Eye Tracking Data Representation and Visualization: on Information and Communication studies at CETAC.MEDIA

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ABSTRACT

Eye tracking has become a preponderant technique in the evaluation of user interaction and behaviour with study objects in defined contexts. Common eye tracking related data representation techniques offer valuable input regarding user interaction and eye gaze behaviour, namely through fixations and saccades measurement. However, these and other techniques may be insufficient for the representation of acquired data in specific studies, namely because of the complexity of the study object being analysed. This paper intends to contribute with a summary of data representation and information visualization techniques used in data analysis within different contexts (advertising, websites, television news and video games). Additionally, several methodological approaches are presented in this paper, which resulted from several studies developed and under development at CETAC.MEDIA - Communication Sciences and Technologies Research Centre. In the studies described, traditional data representation techniques were insufficient. As a result, new approaches were necessary and therefore, new forms of representing data, based on common techniques were developed with the objective of improving communication and information strategies. In each of these studies, a brief summary of the contribution to their respective area will be presented, as well as the data representation techniques used and some of the acquired results.

1. INTRODUCTION

Founded in 2007, the CETAC.MEDIA research centre (*http://www.cetacmedia.org/*) focuses on information and communication in new technology mediated contexts. Topics covered at CETAC.MEDIA include Information Representation and Organization, Informational Behaviour, Analysis of Communication processes in New Media and Design, and prototyping and validation of new applications of Participatory Media. CETAC.MEDIA has partnered up with several institutions including the Fundação para a Ciência e Tecnologia (FCT), PT Inovação, PT Comunicações and Fundação Calouste Gulbenkian. These partnerships have resulted in several projects such as 'Seduce', 'Crossed TV Games', 'iNeighbour TV', 'SAPO Campus', 'SkilledArt' and 'MeshT'. In 2008, CETAC.MEDIA promoted the creation of the PhD program 'Information and Communication on Digital Platforms' (ICDP), a joint program of the University of Aveiro and the University of Porto. The centre also participates in the Multimedia in Education (MMEdu) doctoral program and the Multimedia Communication (COMM) Masters program. As of May 2011, the research centre has 22 members, 30 hired researchers and grants as well as 71 PhD students.

One context in which CETAC.MEDIA has focused its research is studies that use eye tracking as an evaluation technique. With the advances in technology and different consumer needs, as well as their relation with systems and products, the development of new ways to accompany this progress were necessary. Therefore, understanding the processes and decisions made by users to achieve a result is just as relevant as observing and analysing the final result. Consequently, eye tracking becomes an essential instrument as it allows the evaluation of the experience and interaction of a user with a given study object.

Eye tracking is nowadays frequently used as an analysis tool in diverse scientific areas such as medicine, psychology and marketing, but essentially in usability studies applied to the web, television - publicity, television programs and information - as well as video games. This multiplicity of uses allows eye tracking to occupy a central and influential role in what concerns the evaluation of a user's interaction and behaviour with a given service or product, allowing entities and researchers to develop more effective and efficient products for the consumer.

This work seeks to systematize some of the work developed at CETAC.MEDIA, namely related to representation and visualization of data.

2. EYE TRACKING

Eye movement research dates back many years as well as the methods and techniques used to study these movements (Jacob & Karn, 2003). The earliest eye movement analysis techniques were done through introspection or directly by the researcher, who observed a user's eye with a mirror, a telescope or a peephole. These methods were doubtful because it was the researcher's eyes that analysed the eye movements (Richardson & Spivey, 2008).

In 1879, Louis Émile Javal commenced some of the earliest registered empirical studies regarding eye movements. At the time, Javal suggested that eyes moved through a series of 'jerks' – a quick and sudden movement (Richardson & Spivey, 2008). In the late 1800s, Delabarre studied 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. Near that same 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 aluminium pointer that responded to the slightest of eye movements. These movements were registered on a moving drum-cylinder by the aluminium pointer.

