The Eyes and Games: A Survey of Visual Attention and Eye Tracking Input in Video Games

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Abstract

Video games have existed for over half a century. Visual attention and eye movement studies, as well as techniques to analyze these movements, have occupied the attention of researchers since late 19th century. This paper presents a review of the state of the art on how video games and visual attention relate as well as how eye tracking has been used to the benefit of video games, both as a form of input as well as a method of evaluation and analysis. To conclude, a brief look into future perspectives of visual attention and eye tracking with video games will be presented.

Keywords: Video games, visual attention, eye gaze, eye movements, eye tracking

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1. Introduction

Video games have been entertaining the public for over half a century. However, more than 50 years before that mark, eye movement and visual attention studies began concentrating the interest of researchers. Eye tracking resulted from the need to analyze and understand these movements. The application of eye tracking in video games can be used as a form of input, substituting or complementing traditional input methods such as the mouse, keyboard or joystick [Isokoski and Martin 2006; Jönsson 2005]. This alternative input method can make games more accessible to those with motor difficulties as eye movement becomes a primary solution for game control. Additionally, the use of eye tracking may even contribute to players' gaming experiences as a whole [Smith and Graham 2006]. While many individual projects [Isokoski and Martin 2006; Jönsson 2005; Špakov 2005] have taken advantage of the potential of eye tracking, commercial games have yet to explore the possibility. Another opportunity associated to eye tracking and yet to be fully explored by researchers is its application as a video game evaluation method [Almeida 2009; El-Nasr and Yan 2006]. Eye tracking has proven to be a valuable analysis and evaluation instrument in areas such as the web [Almeida et al. 2010b; Goldberg et al. 2002] and television [Brasel and Gips 2008; Rodrigues 2010] but has yet to convince video game researchers. This paper explores the state of the art of research related to visual attention and video game studies, namely how playing games can positively alter an individual's visual attention skills.

In addition, studies that have analyzed the potential of eye movements as a form of input in video games as well as an analysis method of evaluation will be explored. Lastly, a look into some of the future perspectives of the use of eye movements and eye tracking with games will be presented.

2. The Human Visual System

The human's ability to see is the responsibility of the human visual system (HVS). The HVS is a group of complex components that extract light from the world and transform it into an understandable image. Figure 1 is a simplified representation of the anatomy of the eye.

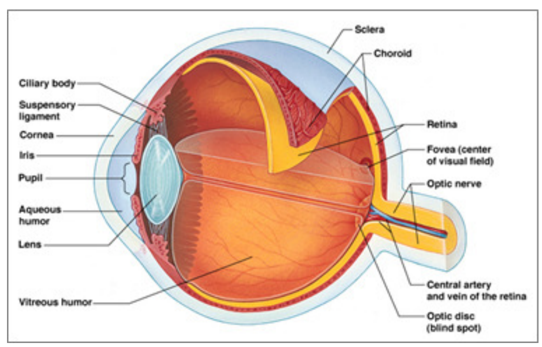

Figure 1: Anatomy of the eye[1]

Some of the key components of the HVS include the cornea, iris and the retina. The cornea, the outermost component of the eye, is the first to be hit by light. The cornea and the lens, located behind the pupil, function similarly to the lens of a photo camera. Together they focus images through the refraction of light at determined points on the retina [Hubel 1995; Ramos 2006]. The iris is located behind the cornea. Through its muscles, the iris controls the quantity of light that is processed by the inner eye. The pupil is found at the center of the iris. Light passes through the pupil before hitting the retina [Ramos 2006]. The retina is

[1] Image retrieved from *http://goo.gl/qVKSv*

responsible for converting light waves (or light energy) that enters the eyes into nerve signals that allow vision in various types of conditions. The retina is also capable of differentiating wave-lengths, which allow the visualization of color, once the signal is sent to the visual cortex (located at the back of the brain) through the optic nerve [Hubel 1995]. The light receptors – rods (responsible for vision in reduced light) and cones (responsible for color vision and detail) – are found at the innermost part of the retina [Bianco 2000].

2.1 Taxonomy of Eye Movements

In addition to vision, the HVS is capable of executing a series of eye movements through the coordination of six extraocular muscles that move the eyeball: 'lateral and medial recti' (responsible for sideways movement); 'superior and inferior recti' (responsible for vertical movement) and the 'superior and inferior obliques' (responsible for twist). These muscles work in pairs through control of the brain. For eye movements to occur, while one muscle relaxes, the other must contract, with an equivalent intensity to create the desired movement [Hubel 1995]. Through the contract-expand mechanism, the eyes are capable of performing 5 different movements: (i) 'smooth pursuits', (ii) 'vergence movements', (iii) 'vestibular movements', (iv) 'saccades' and (v) 'fixations'.

