Eye-tracking Techniques and Methods - Important Trends in e-Learning Environments

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Abstract: *The research on eye movements has spread along with advances in eye-tracking technology and psychological theory on the relationship between eye behaviour and cognitive processes. This paper examines successful methods, measurements and rules intended for investigation on how eye movements could be related to cognitive processes during learning and tasks solving. A number of opportunities and contemporary challenges are considered, facing with the implementation of eye-tracking technologies and methods in the context of education.*

Key words: *e-learning, eye-tracking, cognitive load, human–computer interaction*

INTRODUCTION

Eye-tracking technology includes a set of methods and techniques used to discover, identify and record the activities of eye movements. Significant enhancements over the past three decades in the development of eye-tracking systems have permitted researchers to attain more precise eye-gaze measurements with a reduced amount of obtrusive technologies [9]. In order to record eye movements throughout visual interaction or use gaze-based devices for communication and control, different eye-tracking systems have been developed.

Eye-tracking confirmed its usefulness in terms of identifying behavioural response, presenting cognitive load, providing an alternative means for human–computer interaction, prompting interface design and adapting appearance of elements according to user data [5].

Some areas lack such support, regardless of the fact that there is a significant amount of supporting literature. In particular, additional research should be recommended for intelligent notification, presentation, adaptation and validation, expending further detection methods and identifying different levels of cognitive load. Continued exploration according to the human psychology using eye-tracking systems has the potential to encourage the usage of such systems in e-learning environments because it permits personalized training of individual learner [19].

Incorporating eye tracking into adaptive e-learning systems by using data about pupil and gaze to indicate attentional focus and cognitive load levels can be useful in a process of adaptation to the requirements and needs of the learner. Personalization of an e-learning program based on the learner's cognitive load levels calculated from eye-tracking data will bring the advantage of having a personal tutoring system into a wideband environment, with successful training by increasing information transfer and maintenance.

This paper focuses on the significance of eye-tracking systems in the field of education processes by analysing how valuable measures underlying a user's cognitive processes can be achieved with different eye-tracking technologies. The paper is organized as follows. After an introduction about research objectives, Section 2 offers a short survey about eye-tracking technologies. The attention of section 3 is both on the eye tracking measurements and rules and on important trends in eye-tracking research connected with eye data and e-learning. E-learning systems explicitly based on eye-tacking technologies are described in section 4. Section 5 provides some conclusions and proposes several indications for future work.

EYE-TRACKING TECHNOLOGIES

Eye-tracking technologies perform eye operations and are shaped out of repetitions and returns by cognitive functioning and information handling [2]. Eye-tracking technologies, such as Tobii-TX/T120/T60 (Figure 1) or Eye-Tribe, can capture eye movements by focusing infrared light into the user's eyes and implement a mathematical algorithm to discover the precise gaze point of the eye [1].