Despite the value of Delabarre and Huey's early contributions, their devices were criticized for inhibiting eye movements and straining the eye (Richardson & Spivey, 2008). In an attempt to resolve these limitations, Dodge & Cline (1901) developed a non-invasive eye movement technique based on the use of photography, frequently used up to the 1970s. Years later, in 1985, McAllister and Steel improved the photography-based technique, developing a system with the objective of registering eye movements in two dimensions (Jacob & Karn, 2003). According to Rayner (2004), this time period is associated to the discovery of the function of the basic eye movements.

These initial studies led to the development of eye tracking equipment, which has evolved to this date. Hartridge & Thompson invented in 1948 the first head-mounted eye tracker (Jacob & Karn, 2003). These first developments were the foundation for the advancements in precise and sophisticated head-mounted eye trackers, namely in terms of the reduction of the limitations this equipment forced on head movement (Jacob & Karn, 2003).

Even with the advancements on existing eye tracking techniques, until the first half of the 20th century, these techniques only measured the subjects' eyes in relation to the head. This limitation implied that in eye movement studies, a subject's head had to remain fixed (Richardson & Spivey, 2008). In the 1970s, a new solution was presented with the simultaneous measurement of two optical characteristics of the moving eye. Because these characteristics perform differently under head movement and eye rotation, the differential between these characteristics helps calculate the 'point of regard' (POR), the place/object a subject is looking at (Duchowski, 2007; Richardson & Spivey, 2008). While the use of older or modern POR techniques still require some head stability, some head movement is tolerated without it altering the quality of the acquired results. Much of the technological advancements during this time are still applied in modern eye tracking equipment.

3. EYE TRACKING AS AN EVALUATION TECHNIQUE

In recent years, with the evolution of technology and the development of new needs by consumers, it was important to develop new means and methods to accompany this progress. Thereby, the inclusion of eye tracking is relevant in order to assess the experience and interaction of a user with a specific study object. Furthermore, not only does it become relevant to observe and analyse the final result, but also the entire process, as well as the decisions made by users that led them to achieve a certain result. Eye tracking becomes pertinent in this process as it is a technology that tracks eye movements in a specific visual environment (Duchowski, 2007).

Eye tracking is increasingly used as an analysis instrument in various scientific fields, such as medicine, psychology, as well as in usability studies applied to the web, video games and television (advertising, TV News, entertainment, among others). This multiplicity of uses allows eye tracking to be a relevant instrument in the evaluation of human behaviour as well as user interaction with a specific product or service. The potential offered by eye tracking allows companies and researchers to develop more efficient and effective services and products that emotionally appeal to the consumer. So, it is important to develop a set of methods and techniques to understand how users receive and process information. This multiplicity of uses indicates that eye tracking is a very powerful technology regarding performance evaluation and user interaction with a given product or service. Therefore, it is considered that the use of eye tracking becomes relevant in better understanding the reception of visual and auditory stimuli in the information processing of contents.

3.1 Representation and Data Visualization

Representing and visualizing data and information is of importance as it helps a person see and comprehend abstract data that is non-understandable. "*Information visualization deals with making an abstract set of information visible, usually in circumstances where no metaphor exists in the physical world*" (Fry, 2004, p. 39).

Some of the most common and used information visualization techniques have been summarized in works developed by Fry and Behrens (Behrens, 2008; Fry, 2004). These include the 'scatter plot', 'star plot', 'bubble chart', 'dot matrix', 'pie chart', 'tree map', and 'tree diagram'. In the context of eye tracking data visualization, other techniques have been favored, namely the 'gaze plot', the 'heat map', the 'bee swarm', 'clusters', 'areas of interest' (AOI), among others. Figure 1 represents some of these visualization techniques.