(i) Smooth pursuits are the result of a complex mechanism that, in the presence of an object in movement, respond with a complementary course of movement, allowing vision to maintain fixed an object [Guyton and Hall 2006]. (ii) Vergence movements are disjunctive as they move in opposite directions. When a person is looking from an object at a greater distance to one placed closer, the eyes will converge (i.e., rotate towards the nose); however, moving from an object placed closed by to one further away, the eyes will diverge (i.e., rotate towards the ears). (iii) Vestibular movements, also known as the vestibular-ocular reflex (VOR), are movements that focus the retinal image while the head is in movement. This is possible through the counter-rotation of the eyes at the same velocity the head moves in the opposite direction [Wong 2008]. (iv) Saccades are defined as rapid, voluntary and reflexive eye movements. Saccades are used to reposition the fovea – an area of the retina responsible for sharp vision – to a new location in the visual field. (v) Fixations are responsible for the ability to fix eye gaze on a specific object in the visual field. Fixations are controlled by two neuronal mechanisms: (1) the voluntary fixation mechanism, which allows humans to voluntarily find the object on which they want to fix their vision; (2) the involuntary fixation mechanism, which holds the eye on the object once it has been found [Guyton and Hall 2006]. Humans spend approximately 90% of their viewing time in a fixation movement.

3. Visual Attention

At any given moment, a large quantity of information invades an individual's senses. A human's capacity to process such a quantity of information is limited. Therefore, there is a need for selection. While stimulus selection in theory can be random, individuals have the capacity to perform specific selections [Cohen 2006]. The mechanism responsible for the ability to select stimuli is called 'selective attention'. In short, selective attention is the mental ability to select a fraction of all the stimuli present in our surroundings. Cohen [2006] suggests that the act of information selection assumes that in our surroundings information exists to be selected. Therefore, prior to the actual operation of selective attention, 'pre-attentive' processes must be performed.

Attention studies led to research in selective attention, resulting in a group of 'bottleneck theories'. The most influential theories were those proposed by Broadbent (1958), Treisman (1960) and Deutsch & Deutsch (1963) [Cohen 2006; Rossini and Galera 2006]. As Cohen [2006] notes, when performing a task, information processing begins with input (usually via our senses) and ends with output (normally a behavioral action). In their theories, Broadbent, Treisman and Deutsch & Deutsch discuss the stage in which selective attention information processing takes place. Broadbent proposed an 'early selection' model which proposes that physical properties in a scene are processed in parallel and without limitations. Treisman's model states that incoming stimuli are analyzed preattentively through an attenuation filter based on physical characteristics with resulting information becoming available to the individual's consciousness. Contrary to Broadbent and Treisman, Deutsch & Deutsch propose a late selection model. Their model indicates that all stimuli reach perceptual mechanisms, independently if attention is or not paid to them. All stimuli input activate a semantic representation and all incoming information is recognized. Because the capacity to respond to input is limited, only a part of incoming information is recognized and responded to. The selection of which information is recognized is based on its level of importance and pertinence.

In addition to the aforementioned theories, Cohen [2006] talks of existing literature that refer to 'Multiple Levels of Selection'. This theory suggests that there is a high level selection through processes called 'executive functions' which are used for strategic choices (e.g. task selection). Another lower-level selection mechanism is believed to be modality-specific. Executive functions work in the selection of a task and then shift to another. An example is the case of a person driving a car, listening to the radio and talking to a friend. The 'executive functions' process is responsible for deciding which task has a higher priority and when to shift these priorities. The 'modality selection' mechanism is responsible for selections within tasks.

Visual attention studies include many other studies and theories. Posner, Snyder, & Davidson [1980] theorized on the 'spotlight model' theory, where an individuals' visual attention moves and focuses on specific parts of their visual field, just as a spotlight does over a dark surface. Eriksen & Yeh [1985] proposed the 'zoom-lens model' based on and inheriting all the spotlight model's [Posner et al. 1980] characteristics, with the addition of a property related to size change.

Lastly, in terms of visual processing, human eye sight can process visual data as 'patterns' and 'motion' [Kremers 2009]. 'Pattern recognition' is used frequently when individuals select and process information from their surroundings and divide visual input into important pieces to which meaning and behavior is attributed. 'Motion tracking' deals with the ability to pick out, track and process the movement of objects in an individual's field of view.

