

USING EYE TRACKING TO OPTIMISE THE USABILITY OF
CONTENT RICH E-LEARNING MATERIAL

by
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I declare that USING EYE TRACKING TO OPTIMISE THE USABILITY OF CONTENT RICH E-LEARNING MATERIAL is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

SIGNATURE

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DATE

ABSTRACT

This research was aimed at the optimisation of the usability of content-rich computer and mobile based e-learning material. The goal was to preserve the advantages of paper based material in designing optimised modules that were mobile and computer-based, but at the same time avoiding the pitfalls of converting traditional paper based learning material for use on screen. A mobile eye tracker was used to analyse how students studied similar course content on paper, and on mobile device. Screen based eye tracking was also used to analyse how participants studied corresponding content on a desktop screen. Eye movements which were recorded by an eye tracker revealed the sequences of fixations and saccades on the text that was read by each participant. By analysing and comparing the eye gaze patterns of students reading the same content on three different delivery platforms, the differences between these platforms were identified in terms of their delivery of content rich, text based study material. The results showed that more students read online content on a computer screen than on mobile devices. The inferential analysis revealed that the differences in reading duration, comprehension, linearity and fixation count on the three platforms were insignificant. There were significant differences in saccade length. This analysis was used to identify strong aspects of the respective platforms and consequently derive guidelines for using these aspects optimally to design content rich material for delivery on computer screen and mobile device. The limitations of each platform were revealed and guidelines for avoiding these were derived.

Keywords: Distance Education, E-learning, Learning Theories, Usability, Navigation, On-screen reading, Eye Tracking, Human Computer Interaction, Optimisation, Duration, Linearity

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STYLE OF WRITING

Writing style:

Use of the term “researcher”

The term “the researcher” was used to show my involvement in the processes of the study.

Use of the terms “he” and “she”

The term “he” was used when discussing my data. However, when referring to the participants in my discussion and presentation of the results, I used “he or she”.

CHAPTER 1

INTRODUCTION AND OVERVIEW

1.1 Introduction

The improvement in availability and evolution of technology has made it easier for computers and mobile phones to be accessible in schools, homes and workplaces (Wei, et al., 2009). As a result, more students have access to the Internet on both computers and mobile phones. As the Internet has become more widely used and there is a need to deliver educational content, web-based learning or e-learning is now acceptable to many people. E-learning stems from one aspect of the evolution of distance learning and refers to learning where learners and tutors are separated by distance, time or both (Raab, et al., 2002; Cantoni, et al., 2004). It has decreased the distance learning limitation of learning location (Blocher, et al., 2002).

Research in e-learning methods is focused on the usability and effectiveness of e-learning systems incorporating better didactical and pedagogical approaches (Novák, et al., 2010). Human Computer Interaction (HCI) theories and methodologies can support the design of learning systems that are suitable for students' learning styles and have high standards of accessibility and usability, in order to make learners' interaction with the systems as natural and intuitive as possible (Dix, et al., 2006; Ssemugabi & de Villiers, 2012; Wachowiak, et al., 2010).

Universities need to design and deliver quality e-learning materials to enhance the learning process (Engelbrecht, 2003). E-learning must encourage active learning. Discussion boards, frequent assessments by making use of structured exercises and peer communication are some of the examples of active learning (le Roux & le Roux, 2004). An effective e-learning environment depends on building a strategy that meets the needs of the learners and the business goals of the institution (Engelbrecht, 2003).

The University of South Africa (UNISA) is an open distance learning institution with more than 300,000 students. Although a paper based education has been UNISA's

main delivery mechanism for many decades, it is becoming a non-viable option and therefore there is need to investigate the best way to transfer to a fully online learning environment. The researcher believes that improving the learnability of content-rich e-learning material will enhance the learners' achievements. Learnability is an aspect of usability and it is the understandability, operability and attractiveness of a system to casual users (Joo, et al., 2011).

1.2 Background and Motivation

The first distance education courses leading to college-level degrees were offered by mail in 1873. At that time, Illinois Wesleyan University, a private institution, developed a curriculum leading to bachelors, masters and doctoral degrees (Bittner & Mallory, 1933 as cited by Adams, 2006). Throughout its history, experimentation with various forms of new communication technologies to enhance the learning experience has been incorporated into distance education (Adams, 2006).