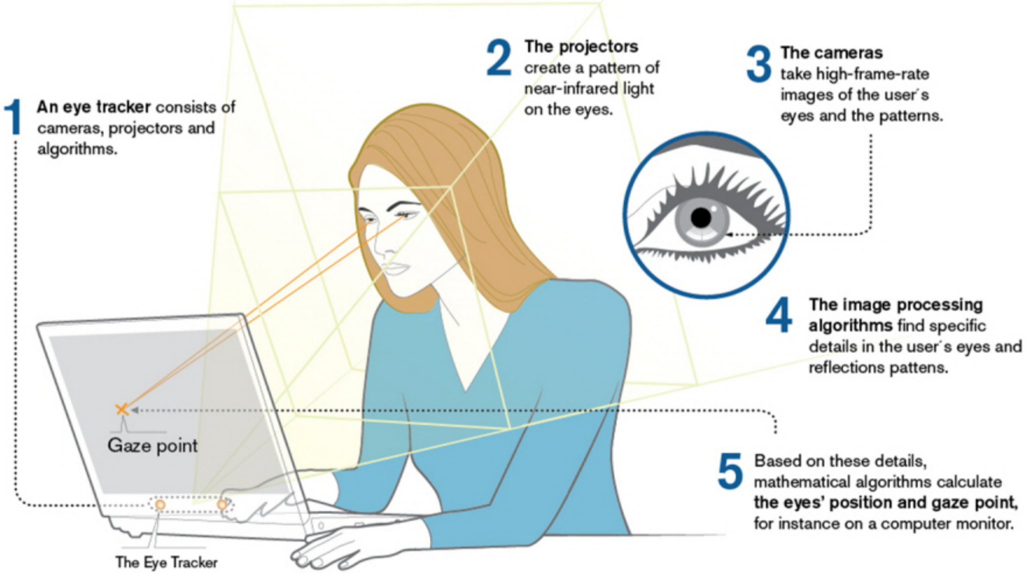

Figure 1. High performing eye-tracker system (http://www.tobii.com/group/about/this-is-eye-tracking/)

In Figure 1 an example of high performing eye tracking system is presented. Three essential parts of this system are [1]:

- High-performance sensor — It consists of custom designed infrared projectors, customized image sensors, optics and custom processing with embedded algorithms.
- Advanced algorithms — Algorithms are necessary for interpreting the image stream generated by the sensors.
- User-oriented application layer — An intelligent layer is available to enable the numerous ways the technology can be used.

Learners' eyes can be a significant source of information for e-learning systems. What we look at, and the manner we do that, can in fact be utilized to advance the learning process, revealing information which would otherwise remain concealed [19].

EYE TRACKING MEASUREMENTS AND RULES

Considering that the most relevant metrics related to eye position vary from task to task and study to study, we will present the most important conclusions that have been reached in the field of eye tracking measurements and their possible exploitation in the field of e-learning.

Total Number of fixations. The total number of fixations is believed to be adversely associated with search effectiveness [18]. A larger number of fixations specifies less efficient search resulting from a poor organization of display elements. In e-learning environments, it is important to consider the relationship between number of fixations and task solving time. For example, more demanding tasks will require more fixations.

Number of fixations on each area of interest. The number of fixations on a particular display element should reflect the importance of that element. More important display elements will be fixated more frequently [6]. Several researchers have come up with innovative techniques for analyzing and presenting this eye tracking metric. Wooding [23] has introduced the "Fixation Map" for highlighting the most frequently fixated areas in an image. In e-learning environments, the percentage of fixations in an area of interest can serve as a simple indicator of the attention on an interface element or content region. We can analyze the number of fixations on various elements (text portions, graphics, diagrams, programming code, figures, etc.) and make conclusions useful for the learning process.

Gaze (proportion of time) on each area of interest (AOI). This metric considers **gaze duration** and **frequency of gazing** on a display element**.** In order to reveal patterns describing how a user's attention is directed to a given visual area, it can be useful to measure the duration of eye fixations, the number of fixations, and the amount of re-fixations (i.e. fixating on an area or object multiple times) [14]. According to Fitts et al., these should be treated as separate metrics [6].

Fixation duration and saccade length. For getting information about the user's mental state, the fixation duration and the saccade length are the most common variables [14]. An eye-tracking system offers large benefits providing a continuous stream of user's information in real time that can be used to evaluate the changes in user's mental state and functionality, as well as their focus of attention [14]. Velocity profiles of saccadic eye movements show essentially two distributions of velocities: low velocities for fixations (i.e., <100 deg/sec), and high velocities (i.e., >300 deg/sec) for saccades. This aspect of saccadic eye movements makes velocity-based perception fairly straightforward. Fixation duration is determined by the time necessary for processing the visual information. These metrics indicate difficulty of information extraction and reflect the importance of that area of the display [6]. Fixations have been successfully applied to measure the level of image and problem complexity, as well as to identify the part of a screen or slide that is viewed during instruction. Also, researchers identified that saccade length decreases when task complexity increases [16] [22]. In the field of e-learning this might be useful during studying examples, solving tasks or code exercises in the programming field.

