# Title: The Use of Eye Tracking Technology in the Evaluation of e-Learning: A feasibility study

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## *Abstract:*
*Higher Education is increasingly relying on e-learning as a means of providing students with teaching and learning resources. Almost inevitably, this means that students interact with these learning resources through the medium of the computer screen. Although there have been significant advances in the design and implementation of online resources, exactly how students interact with these resources is a relatively new field of research. In this feasibility study students were asked to interact with a virtual learning environment, i.e. Blackboard, as well as Internet based resources, i.e. Ingenta and Wikipedia. Specifically, the students were asked to find the answer to a question provided, e.g. "what is classical conditioning?"or to locate a body of research related to a given topic, e.g. "theories of forgetting". As they searched for the information the eye movements of the students were recorded using a Tobii X50 eye tracking system. The data gathered was analysed dynamically, statistically, and graphically in order to identify search patterns and "hot spots" within the online information source. It was concluded that the use of eye tracking technology can provide the designers of online learning resources with an added dimension for the evaluation of their products and should be also be considered by tutors when developing their own online learning materials.*


## *Introduction*
Someone once said that the "eyes are the windows to the soul" but in eye tracking research they may best be considered as a portal to higher cognitive processes. The "camera" analogy that is often used in describing the human visal system is quite misleading. Far from being a passive receptor of visual information the human eye has already started to process visual stimulation before passing this information onto higher centres in the brain where it will be processed and meaning extracted.
The distribution of the light sensitive retinal elements, rods and cones, over the surface of the retina is not even. The most sensitive region of the retina is approximately 1mm across and is densely packed with cones. This is the part of the retina that we use for looking at detailed visual stimulation. In order to read a sentence on a page the fovea must be tracked over the words sequentially. Tracking of the fovea is required not only in reading, but in the processing of any visual information where detail is important. Visual information processing is also occurring in the periphery of the retina, but for eye tracking researchers this is of less significance. One of the most crucial questions for researchers involved in eye tracking is concerned with what eye tracking can tell us about the way in which information is obtained from visual stimuli before processing at a higher level takes place. For human-computer interface (HCI) researchers this information is vital for the design of hardware and software that involves people interacting with computer systems.

Eye movement research has a relatively long history with the basic characteristics of eye movements being discovered between 1879 – 1920, (Rayner, 1998). Early research was often quite invasive with eye movements being tracked through devices that were in direct contact with the cornea. The first non-invasive technique was developed by Dodge and Kline in 1901 who used a method that involved reflecting light from the cornea.
One of the first studies to examine the role of eye movements in a practical task was that of Tinker et al who in the 1930's looked at the influence of typeface, font size, and page layout on reading speed and patterns of eye movement (Tinker, 1963). At the end of the second World War, human factors research was becoming increasingly important in the training of military personnel. Fitz et al (1947) used motion picture cameras to capture the eye movements of pilots as they used the cockpit controls of their aircraft.

One difficulty with eye tracking research up until this time was that the head often had to be constrained to prevent any movement that might confound the eye tracking data. The first head mounted eye tracker to overcome this problem was developed by Hartridge and Thompson

(1948) and by 1958 Mackworth and Mackworth had developed a system that could record eye movements superimposed on the visual scene that was being viewed.
The use of eye tracking research in HCI began in earnest in the 1980's with the advent of the personal computer. Before this time interaction with computers tended to be via punched cards or teletype and therefore the scope for eye tracking research was minimal. With personal computers came video screens and graphical user interfaces (GUI), thus providing eye tracking researchers with yet further opportunities.
The 1990's saw greater technological advances with the Internet, email, video conferencing and of course computer games consoles. As the interfaces become ever more complex, eye tracking research has found a niche in helping to answer questions about usability. How do the visual displays used in these technologies influence the manner in which people are able to interact with them?