The media developed in the early 20th century which were used in instructional programming included the radio, film, slides, television, videotape, audiotape and telephone (Keegan, 2002; Adams, 2006; Harper, et al., 2004). These media were introduced to help create a classroom illusion to enhance the sense of "being there" and to foster two-way communication where students had no face-to-face contact with their instructors or peers (Adams, 2006; Harper, et al., 2004).

The evolution of the Internet has led to the widespread adoption of e-learning (Keegan, 2002). In addition to previous descriptions, e-learning is the use of the Internet to deliver learning, training, or educational material (Stockley, 2003; Sun, et al., 2008). It also includes learning through other kinds of electronic mechanisms, e.g. computer based learning material distributed on CDs, video tape, TV, DVD and personal organisers (Kahiigi, et al., 2008).

E-learning is used to provide educational content as an alternative to traditional instructor-led learning when face-to-face teaching is not possible (Wei, et al., 2009). Several virtual-only universities which include the Indira Gandhi National Open University, British Open University, the Globe Network Academy in Denmark, World

Lecture Hall of the University of Texas and Africa Virtual University (AVU) have been established (Cantoni, et al., 2004). Paper has been rated the best form of readable material (Waycott & Kukulska-Hulme, 2003; Dundar & Akcayir, 2012; Zaphiris & Kurniawan, 2001). Many studies have concluded that screen and mobile reading is slower, less accurate and less comprehensive than paper reading. With the improvement of technology, attitudes are changing as tablets and e-reading technology improves. Though people still prefer to read on paper, reading digital books for facts is becoming common (Jabr, 2013; Dundar & Akcayir, 2012).

The predominant use of computers and mobile technologies is a reason to utilise them for learning. Mobile devices can be used to deliver dynamic and interactive content in many different settings for a wide range of uses and situated learning activities. Tablets, particularly the iPad have contributed to the growth of mobile learning. This study resulted because of our interest in knowing how e-learning students read content-based material on computers and mobile devices. At UNISA, some students not only read printed study guides and tutorial letters, but also download notes in pdf format on computer screens or mobile devices. Our intention was to utilise the advantages of paper based material to design content-rich, text-based study material for reading on computer screen and mobile devices.

1.3 Research Problem

The paper based study material at UNISA is often just converted into pdf format and placed on myUnisa from where students can download it. Initially only few UNISA modules have had study guides that were designed specifically for delivery on screen (incorporating some interactivity). The problem was that merely providing students with online versions of paper based material did not utilise support mechanisms that could potentially be built into an electronic version of the material.

1.4 Research Questions

The objective of the study was to determine how to optimise the readability of content rich electronic study material.

1.4.1 Main Question

The main research question was:

How can we optimise the design of computer based and mobile based e-learning material using students' eye tracking patterns when studying how students interact with the paper based HCI study guide and the electronic version of the study guide respectively?

1.4.2 Secondary Research Questions

In order to answer the above research question we searched for answers to the following sub-questions:

- i) How do students currently use computers and personal mobile devices for educational purposes?
- ii) How do the eye tracking patterns of students differ when they read the same content on paper and on a computer screen respectively?
- iii) How do the eye tracking patterns of students differ when they read the same content on a mobile device and on a computer screen?
- iv) What general guidelines can be derived from the above with respect to the design of online delivery of course content?
- v) How should paper based material be adapted for delivery on a computer screen?
- vi) How should paper based material be adapted for delivery on a mobile device?

1.5 Study Objectives

The main objective of the study was to investigate how the eye tracking patterns of students differed when they read the same content on paper, computer screen and mobile phone respectively.

The specific objectives of the study were to:

- Discover guidelines with respect to design of online delivery of course content.
- Derive guidelines, which optimise readability, for adapting paper based material for computer screen.
- Derive guidelines, which optimise readability, for adapting paper based material for mobile phone.

1.6 Research Methodology

Eye tracking was used to assess the students' reading patterns on paper, computer screen and on mobile device. Eye tracking is the process of measuring either the point of gaze or the motion of an eye relative to the head. Normal reading consists of a series of saccadic eye movements along lines of text, separated by periods of brief fixations during which the eye is relatively stationary and visual information is acquired from the text (Rayner, 2009).

In this study, the Tobii T120 and X120 eye trackers recorded eye movements at the rate of 120Hz. A Tobii T120 eye tracker is designed for on screen eye tracking and therefore was used in this study for the eye tracking of students reading text on screen. A Tobii T120 eye tracker has a 17 inch LCD monitor, built in camera and speakers (Tobii T120, 2012). The Tobii X120 eye tracker is a stand-alone unit and is suitable for eye tracking of physical objects (Tobii X120, 2012). The high tracking frequency of the eye trackers enables finer gaze eye tracking and the eye trackers were therefore suitable for the eye tracking of reading patterns (Tobii, 2012). Both eye trackers allow an automatic selection of bright or dark pupil eye tracking, a large degree of head movements and provide a distraction free environment (Tobii, 2012).