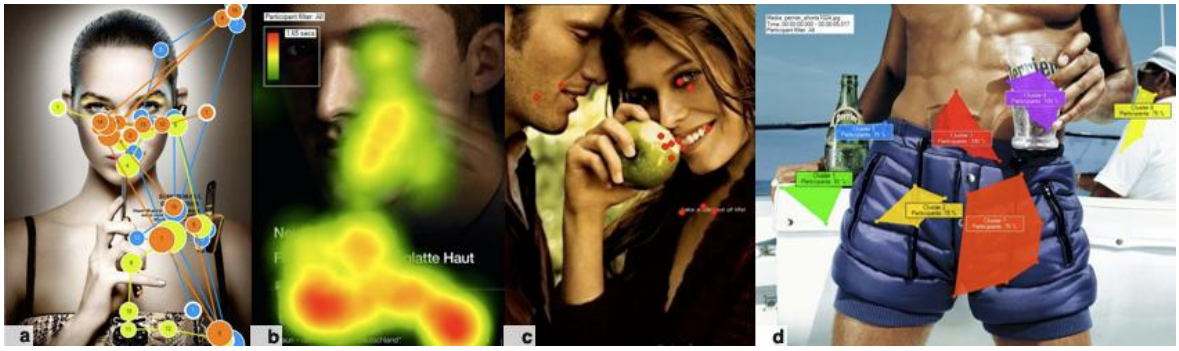

Figure 1. *Representation of common visualization techniques used with eye tracking: (a) Gaze plot, (b) Heat map, (c) Bee swarm, (d) Clusters*

A gaze plot (Figure 1a) displays an individual's eye movement sequence and the order of the sequence. In a gaze plot, circles represent fixations (the place where eye movement briefly stopped). The variation in circle size indicates different fixation times: the larger the circle, the longer the fixation. The lines that connect the circles represent saccadic movements (rapid eye movements that occur between fixations). A heat map (Figure 1b) is "*a map that uses color or some other feature to show an additional dimension*" (Fry, 2004, p. 106). A heat map will also display elements of greater interest through the use of 'hot' and 'cold' spots. A Bee Swarm (Figure 1c) consists in showing in the form of points, the spot where a user focuses. It can also simultaneously present the attention points of different users. Clusters (Figure 1d) consist in representing the areas where there is a greater concentration of fixation points.

Taking into account some of the limitations associated to the use of eye tracking, several authors have developed techniques in order to provide other solutions for eye tracking data representation and visualization. Räihä et al. (2005) proposed a new technique where temporal information played a key role in eye tracking data representation and visualization. These authors designated this technique as 'time plot of the gaze data'.

4. CETAC.MEDIA STUDIES

Eye tracking allows the detection and the recording of a viewer's eye movements (Duchowski, 2007). This possibility had led to an increase in recent years of the use of eye tracking in various contexts of communication research. CETAC.MEDIA has developed studies in various areas, such as advertising (Manteigueiro, 2011), websites (Almeida, Mealha, Veloso, & Luís, 2010), TV News (Marques, 2009; Rodrigues, 2010), and video games (Almeida, 2009; Almeida, Mealha, & Veloso, 2010). These studies will be detailed below.

4.1 Television Advertising

The use of eye tracking in advertising has resulted in several studies. Existing studies have commonly been divided into three main areas: (i) internet advertising (Dreze & Hussher, 2003; J. Goldberg, Probart, & Zak, 1999); (ii) print advertising (Rik Pieters & Wedel, 2007; R. Pieters, Wedel, & Zhang, 2007; Treistman & Gregg, 1979) and (iii) television advertising, the most important area for this research.

Few studies have been developed regarding television advertising. One study was conducted by d'Ydewalle & Tamsin (1993) which focused on advertisements that ran during football game commercials. d'Ydewalle et al. (1998) developed another study that tested the effectiveness of different advertising shots and how transitions could block perception. Aoki and Itoh (2000) focused on users' attention in TV advertisements and concluded that product preference isn't a key factor in viewers' attention. However, viewers may be influenced by factors such as the use of celebrities and the frequency in which scenery changes. Aoki and Itoh (2001) conducted another study in order to understand the influence of sound in the users' attention during the viewing of television advertising.