Pupil response. In terms of specifying a user's cognitive load, pupil response, known as 'pupillometrics' [10], pupil response has gained important acceptance. The study of pupil response encompasses the effects of psychological influences, perceptual processes, and mental activities based on pupil size. Pupil size seems to be task-dependent. For example, pupil diameter is especially larger when "solving tasks" than when simply "reading". Marshall states the index of cognitive activity as a new manner for estimating cognitive load from pupil dilation [15]. The index is defined as the average number of sudden discontinuities in the signal per second over a chosen period of time. Pupillary responses, for example, can be used in a procedure of emotional stimulation [10]: the size of the pupil is significantly larger after high initial stimulation than after neutral arousal. Pupil size is also analysed with the aim to discovery the best moments when to interfere interactive tasks [8]. Precise evaluation of a learner's mental capacity will be critical for evolving systems that achieve learner disruptions in the learner interface.

Scan path (sequence of fixations). Scan path and derived measures such as the transition probability between areas of learning sequences can indicate the efficiency of the elements arrangement in the user interface [11]. If we know the sequence of fixation through the lessons and perform the assessment of the knowledge level the learner gained, we can improve the adaptability of an e-learning system.

In the literature several important eye-tracking studies have been observed [3][7][14]. We will analyze these studies from the perspective of learners who access to, use and learn with an e-learning system.

The 'Fitts's law' defines a rule according to the size of the displayed objects [3]. Namely, visually emphasized objects get much attention over every other section on the page. For the preparation of high-quality lesson's pages, it is important that the elements that "pop" are those that are relevant, and content that do not encourage learners to take action should not be emphasized and prominent.

The Effect of Video material. Moz.com[21] published an interesting study (using heat maps) showing the user's behaviour while inspecting search engine result pages. As a result of this study, videos turned out to be the most powerful in capturing eyeballs, even when they were not the first results. Video results attracted more attention than a regular search listing, especially when they were near the top of the page [7]. We can suppose that placing appropriate video recordings in the form of tutorials at the top of the lesson’s page could attract more attention of learners.

The Power of Directional Cues. Human beings have a natural tendency to follow the gaze of others. Since birth, we have been taught to follow arrows directing us to where we should be looking/going. Visual elements (graphical presentations, pictures, figures and diagrams) are an important part of a website’s overall design, but most pages can be optimized by including images that serve as visual cues to indicate where visitors should look next [14]. From the perspective of the learning process, being guided throw the didactic material can be very useful (especially if this guidance is performed by taking as a reference behaviours that previously produced good results in terms of the level of learners’ knowledge.

The F-Pattern. It is generally known that F-pattern[22] of reading is usual throughout the Web. But, new literature surveys have suggested that the F-pattern could be functional everywhere [7]. Users on the Web tend to browse sites based on their reading habits. For English speaking people and languages with similar reading patterns, the left side of the screen is deeply favoured in all articles, e-commerce sites or search engine results. Therefore, in e-learning environments it would be useful to deploy the most important facts and definitions of the lessons according to the F-pattern.

In the next section, we will consider how eye-tracking techniques have developed in recent years, and investigate the major trends in e-learning environments, towards understanding which eye-tracking attributes have an important and significant impact.

EYE-TRACKING INTEGRATION IN E-LEARNING ENVIRONMENTS

Eye tracking in e-learning domain has been successfully used for implicit recognition of learner intention, intention deducing, observing learners’ multitasking activity, enhancement of navigation and determining learning patterns or decreasing learner attrition level [13]. These approaches expand the tracking of learners’ actions, recognizing learners’ face or gesticulations, which can specify learners’ emotions or even mood.