## *Technologies involved*

The two basic types of eye tracking technology available to researchers are the head mounted systems and those that are independent of the participant, for example being positioned on the desktop in front of the participant. Most systems rely on the use of infrared light that is reflected from the cornea and the retina in order to generate data that can then be used by the researcher to examine the individual's pattern of eye movements. In modern systems the manufactures usually provide software that helps with the calibration of the system as well as the data collection. Although modern systems are quite easy to set up and use, reliability can still be a problem and typically 10%-20% of people cannot be tracked reliably. Spectacles, contact lenses, ambient lighting and even seating arrangements can all cause reliability problems.

*Figure 1: ASL H6 HS Head Mounted System*
*(Courtesy of Applied Science Laboratories)*

As can be seen in Figure 1, head mounted systems, this one is produced by ASL (http://www.a-s-l.com/ ), can be quite cumbersome and this can limit the range of possible applications. Lightweight versions of the head mounted systems are available (Figure 2) and these are particularly useful where the researcher is working with participants who have to be active, e.g playing sport or moving around their environment.

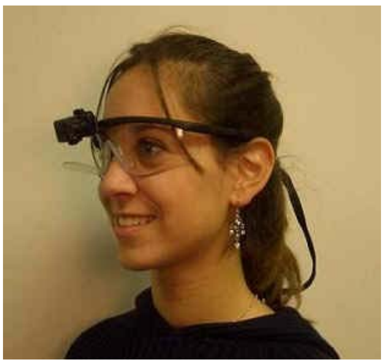


*Figure 2 Mobile Eye*
*(Courtesy of Applied Science Laboratories)*

For some applications it is important that the participant can move their head easily and without the constraints of head mounted eye trackers. For example research with infants would be very difficult using a head mounted system or even one that required head restraint. One system that does offer this degree of freedom is that produced by Tobii (http://www.tobii.com/).

*Figure 3 Tobii X50*

The Tobii X50 is a relatively small stand alone unit that is positioned just in front of the participant. Calibration is simple using the Clearview software system that is provided with the eye tracker. The Clearview software also deals with the analysis of the data which can be accessed in a variety of formats.

Typically the participant will be positioned in front of the computer screen and if interaction is required they will be given a key board or mouse but this isn't a requirement. The visual stimulus may be a web site, a picture, or a moving image. Almost any image that can be presented via a computer screen can be used. The X50 uses an infrared light source to monitor eye tracking and this is invisible from the participants perspective. The participant may be given a specific task to undertake, for example finding information from an Internet source, or they may be presented with a static image to peruse. It should be noted that if using a keyboard some data may be lost as the participant looks down at the keys rather than directly at the screen. The length of a typical session will obviously vary with the task but it may last from a few seconds to several minutes. Researchers should be aware that a voluminous amount of data will be produced with the longer studies.