3.1 Visual Attention Studies in Video Games

Studies have shown that video games may lead to specific visual attention patterns while playing games as well as alter a series of visual skills. In this section, studies that have focused on this question will be explored.

Green & Bavelier have developed a series of studies demonstrating that playing games can alter an individual's visual skills [2003; 2006b; 2006a; 2007]. In their original study [Green and Bavelier 2003], they demonstrated through a set of experiments that playing action-video games is capable of changing an individual's visual skills. In initial tests, Green & Bavelier tested a hypothesis that suggested that if video game players (VGP) have a greater attentional capacity, their attentional resources should last longer when compared to non-video game players (NVGP). In applied tests, VGP outperformed NVGP. In order to guarantee the validity of these results, Green & Bavelier had a group of NVGP undergo game training, playing 'Medal of Honor' for one hour a day, during 10 consecutive days. A control group was also trained under the same time conditions with the game 'Tetris'. Prior to the training, subjects were tested with several experiments which were equally applied posterior to the training sessions. Results showed that participants that played the action video game showed greater improvement for all tested tasks. Based on these results, the authors suggest that 10 days of training is sufficient to improve the capacity of visual attention, the spatial distribution and temporal resolution of attention.

Boot & colleagues [2008] developed a study intended to replicate and extend on Green & Bavelier's [2003] aforementioned work. Their study consisted in examining the differences between expert video game players (VGP) and non-video game players (NVGP) in areas such as attention, memory and executive control. Eleven VPG and ten NVGP played three games: 'Medal of Honor: Allied Assault' (First-person shooter), 'Tetris' (puzzle game) and 'Rise of Nations' (real-time strategy game). Several tests were conducted related to visual and attentional tasks, spatial processing and spatial memory. In a number of the executed tasks, expert gamers outperformed novice players. Specifically, VGP were able to track objects that moved at greater speeds, performed better in a visual memory test, switch between tasks more quickly as well as make decisions about rotated objects more quickly and accurately. In addition, their results showed that, with exception to the 'Tetris', 20h of training was insufficient for inexperienced players to show improvements in their tasks, contradicting results presented by Green & Bavelier [2003]. Boot & colleagues suggest that this difference could be related to the variances in the tasks they applied when compared to other studies.

Castel & colleagues [2005] also conducted a study regarding visual search capacities and differences between video game players (VGP) and non-video game players (NVGP). In a first experiment, they examined the similarities and differences between VGP and NVGP in terms of the ability to disengage attention from cued locations and later avoid these locations. In a second experiment, the authors examined performance differences and similarities between VGP and NVGP in visual search tasks that involved finding a target letter among various other distractor letters. The authors' findings corroborate those found in other similar research. In general, their results demonstrated that both VGP and NVGP were equally competent at constraining from returning their attention to previously seen locations. Nonetheless, VGP outperformed NVGP in terms of reaction times when detecting selected targets. Despite this, Castel & colleagues believe that VGP and NVGP share similarities in terms of attentional processing mechanisms in specific situations.

A final study, not specifically related to game players, focused on issues of attention using video games. Clark & colleagues [1987] developed a study to validate the possibility of reversing the decline of senior people's (57-83 years of age) response selection time to stimuli. A group of participants played video games for 7 weeks whereas a second control group did not. Study results showed that the participants that played the video games were able to perform faster and had better reaction times in the experimental tasks when compared to those that did not play the game.

4. Eye Tracking

The study of eye movements has witnessed interest in several areas of studies such as the web, television, advertising and video games. Eye movement research dates back many years as well as the methods and techniques used to study these movements.

Early eye movement analysis was done through introspection or directly by the researcher which observed a user's eye with a mirror, a telescope or a peep hole. These methods were doubtful because it was the researcher's eyes that measured the eye movements [Richardson and Spivey 2008]. Eye movement measurement only became properly valid when mechanical devices that permanently recorded eye movements appeared.

Louis Émile Javal is credited with some of the earliest empirical studies as of 1879, having suggested that eyes moved through a series of 'jerks' [Richardson and Spivey 2008]. Edmund Delabarre analyzed eye movements by attaching a cap connected to a wire to his eye. The wire, which was connected to a lever, drew the movements on a kymograph cylinder. At a similar time, Edmund Huey [2009] presented a similar measurement device. Huey molded a piece of a cup to fit the eye which was attached to a flat and thin aluminum pointer that responded to the slightest of eye movements. These movements were registered by the aluminum pointer on a moving drum-cylinder.