4.1.1 Advertising studies at CETAC.MEDIA

In today's consumer society, advertising has great potential to lead an individual to act over services or products. Therefore, the aim of advertising is to draw attention, arouse interest in a product, create desire and lead to an action: a purchase. Disguised advertising is related to advertisements that appear in audiovisual narratives without the awareness of the viewer. The main objective of Manteigueiro's (2011) was to understand the influence of disguised advertising in an audio-visual narrative with the help of eye tracking. Preliminary data resulted in important indicators that can contribute to the elaboration of guidelines for the development of disguised publicity. This study marks spatial and temporal audio-visual content areas containing disguised advertising artefacts. The audio-visual content is then used in an empirical study to gather eye gaze data. This user/spectator data is then correlated with the pre-marked audio-visual data to analyse the relevance of the disguised advertising artefacts in the attention of the viewer. Visualization techniques used to integrate and understand the results are visually correlated (spatially and temporally) with the audio-visual material that is being studied, an additional layer on audio-visual content.

4.2 Websites

Regarding eye tracking studies and the web, these are essentially done in two main areas: (i) search engines and (ii) websites. Research focused on search engines is important because 'search activity' is one of the most common activities done by users. Furthermore, 75% of internet users consider that search systems are not efficient (Fallows, 2005). Many of the existing studies focus on evaluating how users interact with the results of a search engine and how links are selected for further exploration (Granka, Joachims, & Gay, 2004); how users interact with two types of interfaces (list or tabular) (Rele & Duchowski, 2005); how user search behaviour varies when the information in the search results they look for is placed at different positions (Fox et al., 2004); and, the influence of adding information to contextual snippets in search results (Cutrell & Guan, 2007).

Regarding websites/portals, eye tracking studies are of value in order to understand the areas on which users focus the most, providing a greater understanding of what content should be placed on a website, as well as how it should be laid out. The 'Stanford Poynter' project (Lewenstein, Edwards, Tatar, & DeVigal, 2000) is possibly the first eye tracking study applied to websites and broke ground for the many eye tracking web studies that followed. Results from the 'Stanford Poynter project showed – among other conclusions – that users first read text content, followed by photographs and graphics. Studies related to the usability of websites' layouts were conducted (Cowen, 2001) as well as how users viewed three different types of webpages - a portal, an advertising page and a news story page (Josephson & Holmes, 2002). Goldberg et al. (2002) studied various design features on a web portal while participants completed several tasks. Their results led them to suggest, for example, the placement of the search bar on the top of the left side of the page for better visualization. Pan et al. (2004) studied 22 pages of 11 websites with the intent of evaluating differences among participant genre, website typology and the order in which the websites were viewed. Nielsen & Pernice (2009) focussed on visualization patterns on business related websites. Lastly, Djamasbi et al. (2005) studied the relation between the web and 'Generation Y' (individuals born in the mid-1980s and later) indicating that this group of individuals prefer pages with a large main image, little text, a search feature and pictures of celebrities.

4.2.1 Website studies at CETAC.MEDIA

Almeida et al. (2010) developed an empirical study with 58 participants of the University of Aveiro community. Participants were asked to read news on the SAPO homepage (*http://www.sapo.pt)* while their eye movements and mouse interaction was simultaneously recorded. A global analysis of their visual and interactive behaviour on the news areas was made, as well as on other areas of the homepage: side menus, advertising areas and other highlighted areas of interest. Acquired data was analysed and then represented. Figure 2 represents the holistic results of visual attention and mouse clicks for the SAPO homepage grouped into areas: 'blue' corresponds to the 'news area', 'yellow' to the 'side menu', 'red' to advertising' and 'green' to other areas of interest. Figure 3 represents the 'news area' and individual sections (e.g.: superior news tab, the featured image and news piece and other) analysed individually and in greater detail. Some of the conclusions made indicate that tabs are a more efficient solution for interaction than vertical menus. Another conclusion regarding the advertising areas showed that advertisements placed in favourable locations (in the centre) or near important areas of information are visualized the most. Lastly, data collected in this study complemented and supported other studies done internally at SAPO's usability laboratory, which had consequences on the reconception and redesign of SAPO's current homepage.