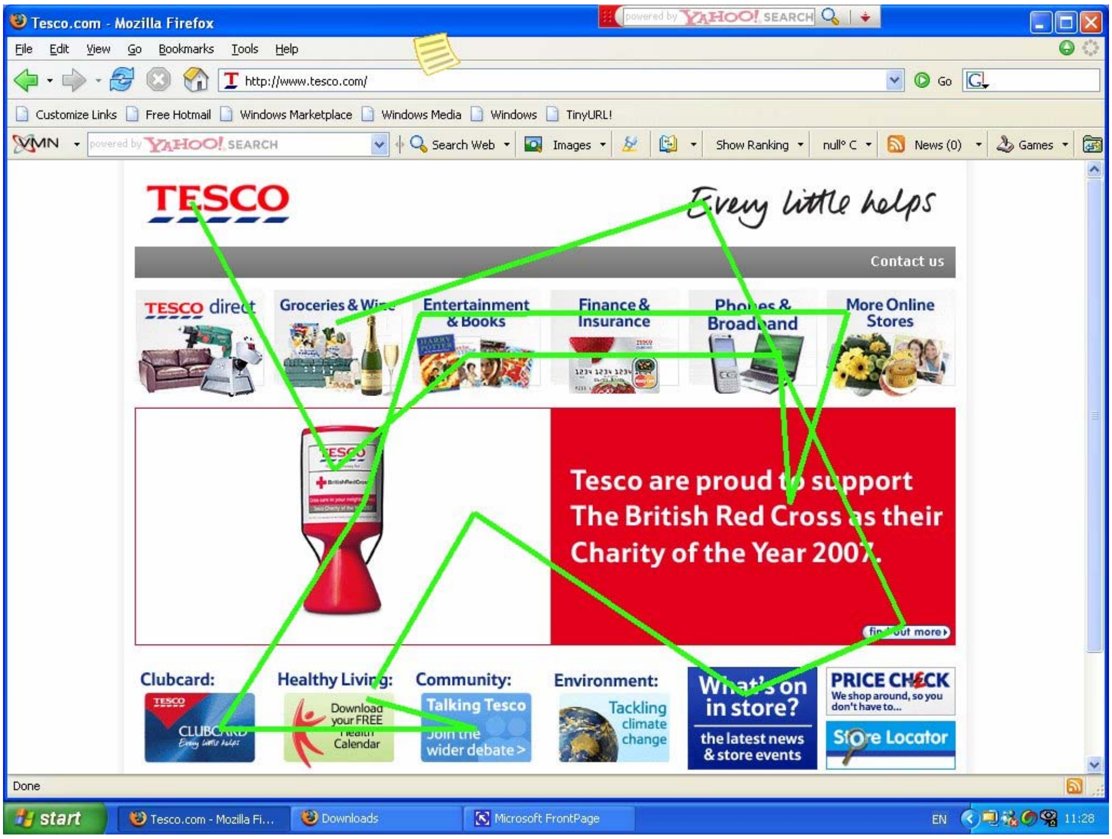
### *Eye tracking Metrics*

Most eye tracking systems produce data that can be examined in several different formats to meet the needs of most researchers.

### *Scan Path:*

This is probably the most basic form of data representation and is simply a trace of fixation points recorded in real time. This enables researchers to see quite precisely what a participant is looking at as well as the sequence of eye movements over the visual stimulus (Figure 4).

*Figure 4: Example of a scan path*




***Spatial Analysis:***
If the researcher wants to quantify rather more precisely what the participant is looking at then spatial analysis can be used. In the example shown in Figure 5 the number of fixations on a particular region of the visual stimulus have been converted into "hot spots" where red indicates a higher number of fixations.

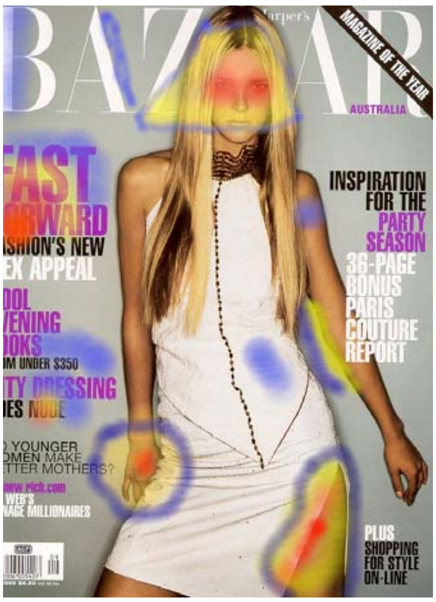



*Figure 5 Spatial analysis via "hot spots"*

### *Statistical Analysis*

The "hot spot" measure described above provides a good qualitative presentation of the data, but if more precise measurements are required then it is possible to measure the proportion of time spent looking at different regions of the visual stimulus. This data can be presented in summary form as in Figure 6, or in terms of actual number and duration of fixations in a particular region. This data can be exported as a text file for further analysis using statistical packages, e.g. SPSS.