The case studied in this research was the HCI module – INF1520. INF1520 is a UNISA module offered to first level students in Computing or Information Systems. Although the module was not designed specifically for online and mobile learning, the pdf version of the study material could be downloaded from module website. Participants were eye-tracked in the UNISA HCI laboratory while reading a page from the module's study guide. The eye tracking data was analysed and the results of the analysis were used to derive recommendations for designing online, content-rich learning material.

Thirty participants volunteered to take part in the study. Ten participants were assessed while reading content on paper. Ten participants were eye tracked while reading content on a computer screen. Ten were eye tracked reading content on a mobile device. Tobii Studio™ was used to analyse data using quantitative and qualitative methods by measuring the gaze and eye movements and observing the gaze replay. A gaze replay

is a dynamic visualisation tool (Falck-Ytter, et al., 2013). It is a visualisation of the gaze path and shows both the screen seen by the viewer and the eye movements in that scene. Thus the eye tracking method provides objective and quantitative evidence of the participants' visual processes. The main parameters used in this study were fixation duration, fixation count, saccades' length and saccades' linearity. The gaze replay enabled the researcher to view what each participant was reading and how long it took them to read that part.

1.7 Significance of the Study

Presently, students are regularly exposed to digital technologies (Cobcroft, et al., 2006). This has led to a new breed of learners that are mobile, experimental and community oriented (Cobcroft, et al., 2006). Like most modules at UNISA, the HCI module that was studied had not been designed for online and mobile learning. The paper based learning platform was not a viable option any longer. There was a need to move to a fully online learning environment.

The research identified and compared how students read specific sections of the study guide on paper, computer screen and on mobile device. The eye tracking results from the study gave inputs as to how content rich study material must be designed for the different platforms. This provided instructional designers with the best design strategies to be implemented for the different platforms so that e-learning could be carried out effectively. There was a need for paper based, computer based and mobile based versions of the study material and each of these could be designed to capitalise on the advantages of that specific medium. It is essential to invest in effective instructional design in view of the fact that course readability has an influence on learning (Merkt, et al., 2011).

1.8 Assumptions, Delimitations and Limitations

The key assumption made was that people generally read differently on different media. It was also assumed that the e-learning materials on the UNISA website were designed without taking into consideration the differences of reading patterns on different

platforms. Another assumption was that the results of the study could be used to generalise the reading patterns of all people on the different platforms. The limitation of the experimental results was the small sample size, as out of approximately a thousand students that registered for the module, only thirty took part in the study. Students with disabilities did not take part in the study.

1.9 Overview

In this research, a study was carried out on how content-rich e-learning material could best be designed. INF1520, a first level module on human computer interaction (HCI), offered by the School of Computing at UNISA, was to be studied. Participants in the study read specific paragraphs of the INF1520 study guide on paper, computer screen and on mobile phone. An eye tracker, a system enabling observers to locate where a participant is looking in real-time (Tullis & Albert, 2008), was used to monitor participants' areas of focus and the sequences in which the content was read.

The aim was to gain insight into the reading strategies that students applied when studying on paper, computer screen and on mobile phone. The insights gained were used to derive best practices in the design of the study material for computer screen and mobile phone. A questionnaire with demographic and content based questions was used to obtain data from the participants. The data derived from the questionnaires supplemented the eye tracking data. Differences in comprehension from the content read on different platforms were analysed based on the accuracy of the responses given by the participants.

1.10 Layout of Dissertation

Chapter 2 – Literature Review

The usability, cost and accessibility of e-learning materials are discussed. The chapter focuses on studies that have been conducted on e-learning, general eye tracking, eye tracking of mobile devices and design strategies for e-learning materials.

Chapter 3 – Research Methodology

This chapter discusses the research paradigm and the methods of data collection and analysis. Eye tracking apparatus, paper, computers and mobile devices that were used for the experiment are presented. Discussion of participants who took part in the study and how the eye tracking data was recorded and analysed are also included.

Chapter 4 – Data Analysis

The discussion of the main eye tracking parameters used in the study appears in the chapter. The analysis of data recorded during the eye tracking study as well as data obtained from the questionnaires to supplement the eye tracking data, are discussed.