Based on the analyzed literature, we can conclude that a small number of e-learning systems have been aimed to embed eye tracking technology directly in their architecture. AdeLE (Adaptive e-Learning with Eye tracking) is noted as the first and the most popular, even though the project have been abandoned several years ago [7]. In the Adele system, the main objectives are observing the behaviour of learners in learning processes in real time, by monitoring characteristics such as areas of interest, time spent watching them, frequency of visits and sequences or patterns according to which content is studied. iDict is an adaptive e-learning system developed as an assistance for translation in language courses [12]. iDict tracks the learners’ gaze path while they are reading text written in a foreign language. When possible difficulties are noticed, during monitoring the reading process, iDict shows tooltips with the translation of exact words or sentences. e5Learning (Enhanced Exploitation of Eyes for Effective E-learning) is an e-learning environment [4] which allows the author of the course to set some constraints (e.g., minimum time the learner would spend watching a certain part of content). The system has functionalities for simple emotion recognition. It can recognize different states: ‘tiredness’, ‘high workload’ or ‘non-understanding’. An intelligent tutoring system, with an integrated eye tracking system

21 https://moz.com/blog/eyetracking-google-serps
22 https://www.nngroup.com/articles/f-shaped-pattern-reading-web-content/

used to explore learners' attitudes, can allow learners to see what the system "thinks" about them [13].

An e-learning system which exploits eye tracking to evaluate the learner's awareness in specific subjects could be useful in order to achieve content adaptation. Such systems may be used to recognize whether the learner concerns to the visual, verbal or intermediate categories of learning styles [21]. For example it is possible to determine the characteristic phases of e-learning activities (e.g. "preparation", "viewing" and "searching") by exploiting pupil size, which is usually much larger than in the viewing phase [12]. With the intention to gauge the state of learners' learning attention, Liu et al. [14] utilized Support Vector Machines to process eye tracking data, in order to develop a learning feedback system. Rakoczi proposed an eye tracking evaluation of Moodle [20]. It has been established that the "My courses" area and breadcrumb navigation are the most widely used navigation elements, and that finding the logout button and the profile page are not intuitive actions for learners.

Several studies [14] [15] [17] try to measure the cognitive load of learners while watching multimedia elements, such as images, video and animations. The way learners analyse science-related photographs in PowerPoint presentations has been also analyzed, classifying pictures into 'illustrative', 'decorative', 'complementary' and 'explanatory'. Among the obtained results, there is the 'modality effect', which means that an image or animation with spoken text is more effective for learning than written text. Moreover, the effects of the speed of replay of an animation on the learner's attention has been examined, assuming that different speeds will produce different learning outcomes.

CONCLUSIONS AND FUTURE WORK

On the basis of our study of eye-tracking in the education field, we can propose an eye tracking application within a module for recommendation of an intelligent tutoring system. This is a good example of opportunity for upgrading the present e-learning system or developing a new one that supports advanced solutions and enhanced understandings in several areas:

- taking into concern the learner's learning type, perception, cognition, fields of interest and knowledge level monitoring by eye-tracking component,
- supplying personalized course content and enhanced knowledge of the learners' performance and behaviour in the human-computer interaction field,
- achieving a better tracking quality of the progress throw the course content,
- providing more details about the perceptive and mental processes of the learner,
- recognizing the most appropriate content and media presentation
- recognizing potential learner problems and providing recommendations for improvement and adaptation mechanisms,
- recognizing potential problems in the content structuring,
- uncovering the need for additional material related to the learning content,
- applying different methods for recommendation.

Additional proposal for future research include improvements of hardware design in order to make eye-tracking systems more robust, inexpensive, and easy to install and program. An e-learning system could exploit eye-tracking to assess learner interactions with programs, to gauge where, how, and when the program instructions should or could be altered.

REFERENCES

[1] Babenko, A., and A. Kotenko. "The Eye Tribe.", 2016 (https:// theeyetribe.com).