Despite the value of Delabarre and Huey's contributions, their devices were criticized for inhibiting eye movements and straining the eye [Richardson and Spivey 2008]. In an attempt to overcome these limitations, Dodge & Cline [1901] developed a non-invasive eye movement technique based on the use of photography, used frequently until the 1970s. With technological advancements, the division of the eye's reflection beam into horizontal and vertical components and recombination into a fixation point was then possible. These fixation points were then recorded onto a film reel [Richardson and Spivey 2008].

Even with the advancements and improvements on existing techniques, up to the first half of the 20th century, these techniques measured the eyes in relation to the head. This implied that in eye movement research, the subject's head had to remain fixed [Richardson and Spivey 2008]. In the 1970s, a solution for uncomfortable measurement techniques appeared with the simultaneous measurement of two optical characteristics of the moving eye. Because these characteristics behaved in a different manner under head movement and eye rotation, their differential helped calculate the '*point of regard*' (POR), the place in the world where a subject is looking at [Duchowski 2007; Richardson and Spivey 2008]. While older or modern POR measurement techniques still require some head stability, some head movement does not automatically alter the quality of the results.

Two main types of eye movement techniques can be considered: (i) the technique that measures the eye's position relative to the head [Huey 2009; Richardson and Spivey 2008]; and (ii) the technique that measures the orientation of the eye in space, known as the 'point of regard' (POR) [Duchowski 2007]. The first has been extensively applied in the analysis of reading behavior [Richardson and Spivey 2008] and the second in the identification of items in a visual scene.

Over time, existing limitations have slowly been reduced and resolved. The introduction of table and head-mounted eye trackers has allowed greater movements from study subjects [Richardson and Spivey 2008]. Figure 2 represents one example of a table-mounted eye tracker.

Figure 2: Example of a table-mounted eye tracker[2]

Recalling, eye tracking can detect where a subject's eye fixates as well as the movements that occur between fixations: saccades. Gaze plots are one possible visualization instrument used to analyze saccades and fixations [Ross 2009]. Figure 3 represents an example of a 'gaze plot'.

Figure 3: Example of a gaze plot[3]

In a gaze plot, the circles represent fixations; i.e. the place on the interface where an individual briefly stopped to visualize an element. The numbers in these circles represent the order in which these fixations occurred. The size of each 'fixation circle' may vary according to the length of a fixation. Smaller circles indicate shorter fixations; larger circles indicate longer

[2] Image retrieved from *http://www.tobii.com*
[3] Image retrieved from *http:// http://goo.gl/K5pi3*

fixations. Finally, the lines that connect the circles represent saccade movements.

Another visualization technique common to eye tracking is the 'heat map'. A 'heat map' can be defined as "*a map that uses color or some other feature to show an additional dimension*" [Fry 2004]. In the case of an image or web site, a heat map will "*display the most attractive elements of the image for consumers in the form of 'hot' and 'cold' spots*" [Group 2011]. Figure 4 represents an example of a heat map (left) and an example of an opacity heat map (right) for the same image.

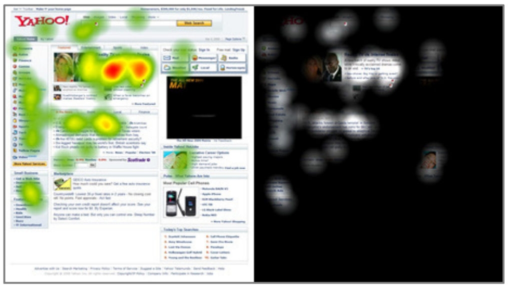

Figure 4: Example of a heat map (left); Example of a opacity heat map (right)[4]

5. Eye Tracking applied to Games

Eye tracking has been applied to a wide variety of research fields. Many of the first studies up to the 1950s were directly related to reading processes and habits [Richardson and Spivey 2008]. The first use of eye tracking in the HCI field is credited to Fitts & colleagues [Fitts et al. 1950]. Other studies related to the web [Goldberg et al. 2002; Almeida et al. 2010b]; television [Rodrigues 2010; Brasel and Gips 2008]; and reading have been developed [Quinn and Adam 2008; Buscher et al. 2010] as well as regarding; medicine [Law et al. 2004] and sports [Wood and Wilson 2010].

For the purposes of this paper, we will look into the contributions of eye tracking in video games in two areas: (i) as an input method or (ii) as an analysis and evaluation instrument.

5.1 Eye Tracking as Input for Video Games

The following studies have concentrated their attention on the possibilities of eye tracking in a video game context as a method of input in the control of video games.