Chapter 5 – Discussion of the Findings

An outline of how participants study on paper, computer screen and on mobile device is included. The chapter discusses and summarises the major and additional findings of the study in relation to the objectives of the research and the literature reviewed.

Chapter 6 – Conclusion

The final recommendation for the optimal design of content-rich material for delivery on mobile and desktop computer is presented. The significance of the study is also presented as well as pointers to future research.

1.11 Summary

This chapter discusses the background of the study, research questions, and objectives, significance of the study and what motivated me to work on the study. Chapter 2 provides the theoretical literature review, learning theories, concepts and principles relevant to the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Mobile devices are significantly transforming how shared knowledge resources are accessed by keeping us constantly connected with vast amounts of raw data and information (Smith, et al., 2011; Wobbrock, 2006; Cui & Roto, 2008). A mobile device is a handheld computing device with a touch input and/or a miniature keyboard. Mobile device uses include making and receiving calls, sending text messages, browsing the Internet, conferencing and creating images and video.

Educational content can be delivered on mobile devices (Ozcelik & Acarturk, 2011). Students may take photographs of objects, record homework, create revision podcasts and animation. Students may also access resources from the Internet for research and read files from mobile devices. The significant increase in mobile devices' usage has led to a rise in the number of mobile websites – also in the educational sector.

Research on human computer interaction (HCI) with mobile devices, aims to make the use of mobile devices easier and more efficient (Ardito, et al., 2006). Eye tracking can be used to track users' eye gaze on mobile devices. Eye movements recorded by eye trackers help HCI researchers understand visual and display based information processing and the factors that may impact upon the usability of system interfaces (Dix, et al., 2006). HCI researchers may use eye tracking results to design software that will engage novice learners. They must take into account the different ways students learn and ensure that students' interactions are as intuitive and natural as possible (Dix, et al., 2006; Ardito, et al., 2006; Gawande, 2009; Novák, et al., 2010).

This literature review begins with a discussion of the nature and theories of distance education and e-learning. The next section discusses mobile learning and mobile learning theories. Subsequent sections examine the human visual system, eye tracking,

e-learning material design strategies, usability and usability principles, and e-learning media accessibility, usability and cost.

2.2 Distance Education and E-learning

2.2.1 Open Distance Learning

Distance education involves processes and methods of delivering educational instruction on an individual basis to students who are physically separated from the learning institution, tutors as well as other students (Adams, 2006; Unisa, 2008). Distance education dates back to 1728 when Caleb Phillips advertised weekly shorthand lessons by post to students in their country (Tejeda-Delgado, et al., 2011). This type of learning was stimulated by the development of the postal service in the 19th century (Stefanescu, et al., 2009). In the 1840s, Isaac Pitman taught shorthand by correspondence in Bath, England. Students would copy Bible passages in shorthand and mail them to Pitman for grading and Pitman would then return the graded assignments. The first university to offer distance learning degrees was the University of London. Its programmes started in 1858. Universities used correspondence courses in the first half of the 20th century, especially to reach rural students (Tejeda-Delgado, et al., 2011).

In the 1930s, the spread of the radio in the United States resulted in proposals to use it for distance education. Many universities and colleges broadcast distance learning education programs. Students would receive their study material by mail and listen over the radio to live classroom discussions that were held on campus. In the 1950s, audio transmission decreased as the new technology, television, replaced it. Technology continues to influence distance education even today (Tejeda-Delgado, et al., 2011).

Open learning is primarily a goal, or an educational policy (Tony Bates, 2008). It is the removal of barriers to learning, which might include no prior qualifications to study, learning for students with disabilities and a determined effort to provide education in a suitable form that overcomes the disability. Ideally, no-one should be denied access to an open learning program. Thus, open learning must be scalable as well as flexible. The open learning policy has particular implications for the use of technology. Some

distance education programs do not involve open learning (Moore & Kearsley, 1997). Open Distance Learning (ODL) is a multi-dimensional concept aimed at bridging the time, geographical, economic, social, educational and communication distance between student and institution, student and academics, student and courseware, and student and peers (Unisa, 2008). The widespread use of computers and the Internet has led to online virtual schools and virtual universities.