[2] Bartels M., The objective interview: Using eye movement to capture pre-cognitive reactions. Qualitative Research Consultants Association: Views, 6, 3, 2008, pp. 58-61.

[3] Boritz, J., and W. B. Cowan, Fitts's law studies of directional mouse movement. human performance, 1, 6. 1991.

[4] Calvi C., M. Porta and D.Sacchi e5Learning, an E-Learning Environment Based on Eye Tracking, International Conference on Advanced Learning Technologies, 2008)

[5] Duchowski A.T.A breadth-first survey of eye-tracking applications. Behav. Res. Methods. Instrum. Comput. 34(4), 2002, pp. 455–470.

[6] Fitts, P. M., R. E., Jones, and J. L. Milton, Eye fixations of aircraft pilots: Frequency, duration, and sequence of fixations when flying Air Force ground controlled approach system (GCA). AF Tech. Rept. 5967 (ATI 69038). 1950.

[7] Gadanidis, G., M. Borba, and R. Scucuglia. (2016). Language diversity and new media: Issues of multimodality and performance. Mathematics Education and Language Diversity, 2016, pp. 237-261.

[8] Graf, W., and H.Krueger, Ergonomic evaluation of user-interfaces by means of eye-movement data. In Proceedings of the third international conference on human-computer interaction, 1989, pp. 659-665.

[9] Hansen D. W., and Q.Ji, In the eye of the beholder: A survey of models for eyes and gaze. IEEE Transactions on pattern analysis, 32(3), 2010, pp. 478-500.

[10] Hess E.H. Attitude and pupil size. Sci Am 212:1965, pp. 46–54

[11] Hughes, A., T. Wilkens, B. M., Wildemuth, and Marchionini, G. Text or pictures? An eyetracking study of how people view digital video surrogates. International Conference on Image and Video Retrieval, 2003, pp. 271-280.

[12] Hyrskykari A., P. Majaranta, A. Aaltonen, and K. Räihä, "Design Issues of iDict: A Gaze-Assisted Translation Aid".Proc. of ETRA 2000, 9-14.

[13] Kassak, O., M., Kompan, and M. Bielikova, Student behavior in a web-based educational system: Exit intent prediction. Engineering Applications of Artificial Intelligence, 51, 2016, pp. 136-149.

[14] Liu H.C and H.H Chuang, An examination of cognitive processing of multimedia information based on viewers' eye movements. Interact Learn Environ. 2010.

[15] Marshall S.P. The index of cognitive activity: measuring cognitive workload. Proceedings of the 2002 IEEE 7th conference on human factors and power plants, 2002.

[16] Pierce E.T. Mental workload measurement using the intersaccadic interval. Masters, Institute of Biomaterials and Biomedical Engineering, 2009

[17] Pivec M., C. Trummer, and J. Pripfl, Eye-Tracking Adaptable e-Learning and Content Authoring Support. Informatica, 30, 2006, pp. 83–86.

[18] Poole, A., and L. J. Ball, Eye tracking in HCI and usability research. Encyclopedia of human computer interaction, 1, 2006, pp. 211-219.

[19] Porta M., E-learning and machine perception: in pursuit of human-like interaction in computer-based teaching systems. Int. Jour of Know and Lear, 2007, 281-298.

[20] Rakoczi G., Cast your Eyes on Moodle: An Eye Tracking Study learning with Moodle, Proc. of the 4th International Conference Moodle.si, 2010.

[21] Sadler-Smith E., "The relationship between learning style and cognitive style", Personality and Individual Differences, 30 (4), 2001, pp. 609-616.

[22] Schrammel J, Deutsch S, Tscheligi M (2009) Visual search strategies of tag clouds—results from an eyetracking study. Human-computer interaction 2009, pp 819–831

[23] Wooding, D. S. Fixation maps: quantifying eye-movement traces. Proceedings of the 2002 symposium on Eye tracking research & applications, 2002, pp. 31-36.

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