Isokoski & colleagues [2009] identified four different ways eye tracking could be implemented in video games. The first (1) does not require any specific modification within the game and is known as the 'dwell-time based selection' technique. This is possible because many eye trackers incorporate a mechanism that controls the operating system to place the cursor at the position where the user is looking. This control technique is sufficient to play certain games. The second (2) solution requires the use of additional software which is independent of the eye tracker and game. When no specific eye tracking software solution is available, a parallel program may be used that registers specific events used to play the game. The third (3) solution is game related and implies modifications in the game code which will allow eye control. This solution is more labor intensive and difficult to apply due to the lack of games that are open and modifiable. The fourth (4) solution is the most labor intensive and implies the development of a game from scratch. While it may also be a more expensive solution, it benefits from the possibility of adapting the game to maximize the potential of eye gaze input.

Isokoski & colleagues [2009] also explored the positive and negative aspects of applying eye tracking in 13 different game genres. Some of the analyzed genres are: (i) computer board games and puzzles; (ii) computer card games; (iii) first-person shooters; (iv) third-person action and adventure games; (v) platform; (vi) real-time strategy; (vii) racing games.

(i) The use of eye tracking in computer board games and puzzles can be considered accessible because they are normally one player or turn-based multiplayer games. Eye tracking versions can be implemented as long as interface elements are large enough for easy selection with the eyes. (ii) Card games are also easily executed because they do not require quick reactions and are normally turn-based. (iii) First-person shooters are played from the view point of the player's character and often involve several controls (e.g. shooting, jumping and crouching). Aiming accuracy and speed are important aspects of FPS games and eye tracker control may not be as precise as mouse control, for example. (iv) Third-person action and adventure games may not require camera control (as occurs with FPS games) but do require avatar control which may be difficult through eye gaze. Furthermore, other issues – also common to FPS games – related to object selection and character interaction suggest difficulties in developing gaze-based games of this genre. (v) Platform games also carry limitations in terms of implementation. Despite simple basic controls, the fact that players may constantly be looking around the game level in an attempt to make a choice for his next move suggests that eye control for character movement would be challenging. (vi) Real-time strategy games normally have sequences where the game takes action before the player completes his selections. Additionally, this game genre also requires constant mouse control. Because of this, the use of eye control will likely place players in disadvantage when playing against other players using typical mouse control. (vii) Racing games can be simple or complex and eye control accompanies this complexity. Racing games also

[4] Image retrieved from *http://goo.gl/K5pi3*

include some differences between the focus of attention and movement control. For example, if movement control is allocated to steering, an attention deviation to the speed indicator may lead the player to crash.

To date and to our knowledge, no commercial games have been developed to make full use of the eye tracking potential. However, many individual and academic projects have resulted in original or adapted games that explore the potential of eye tracking as an input method.

Starker & Bolt [1990] are responsible for one of the first studies to use real-time responsive eye tracking. Starker & Bolt developed a display that showed a rotating planet with identifiable objects. When an observer fixed their eyes on an object for a specific period of time, additional information would be given through speech. Even though their system can't be considered a traditional game, it does share some similarities, namely in terms of object exploration and selection [Isokoski et al. 2009].

Špakov [2005] developed a project named 'EyeChess', a PC based tutorial intended to assist novel players with the game Chess. Selections within the game were done through one of three options: (i) blinking, (ii) eye gesture and (iii) dwell time. In addition to 'Eye Chess', Špakov has developed other games[5] based on gaze control: 'Tic-Tac-Toe'[6], where a player must create a line of three before his opponent; 'Lines', where a player must make a 5-piece line or cross of a single color to get rid of the balls that fill the board, among others.

Jönsson [2005] developed a study to evaluate the use of eye tracking in computer games. Different game prototypes were developed that could be controlled with eye movement. In a focus group session, Jönsson identified how eye tracking could be used in games as well as what actions eye tracking could perform. In terms of requirements, the focus group indicated speed, accuracy, calibration easiness and invisibility of the eye tracker. As actions, they identified aiming/shooting; marking/choosing; changing view/scrolling; and zooming. Based on collected data, Jönsson defined a group of interaction sequences that could be controlled by eyes as well as distinct comparative studies. The game 'Sacrifice' was used in testing as were several prototypes developed using the 'Half Life' SDK. Two interaction methods were selected: (i) change field of view/aim with the eyes; (ii) change field of view with the mouse and aim with the eyes. In many FPS games, the game weapon is aimed at the center of the screen. When a player moves the mouse, the player's field of view changes, but the weapon remains in the center of the screen. The first interaction method attempted to replicate this idea in which the eyes would control the field of view. In the second interaction method, the field of view would be mouse-controlled while the weapon is controlled by eye gaze. Based on Jönsson's work, multiple demos were developed for usability testing and feedback was collected regarding participant satisfaction as well as how participants' performance differed among interaction methods.

