performance differences in these may produce similar results as various eye-typing studies, however, certain implementations may be more suited to specific game situations.

Ultimately, research into the applications of eye-trackers in computer games could lead to creating a new market within the multi-billion dollar gaming industry. Products that employ computer vision, such as Sony's EyeToy, have already been introduced to the market with moderate success. The development of a reliable and responsive ETBAD could increase the ease of use in games for young children or the disabled. It could also be utilized in FPS games such as Counter-Strike and Halo to increase the level of competition for "power gamers."

Such developments would provide more options and opportunities for consumers and developers alike.

6. References

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