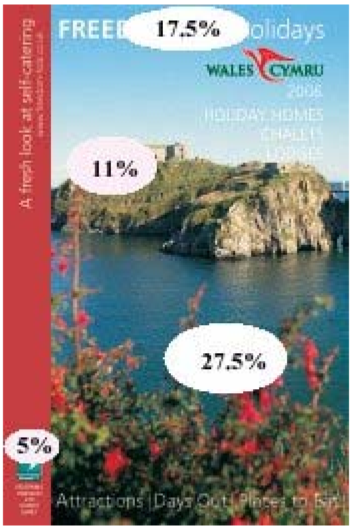



*Figure 6 Statistical analysis*

### *Interpretation of eye tracking metrics*

While it might be relatively straightforward to collect the data in whatever format is chosen, the interpretation of the data requires careful thought. The problem for the researcher is how do they relate a particular pattern of eye movements to the cognitive activity associated with the visual task. For example does a long fixation on a particular element of the image indicate that the individual is having difficulty with that element, or that they just find it attractive in someway, or perhaps both in the case of a visual illusion. In eye tracking research "top-down" approaches tend to be driven by theory or the need to test a particular hypothesis. For example cognitive theory might suggest that scanning takes place from left to right and therefore it might be better to place the most important elements of a visual image towards the left. An alternative strategy, the "bottom-up" approach starts by looking at where people fixate and then asks the question why are they looking more at one particular element of the image rather than another. The two approaches are not mutually exclusive indeed an effective strategy might be to begin without preconceived notions using a "bottom-up" approach, and then to formulate hypotheses based on these observations and what is known from cognitive theory.
From previous research it is possible to suggest what the psychological importance of different metrics might be:

***Fixation Number:*** This appears to be related to search efficiency (Goldberg and Kotval, 1998). Large numbers of fixations probably indicate that the participant is searching for something that they are having difficulty locating, possibly because of poor design of the visual stimulus. .Jacob and Karn (2003) suggest that number of fixations on an element should reflect the importance of that element.

***Gaze:*** The proportion of time spent looking at a particular element of the visual stimulus is generally seen as an indication of the importance of that element. Jacob and Karn 2003). Gaze duration may be measured as eye fixation time on target, or it may be made up of a number of different fixations on the target.

***Area of Interest:*** AOI analysis is used where the researcher wants to quantify gaze data within a defined region of the visual stimulus. For example in the case of a web page, the researcher might be interested in how often or for how long the participant looks at a region of the web page that the designers have designated of high importance. Fitts et al (1950) have shown that gazes on a particular AOI will be longer if the the participant has difficulty extracting meaning from that region of the stimulus.

***Scan Path:*** The scan path is made up of a sequence of fixations as shown in Figure 4. As well as the overall pattern of fixations researchers might be interested in the direction of scan path, e.g. top/bottom, left/right etc, or they may be interested in the scan path duration or scan path length.

***Time to first fixation:*** Where participants are required to identify a particular element in the visual stimulus, the time to first fixation on that element can be a useful measure of efficiency of search strategy, or the "attention-getting" properties of the element.

## *Feasibility Studies*

The purpose of the studies described below was to examine the feasibility of using eye tracking technology in the evaluation of the usabilty of e-learning web sites, specifically, Blackboard virtual learning environment (Fig 7), Ingenta, the online journal database (Fig 8), and Wikipedia the online encyclopedia (Fig 9).
At this stage of the research it was not proposed to test any specific hypotheses, rather it was to identify problems and weaknesses in the use of eye tracking technology that might lead to difficulties in further research. Participants were seated in front of a PC screen with a key board in front of them. The Tobii X50 eye tracker was positioned between the keyboard and the PC screen (see Fig 3). The calibration procedure requires the participant to watch the screen as a series of circles appear and disappear in each corner and in the centre of the screen. The ClearView software then provides a visual guide to the success of the calibration. If there are any problems the calibration process is repeated. This calibration information can be recorded for each participant which means that the calibration procedure doesn't have to be repeated if the same participant is being used in a further trial. Following calibration the researcher sets the parameters for the session, e.g. how long the session will last, what type of visual stimulus is to be used, where this stimulus can be found, in the case of web site a URL can be specified as a location. Once the session begins, eye tracking and recording will occur as the participant undertakes the given task. The eye tracking will cease once the predetermined time interval is reached, or it can be terminated by the researcher whenever they wish. During the task, the participant will not be aware of the eye tracking, there is nothing on the screen to indicate that eye tracking is occurring and they are not aware of the infrared light that is being reflected from their eyes. If required the researcher can connect a second screen to the eye tracker on which the scan path can be observed during the recording session. Following the data collection the ClearView software provides the researcher with several options for data processing. Scan path, fixation points and hot spots are immediately available and it is also possible to export the data for further processing if required. A time line and X Y coordinates of the left and right eye can be exported as a text file that can then be imported into data processing software, e.g. SPSS or EXCEL. Scan path data can also be exported as a video (AVI) file for further observation.
In this feasibility study participants were presented with tasks that required them to interact with three web based learning resources, specifically, the Blackboard virtual learning environment, Ingenta, an academic journal database, and Wikipedia an online encyclopedia. For the Blackboard trial participants were asked to find the module specification sheet for a Forensic Psychology module. In the second task they were asked to find journal articles dealing with learning theory, and for the Wikipedia task they were asked to find out what B.F. Skinner was best known for. None of these tasks were particularly difficult, their main purpose was to provide a vehicle through which the participant could interact with an e-learning resource while eye tracking data