Isokoski & Martin [2006] reported early findings regarding the use of an eye tracker as an input device in First-Person Shooter games. The authors also looked to compare the efficiency of eye trackers as game controllers when compared to common input devices. In their work, Isokoski & Martin used an originally developed game rather than an existing game engine. In their study experiments, unintelligent targets were created so game situations could be easily controlled. The developed game world was of simple nature and contained random hills and valleys with trees scattered throughout the level. As occurred with Jönsson's study [2005], Isokoski & Martin defined a use for the eye tracker input, and decided that it would be used for weapon aiming within the game. Additional control of the camera and the game character were provided through the mouse and keyboard. A red point on the screen indicated where the player was looking at. Shooting at the 'visually selected' region was done through the use of mouse clicks. Isokoski & Martin suggested that aiming at targets with eye gaze rather than through mouse control would be an advantage, namely in situations where the player would reach the top of a hill and targets are revealed. However, the level of accuracy could be affected using this type of control. At the time of their work, existing limited results suggested that the use of the eye tracking did not outperform the simple keyboard and mouse combination. However, eye tracking in addition with the keyboard and mouse did perform better when compared to an Xbox 360 controller. Figure 5 represents a screenshot from Isokoski & Martin's [2006] eye controlled game.

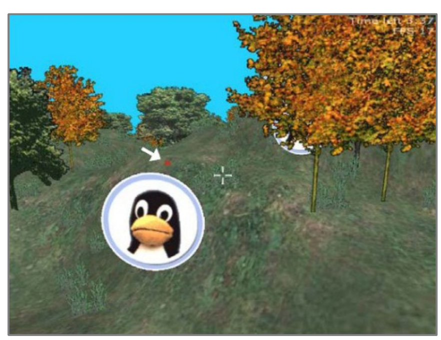

Figure 5: Screenshot from Isokoski & Martin's eye gaze controlled game

Smith & Graham [2006] also developed a study focused on eye tracking as an input device for video

[5] Additional information on Špakov's [2005] projects can be found at *http://www.cs.uta.fi/~oleg/*

[6] Video demonstration of the games 'Tic-Tac-Toe' and 'Lines' available at *http://y2u.be/0Nz68kz51Os*

games. Smith & Graham studied the effects of eye-based input on the experience of playing games. In their studies, three games from three different game genres were used: 'Quake 2' (FPS); 'Neverwinter Nights' (Role-playing game); 'Lunar Command' (action/arcade game). For each game, player performance with the mouse and eye tracker was collected in addition to player's subjective data. Twelve participants played each of the three defined video games. Collected results were divided into two types: performance measures and subjective measures. Regarding performance measures, ANOVA analysis results indicated that for the 'Quake 2' and 'Neverwinter Nights' games, no significant differences were found between mouse and eye input. However, for 'Lunar Command', mouse interaction was better than eye based input. In terms of subjective measures, results indicated that players only enjoyed playing 'Neverwinter Nights' more with the use of eye gaze. For 'Quake 2' and 'Lunar Command', participants indicated that using the mouse was easier; 'Neverwinter Nights' received divided opinions. In regards to immersion, the majority of players for all three games suggested that they felt more immersed when using their eyes as input, possibly because of the continuous nature of eye based control.

Dorr & colleagues [2007] developed a study with the objective of verifying if eye control performed better than mouse control. In their experiments, two players would play against each other. One player would control the paddle with the mouse while the other controlled the paddle with their eye movements. Results indicated that the eye tracker performed well when compared to mouse control.

Ekman & colleagues [2008] in an ongoing study introduced the game 'Invisible Eni', an 'eyes only' computer game which uses gaze, blinking and pupil size for control. Pupil size was introduced in the study as a novel element in gaze related game studies. Ekman & colleagues [2008, p. 3136] state, "*since pupil size is sensitive to excitement and mental effort, the control itself is always partly responding to the act of using it as a control. This can serve as a positive feedback loop: If the interaction is engaging enough, pupil sizes will increase to reflect this feeling, further influencing the action of pupil control. In our game, we use this loop to model magic powers.*" The 'Invisible Eli' game's objective is to free butterflies in captivity by feeding them magic nectar while avoiding nearby nightmare monsters. The games uses the following controls: gaze direction controls the game characters; blinking serves as a mechanism for escaping from enemies; and pupil size is used to model magic. At the time of their work, limited results indicated that feedback and training would be essential for the success of their pupil-based interaction option.