2.2.2 E-learning

E-learning is the delivery of educational content via electronic media, including the Internet, intranet, extranet, satellite broadcasts, CD-ROM, audio/video and interactive TV (Henry, 2001; Kahiigi, et al., 2008; Dharmawansa, et al., 2013). It has been adopted by many educational institutions and is not restricted to any courses, technologies or infrastructures (Blocher, et al., 2002). Students from different backgrounds can study without leaving their employment or homes (Blocher, et al., 2002). Generally, e-learning is the use of telecommunication technology to deliver information for education and training (Kahiigi, et al., 2008). The advantages of e-learning include liberating interactions between learners and instructors, or learners and learners, from limitations of time and space through the asynchronous and synchronous learning network model (Sun, et al., 2008).

2.2.2.1 Generations of Distance Education

According to Taylor (2001), distance education operations have evolved through five generations (see Table 2.1). The first generation is the Correspondence Model that is based on the print technology. The Multi-media Model based on print, audio and video technologies is the second generation.

The third generation is the Tele-learning Model, which is based on applications of telecommunications technologies to provide opportunities for synchronous communication. The Flexible Learning Model based on online delivery via the Internet is the fourth generation. The fifth generation is the Intelligent Flexible Learning Model (Taylor, 2001).

Table 2.1: Generations of Distance Education, (Taylor, 2001)

| Models of Distance Education and Associated Delivery Technologies | Characteristics of Delivery Technologies | | | | | |
|---|--|-------|------|--------------------------|-------------------------------|---|
| | Flexibility | | | Highly Refined Materials | Advanced Interactive Delivery | Institutional Variable Costs Approaching Zero |
| | Time | Place | Pace | | | |
| FIRST GENERATION - The Correspondence Model · Print | Yes | Yes | Yes | Yes | No | No |
| SECOND GENERATION - The Multi-media Model | | | | | | |
| Print | Yes | Yes | Yes | Yes | No | No |
| Audiotape | Yes | Yes | Yes | Yes | No | No |
| Videotape | Yes | Yes | Yes | Yes | No | No |
| Computer-based learning (e.g. CML/CAL/IMM) | Yes | Yes | Yes | Yes | Yes | No |
| Interactive video (disk and tape) | Yes | Yes | Yes | Yes | Yes | No |
| THIRD GENERATION - The Tele-learning Model | | | | | | |
| Audio teleconferencing | No | No | No | No | Yes | No |
| Videoconferencing | No | No | No | No | Yes | No |
| Audio graphic Communication | No | No | No | Yes | Yes | No |
| Broadcast TV/Radio and Audio teleconferencing | No | No | No | No | No | No |
| FOURTH GENERATION - The Flexible Learning Model | | | | | | |
| Interactive multimedia (IMM) Online | Yes | Yes | Yes | Yes | Yes | Yes |
| Internet-based access to WWW resources | Yes | Yes | Yes | Yes | Yes | Yes |
| Computer mediated Communication | Yes | Yes | Yes | Yes | Yes | No |
| FIFTH GENERATION - The Intelligent Flexible Learning Model | | | | | | |
| Interactive multimedia (IMM) online | Yes | Yes | Yes | Yes | Yes | Yes |
| Internet-based access to WWW resources | Yes | Yes | Yes | Yes | Yes | Yes |
| Computer mediated Communication | Yes | Yes | Yes | Yes | Yes | Yes |
| Campus portal access to processes & resources | Yes | Yes | Yes | Yes | Yes | Yes |

The fifth generation of distance education is essentially a derivation of the fourth generation, which aims to fully exploit the features of the Internet and the Web (Taylor, 2001).

Costs

Before the advent of online delivery, costs tended to increase or decrease directly (often linearly) with fluctuations in the volume of activity. For example, in the second generation distance education delivery, the distribution of packages of self-instructional materials e.g. printed study guides, audio tapes, video tapes, is a variable cost, which varies in direct proportion to the number of students enrolled.

In contrast, the fifth generation distance education has the potential to significantly decrease costs associated with providing access to institutional processes and online tuition. The fifth generation of distance education has the potential to deliver a major increase in economies of scale and associated cost-effectiveness through the development and implementation of automated courseware production systems, automated pedagogical advice systems and automated business systems (Taylor, 2001).

2.2.2.2 E-learning Technologies

E-learning technologies dictate how the actual learning will take place (Kahiigi, et al., 2008). These technologies include digital and cable TV, DVDs, CD-ROMs, Content Management Systems, Learning Management Systems as well as virtual worlds (Kahiigi, et al., 2008; Mahmoud, 2008).