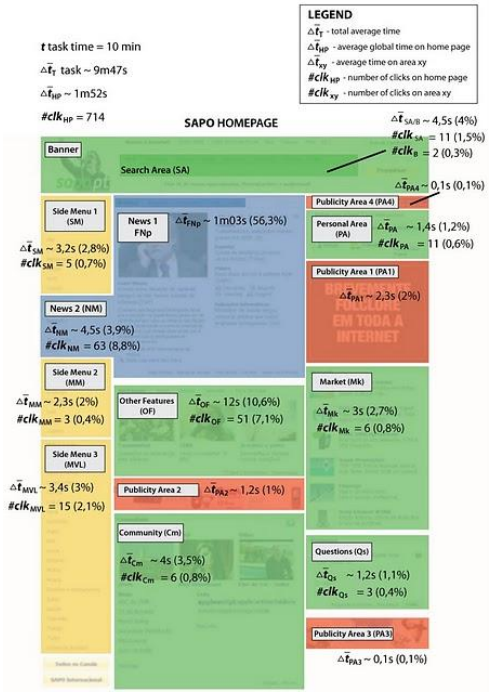

Figure 2. *Holistic view of the SAPO website, divided into AOI*

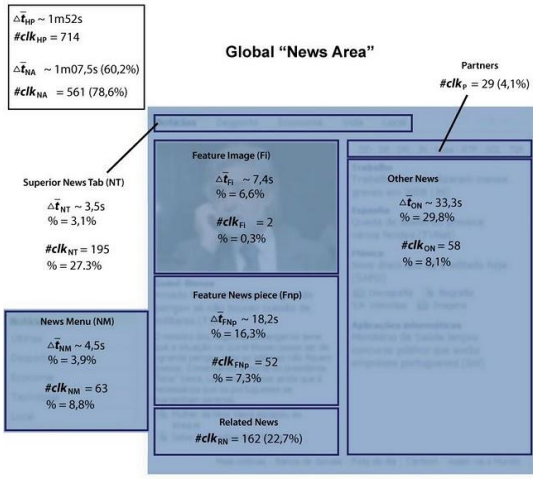

Figure 3. *Detailed view of the sections of the 'News Area' AOI*

4.3 TV News

In recent decades, the way in which TV (Television) contents are presented – specifically TV News – has experienced several changes, both in content and language. These changes in TV News are related to constant technological changes in recent years. As a result, a major problem that has always existed with watching TV news was the way viewers received and processed information broadcasted by these programs.

TV news has been studied by several authors (Azevedo, Fernandes, & Saraiva, 2009; Bergen, Grimes, & Potter, 2005; Brosius, Donsbach, & Birk, 1996; Drew & Grimes, 1987; Fox, 2004; Fox, et al., 2004; Frings, Mader, & Hull, 2010; Graber, 1990; Grimes, 1991; Housel, 1984; Nitz, Reichert, Aune, & Velde, 2007; Reese, 1983). However, few studies have been developed with the use of eye tracking. One study was conducted in 2006 by Josephson & Holmes (2006), with the aim of measuring the attention spent by participants in different areas of TV news (crawler, headline, title, globe and main area), using three versions of TV News. In the Portuguese context, a recent study developed in this area was the research project "Portuguese TV news scenography: from simplicity to profusion of news rooms studios" (Azevedo, et al., 2009). During this project, a preliminary experience was also developed with an eye tracker, which focused on the study of selective attention on TV News' program of the Portuguese public television channel – RTP. The results obtained presented several indicators and evidence of the unexplored field of TV information reception (Saraiva et al., 2011).

4.3.1 Television news studies at CETAC.MEDIA

Rodrigues (2010) conducted a study using eye tracking technology, having developed a controlled study object with the intent of understanding how viewers receive and process different graphics/image overlaid elements during the reception of television news. The main aims of this study were to: (i) identify the graphics (present in TV News) which have greater visual attention and recall of information; (ii) measure the effectiveness of message recall considering audio and video redundancy in clean feed and standard versions; and (iii) identify the differences in recall of messages considering viewers and the anchor's gender.