was collected. Each task lasted no more than 2 minutes and was terminated once the participant had achieved the task goal.

### *Results and Evaluation*

For all three tasks eye tracking data was successfully recorded, though the quality of that data was variable. Scan path data was recorded accurately for all three tasks and could be played back easily using either the ClearView software, or via an exported AVI file. As was expected,data was occasionally lost when the participant looked down at the keyboard, but the eye tracker was able to resume eye tracking as soon as the participant looked back at the screen. Examples of the data collected are shown in Figures 7, 8 and 9.

*Figure 7 Scan Path (BlackBoard VLE)*

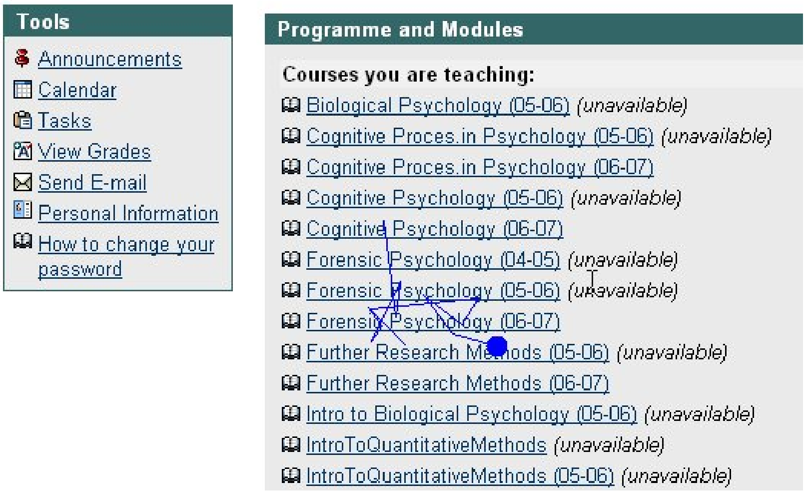
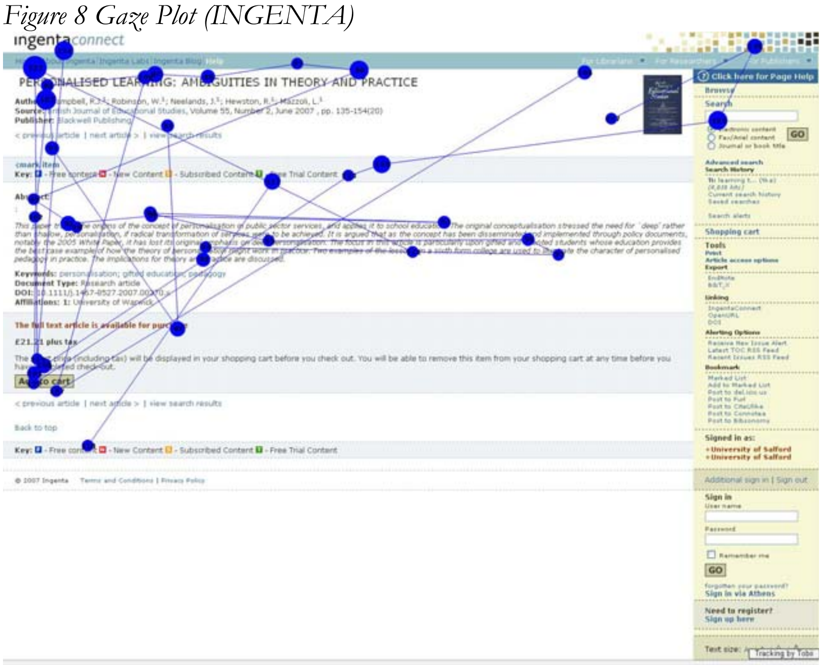