Finally, LC Technologies Inc. developed a software package[7] which includes, among other programs, a visually controlled Paddle game as well as Mahjong and Score Four.

5.2 Eye Tracking as an Evaluation tool for Video Games

In addition to the use of eye tracking and eye gaze as a method of input for video games, eye tracking has also been applied as a method of evaluation of video games. However, few studies have been developed that report on this aspect. Studies by El-Nasr & Yan [2006], Johansen et al. [2008] and Almeida [2009, 2010a] are a sample of existing studies that introduce eye tracking technology as a method of evaluating usability problems found in video games.

El-Nasr & Yan [2006] introduce their study with the opinion that game and level design could be improved if players' visual search patterns were analyzed and understood. Game designers could also improve game play by altering game level elements such as textures, colors and object placement if players' visual attention patterns were comprehended. The authors [2006, p. 1] state: "*many non gamers get lost in 3D game environments, or they don't pick up an important item because they don't notice it*". Consequently, if level designers and game developers understood player visual interaction, object placement, color and texture selection and mixing could be more adequate in order to draw player attention. El-Nasr & Yan conducted two studies in which players' visual attention was analyzed. Their studies aimed to determine if players' visual attention followed the bottom-up or top-down visual theories[8]. In their studies of two games of distinct genres, they concluded that because action-adventure games are goal-oriented, top-down visual patters are more frequent. For example, in the adventure game used, they concluded that if game designers want objects to be more noticeable, these should be placed in places or near items similar or related to the player' search pattern for a specific goal. In the second study, with a FPS game, they concluded that players mostly concentrate their focus on the center of the screen where the weapon's cross indicator is located. These visual search patterns contrast with those found for the adventure game, where players demonstrated a more heterogeneous visual search pattern.

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[7] Additional information on the Eyegaze Edge Programs: *http://www.eyegaze.com/content/programs-eyegaze-edge* [Accessed July 27, 2011]

[8] El-Nasr and Yan [2006] suggest that in the 'bottom-up theory', visual features such as color and motion unconsciously affect perception of a game environment. The 'top-down' theory relates to the idea that visual features are more effective in attracting player attention because these are under voluntary control.

Johansen & colleagues [2008] focused on issues regarding the use of eye tracking in the game industry, specifically within a game development company. Working closely with a game developer (IOI, Denmark), they looked to: (i) understand how they could persuade game designers to consider the relevance of usability results; (ii) understand how they could involve game designers in usability related work; (iii) identify methods that could provide new information about user behavior and experience. The authors also expected to demonstrate the value of eye tracking as a means of providing information related to the importance of usability results in game development. During the elaboration of their study, which coincided with the development of a game by the IOI group, the authors were able to demonstrate the value of eye tracking technology as a means to solve a game level related problem. In conclusion, the authors defend the value of eye tracking as a means to provide valuable information about user behavior and experience.

Almeida [2009] carried out a study which applied eye tracking to understand how players visually interacted with game scenarios. Almeida developed and applied a method in order to understand the extent to which players visualized areas of a video game scenario. The study consisted in three groups of players (inexperienced, casual and hardcore) playing a First-person shooter video game ('Call of Duty: Modern Warfare) while their eye movements were registered with an eye tracker. Data collected from players was then represented on a representation of the game level map played. Represented data included information related to player position on the map and what the player was looking at. Furthermore, the heat map was selected as the visualization instrument to represent data collected from players. Two heat maps were developed to represent player data: (i) a 'Visual Field View' heat map, which characterizes the areas of the map seen by players, whether or not they were in their focal point; (ii) a 'Point of Regard' (POR) heat map, which characterizes the exact location to where a player was looking. Figure 6 represents the 'Visual Field View' heat map, developed using hardcore player's visualizations.