With the data gathered from the eye tracker, it was possible to discern viewers' main focus of attention. However, the visualization tools of the 'Tobii Studio' software are insufficient for this discernment and therefore, it was necessary to develop a manual method for representing data. This representation consisted in associating to each viewer's visualization an *x* and *y* position, as well as the time fixture at each point. These representations allowed to differentiate viewers' main focus of attention as can be seen in Figure 4 and Figure 5.

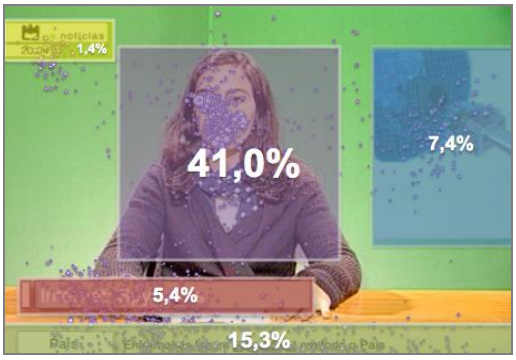

Figure 4. *Representation of the viewers' most focused elements in terms of mean fixation time*

Figure 5. *Representation of density map of analyzed clusters*

Currently, Rodrigues is developing research based on previous work related to TV News (Rodrigues, 2010). The main concept behind this research is to develop a set of methods and techniques to understand how viewers receive and process information broadcasted by TV News, specifically in digital scenography. It also aims to present a proposal with a set of guidelines to enhance the various and simultaneous graphic/image layout elements found in TV News. The study will be conducted with study objects produced in a professional context with RTP (*Rádio Televisão Portuguesa*).

Marques (2009) developed a study where the primary goal was to evaluate the impact of scenography as well as the visual and auditory attention of viewers when viewing news in a television context. Due to the large amount of information that a viewer must absorb during a news broadcast, much uncertainty is created in regards to the reception and perception of this information. The development of the study included additional goals: the execution of usability tests to evaluate the experience of viewing television using eye tracking; the systematization of data provided by the eye tracker – possible with the development of a software application that organized and represented collected data. Results collected in the study show that some visual elements obstruct viewers' memorization and that visual elements act as distractors, affecting selective attention, reception and information perception processes. Presently, Marques is continuing the work commenced in 2009, with the project titled "Comparative study of the influence of visual composition of the different news programs: Eye Tracking Study". The main objective of the study is to understand how news stories with the same topic but with different visual compositions influence selective attention during the process of receiving news information. The study uses eye tracking to evaluate three study objects that share the same news topic and maintain similar audiovisual features in order to conduct a proper comparative study.

4.4 Videogames

Only recently has eye tracking been applied in the video game context. Eye tracking and eye gaze has been mainly used in two areas: (i) as an input method and (ii) as an analysis and evaluation instrument. Many studies have focused on the use of eye gaze and eye tracking as an input method (Ekman, Poikola, & Mäkäräinen, 2008; Grimes, 1991; Isokoski & Martin, 2006; Jönsson, 2005). For the purposes of this paper, our focus will be on the use of eye tracking as an analysis and evaluation instrument for video games.

There are a limited number of studies (El-Nasr & Yan, 2006; Johansen, Noergaard, & Rau, 2008; Nacke & Lindley, 2008) that have explored the potential use of eye tracking in video games. El-Nasr & Yan (2006) explored how players' visual search patterns can help improve game and level design. El-Nasr & Yan concluded that because action-adventure games are goal-oriented, top-down visual search patterns are more frequent. They also showed that for FPS games, player visual attention is concentrated on the centre of the screen while in adventure games, search patterns are more heterogeneous. Johansen et al. (2008) approached eye tracking from a different perspective. They looked to demonstrate the value of eye tracking for usability results throughout game development. Nacke & Lindley (Nacke & Lindley, 2008) explored players' gaming experience (flow and immersion) using subjective and objective measures such as eye tracking.