*Figure 8 Gaze Plot (INGENTA)*




The data collection and analysis was most problematic where changes in the visual image occur, for example with Flash animations, pop-ups, or even when moving from one web page to another. Under these circumstances attempting to view fixation data or hot spots invariably resulted in a blank screen. The explanation for this appears to be that the ClearView software records data continuously and doesn't discriminate between one web page and the next. Or even between a web page with an animation and the same page without. Fixation data and hot-spots extract the data for their plotting from the X Y co-ordinates of each eye as detected by the eye tracker. The X Y co-ordinates are, in a sense, static even though the web page might change. If all the recorded data was plotted then a very confused picture would emerge with, in effect, eye racking data from different web pages being superimposed on each other. Fortunately Tobii, the manufacturers of this system have developed a tool within the ClearView software that can help with this problem. The Scene Tool enables the researcher to view a recording of the visual stimulus, including changes to web pages, and the researcher can then identify and mark on the time-line, where these changes occur. The ClearView software then treats the time between one mark and the next as a single page, and thus fixation and hot-spot data can now be displayed. What is really required is a dynamic fixation and hot-spot display system that would actually change as the scene being viewed changed. Unfortunately at present this level of sophistication doesn't appear to be available.

*Figure 9 Hot Spots (Wikipedia)*


Tobii suggest that data recording problems can arise if the participant is wearing spectacles, especially bifocals, or contact lenses. In this study one of the participants wore varifocal spectacles, but this didn't appear to interfere with the performance of the eye tracker.

## Conclusion

This study has demonstrated the feasibility of using an eye tracking system to record patterns of eye movements while participants interact with e-learning resources. The data produced appears to be reliable, valid and has a degree of sensitivity that would meet the needs of most researchers. The data produced by the Tobii X50 system and the ClearView software is available in a variety of formats an can be used to describe the interaction between participant and e-learning resource in both qualitative and quantitative terms. The technical training required to operate the system is minimal and researchers can quickly learn to use it and adapt it for their own needs.

## ***References***


Dodge and Kline (1901) The angle velocity of eye movements. *Psychological Review,* 8, 145-157.

Fitts, P.M., Jones, R.E., and Milton, J.L. (1950) Eye movements of aircraft pilots during instrument-landing approaches. *Aeronautical Engineering Review*, 9(2), 24-29.

Goldberg, J.H. and Kotval, X.P. (1998) Eye movement-based evaluation of the computer interface. In S.K. Kumar (Ed), *Advances in Occupational Ergonomics and Safety,* (pp529-532). Amsterdam.

Hartridge, H. and Thompson, L.C. (1948). Methods of investigating eye movements. *British Journal of Opthalmology,* 32:581-591.

Jacob, K.J. and Karn, K.S. (2003) Commentary on Section 4. Eye tracking in human-computer interaction and usability research: ready to deliver the promises. In J. Hyona, R. Radach, and H. Deubel (Eds) *The mind's eyes: Cognitive and applied aspects of eye movements.* Oxford:Elsivier Science.

Mackworth, J.F. and Mackworth, N.H. (1958). Eye fixations recorded on changing visual scenes by television eye-marker. *Journal of Optical Society of America.* 52, 713-716.

Rayner, K. (1998) Eye Movements in Reading and Information Processing: 20 Years of Research. *Psychological Bulletin,* 124(3), 372-422.

Tinker, M.A. (1963) *Legibility of Print.* Ames, Iowa State University Press