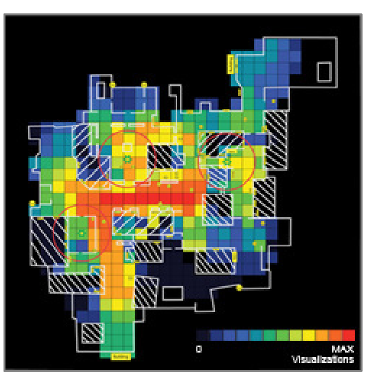

Figure 6: Representation of hardcore players' 'Visual Field View' heat map

In another study, Almeida & colleagues [2010a] applied the method proposed by Almeida [2009] and analyzed the differences between hardcore and inexperienced players' interaction behavior with the FPS game 'Call of Duty: Modern Warfare'. In the study, 12 hardcore and inexperienced players played a game mode with the objective of conquering flags placed in the map while playing as a team. While playing, participants' eye movements were recorded with an eye tracker. The applied method resulted in four heat maps, two for each gaming group: 2 'visual field view' heat maps and 2 'point of regard' heat maps. Results from the heat maps in addition to video analysis demonstrated differences between hardcore and inexperienced players. Specifically, hardcore players revealed to have a more objective approach when playing. This idea can be corroborated by the fact that hardcore players had a greater number of visualizations in the areas where the flags were located. Video analysis also confirmed this behavior. When beginning the game or, after spawning, hardcore players would move towards the flags. In contrast, inexperienced players adopted a more exploring orientated behavior. This approach led to a greater number of visualizations in their 'visual field view' heat map when compared to the hardcore players' same heat map. Other findings showed that both player groups concentrated much of their attention on the central corridor of the map.

User Experience consultancy group 'User Vision'[9] tested and explored player's in-game experience with Microsoft's Kinect [Duke 2011]. Their work identified a number of issues that are valuable to game designers. Twelve participants, all infrequent gamers, were instructed to play the 'Reflex Ridge' game and achieve the highest score possible. Their results indicated that the Kinect system was easy to use and intuitive. However, the game played was confusing at certain points and had a negative impact on the user experience. General results offer some valuable insight for game designers. As the author of the report writes [Duke 2011], "*a game needs to be easy to learn, to provide a satisfactory experience for new users, while being significantly challenging to ensure interest in it lasts. If game play experiences are negative, there is a real chance that this will impact on players' enjoyment (…).*"

6. Present & Future Perspectives

Eye tracking and visual attention studies continue to raise interest among researchers. New uses and methods of exploring the potential of eye movements and gaze input are being considered both as forms of input and evaluation methods.

[9] User Vision: *http://www.uservision.co.uk*

In early March 2011, eye tracker manufacturer Tobii[10] unveiled the first laptop[11,12] to integrate eye movement control. In a partnership with computer manufacturer Lenovo, both companies developed 20 laptop prototypes which brings eye tracking technology closer to the consumer. The laptop integrates several functions that will benefit from the potential of eye gaze input, namely: switching between windows, zoom into pictures or maps, scroll within documents and, play video games. This type of laptop may bring new life to computers and make them reachable to a greater variety of players, namely those with motor disabilities. While limitations related to eye movement input in games [Isokoski et al. 2009] must always be considered, the existence of a laptop with this potential is a first step in overcoming barriers felt by those with motor difficulties.

In addition to computers and laptops, eye tracking technology may soon enough proliferate in other technology such as smartphones and tablet computers. Benefiting from powerful and quality cameras, these devices may soon include eye controlled gaming. News from late July 2011 indicates that game developer 'TopWare Interactive'[13] has taken the iPad's camera and used it for eye movement control in the game 'Two Worlds II: Castle Defense' [Winslett 2011; Davison 2011]. This may be the first of many eye tracking games to come.

Eye tracking and visual attention may also continue to play a role in video game evaluation. As seen in section 5.2, few studies have explored all the possibilities of eye tracking as a method of evaluation. In his PhD work, Almeida is continuing work related to the evaluation and analysis of player interaction within game levels [Mealha et al. 2011].

7. Conclusion

In this paper, some of the most relevant work related to research studies in the areas of visual attention, eye tracking and video games have been presented. Eye tracking has been widely applied in many areas of research but has yet to make full impact with video games. Additionally, it has been shown that playing video games can aid in the acquisition and improvement of visual skills. Video game sales and proliferation can benefit largely with the potential of eye tracking as more people, namely those with motor disabilities, can be then considered as a potential target audience. The application of eye tracking in video games can be considered two-fold: first, as a form of input, substituting or complementing traditional input methods (e.g. mouse, keyboard or joystick) while making games more accessible to those with motor difficulties as their eye movements become a main solution for game control. Second, eye tracking can be applied as a method of evaluation and analysis in video games, providing information related to how players visualize the game interface and explore the game levels and worlds they play. While much work and further studies must be done to make the most of the potential of eye tracking, the work reported in this paper suggests that research is on the right track and that the future is promising.

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[10] Tobii: *http://www.tobii.com/*
[11] Tobii/Lenovo eye-controlled laptop: *http://goo.gl/Plhcx*
[12] More information on the Tobii/Lenovo laptop: *http://youtu.be/GFwhx0Wy8PI*
[13] TopWare Interactive: *http://www.topware.com/*

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