4.4.1 Video Game studies at CETAC.MEDIA

Almeida (2009) developed a study that used eye tracking in an attempt to understand how players visually interacted with game scenarios. Three groups of players (inexperienced, casual and hardcore) played a First-person shooter (FPS) video game ('Call of Duty 4: Modern Warfare') while their eye movements were registered with an eye tracker. Data related to players' positions, movements and what they were looking at throughout the game was later represented on the game level map played. In order to represent data related to how players visualized the map, a heat map visualization technique was used. Because many modern video games take place in complex, three dimensional, dynamic worlds (El-Nasr & Yan, 2006), heat maps or other visualization instruments generated by software are insufficient or unable to represent acquired data. As a result, two manually developed heat maps were built which represented player movement and interaction data: (i) a 'Visual Field View' heat map, characterizing areas of the map seen by players, whether or not they were in their focal point; (ii) a 'Point of Regard' (POR) heat map, characterizing the exact location to where a player was looking. Figure 6 represents the 'Visual Field View' heat map and Figure 7 represents the 'Peripheral View' heat map, both developed using hardcore player's visualizations. A look up table of 12 colours was used to codify the maps (previously divided into individual cells). Black and darker colours represented a low visualization count; red and warmer colours represented a higher visualization count.

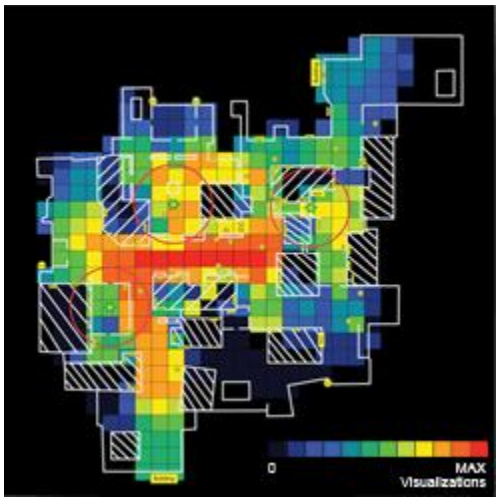

Figure 6. *Representation of hardcore players' 'Visual Field View' heat map*

Figure 7. *Representation of hardcore player's 'Peripheral View' heat map*

In another study, Almeida et al. (2010) applied the method proposed by Almeida (2009) in order to analyse and understand differences between hardcore and inexperienced players' interaction behaviour while playing the FPS 'Call of Duty 4: Modern Warfare'. In the study, 12 hardcore and inexperience players played a specific game mode, which required players to conquer three flags placed in the map. While playing, player's eye movements were recorded with an eye tracker. The applied method resulted in four heat maps, two for hardcore and two for inexperienced players. Results showed that hardcore players have a more objective approach when playing while inexperienced players have a more exploring orientated behaviour.

Currently, for his PhD work, Almeida is continuing research related to his Master's dissertation regarding eye tracking and video games. Specifically, Almeida is developing a 'Video Game Level Analysis Model'

that will be used to analyse how player's explore visually and interactively game level scenarios. Information will be collected through the correlation of video game and eye tracking data and will be represented through several manners, for example, heat maps (similar to that of Figure 6 and Figure 7).

5. CONCLUSIONS

Eye tracking has become a significant and widely used technique in the evaluation of user interaction and behaviour with study objects in various contexts. The complexity of specific study objects in multiple contexts requires visualization techniques that eye tracking software alone cannot always interpret. This implies that on many occasions, visualization techniques – often based on common techniques such as the 'heat map' or 'bee swarm' – be developed in order to better understand data acquired with eye tracking. The value of eye tracking as an evaluation and analysis instrument has not gone unnoticed and, at CETAC.MEDIA, several studies have been, and are being developed, on areas such as websites, advertising, TV news and video games. The studies developed at CETAC.MEDIA have shown interest in exploring new ways of representing and visualizing eye tracking data. The visualization techniques explored in this paper are the result of the specificity of each study, and the limitations of existing software. Furthermore, they are the result of renewed methods that were developed in each study. Lastly, because eye tracking data representation and visualization techniques are in constant evolution, CETAC.MEDIA will continue its research in these areas. Furthermore, it will seek to position itself in information and communication related areas of interest. As a result, ongoing projects in CETAC.MEDIA will continue research in the areas explored throughout this paper.

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