CD-ROM Media

They lead the wave of learning in the late 80s and early 90s. Since that time, CD-ROMs have been used to deliver educational material to students who study by means of distance programs. They support learning content in text or multimedia formats. The use of CD-ROM media facilitates independent learning where learners learn by executing special training programs on the computer, irrespective of internet connectivity. This tool is commonly used for Computer Based Training, such as those

usually offered as tutorial with new software and tutorials for learning languages or new applications (Mahmoud, 2008).

Learning Management Systems (LMS)

Learning Management Systems refer to an integrated set of networked, computerised tools that support online learning. Learning Management Systems such as WebCT and the Blackboard have many built-in features that help teachers manage their courses (Kahiigi, et al., 2008). The application is used for the administration, documentation, tracking and reporting of e-learning programs. LMSs are used to deliver online courses and augment on-campus courses.

Content Management Systems (CMS)

Content Management Systems such as Moodle are computer programs that were developed to facilitate the collaborative creation of content, organisation control and to manage the publication of documents in a centralised environment. These content management systems manage workflow in an environment (Kahiigi, et al., 2008).

Learning Content Management Systems (LCMS)

Learning Content Management Systems are mostly web-based systems that combine the management and administrative functionalities of LMS and CMS to author, approve, publish, and manage learning content that will typically be delivered via LMS. Users can both create and re-use e-learning content and reduce duplicated development efforts. An example of such technologies is the Macromedia Course Builder (Kahiigi, et al., 2008; Kaliski, et al., 2008).

Virtual Worlds

A virtual world is a set of computer rendered images that comprise a simulated environment in which users interact through the use of avatars (Franceschi, et al., 2008). Some of the most common and unique characteristics of these worlds are the support of multiple players, their persistent nature, social networking capabilities and the similarity to the real world (Franceschi, et al., 2008). Many educational institutions now use virtual classrooms to facilitate student learning. The virtual class is used as a meeting place and students and the instructors use their computers to go to a virtual

meeting place instead of a classroom. The instructor may select different teaching methods including slide presentation, shared whiteboard and application sharing (Dharmawansa, et al., 2013). Users are provided with tools that allow them to give their personal touch to their virtual world experience. They may modify and create new content in the virtual world.

Virtual worlds provide community building opportunities. They possess the necessary tools to foster effective group collaboration for e-learning initiatives (Franceschi, et al., 2008). Users are visualised through the use of avatars and not just a line of text. This allows users and their classmates to see themselves as part of a community. Voice communications in the virtual world enhance group collaboration by adding a personal element to the communications (Dharmawansa, et al., 2013).

Web conferencing software allows students and instructors to communicate with each other via webcam, microphone and real-time chatting in a group setting. Examples are GoToTraining, WebEx Training or Adobe Connect. These can be used for meetings and presentations.

Massive Open Online Courses

The rapid development of massive open online courses (MOOCs) in the last few years has signified a revolution in higher education. MOOCs have been run by a variety of public and elite universities since 2008 and were developed from the increasing expertise of the universities in the use of distance learning and open educational resources (Clarke, 2013).

The MOOC is online course with free and open registration (Yuan & Powell, 2013). It does not have predefined expectations for participation and no formal accreditation. A MOOC integrates the connectivity of social networking, the facilitation of an acknowledged expert in a field of study, and a collection of freely accessible online resources. MOOCs build on the engagement of learners who self-organise their participation according to learning goals, prior knowledge and skills, and common interests (McAuley, et al., 2010).

MOOCs remain in a developmental stage with a large number of companies associated with elite universities assembling international universities for support. They make use of video lectures, online discussion boards, blogs, wikis, and social networking sites. Support tends to come from the online learning community rather than academics, and assessment is often either peer assessment, written assignments and computer assessed tests (Clarke, 2013). The largest and original MOOCs are Coursera, edX, and Udacity.

Coursera is a social enterprise company with four university partners, namely Stanford University, Princeton University and the Universities of Michigan and Pennsylvania (Yuan & Powell, 2013). EdX was founded by Harvard University and MIT, with the intention not only of offering interactive study on the web, but researching how students learn and how technology can transform learning both on-campus and world-wide. Udacity started by offering free computer science classes through Stanford University in 2011. It is a private educational enterprise with a significant funding from venture capital (Clarke, 2013).

2.2.2.3 Factors for Developing E-learning

Four elements should be considered when developing e-learning environments, namely environmental characteristics, environmental satisfaction, learning activities and learners' characteristics. It is crucial to understand the targeted population when developing an e-learning system (Liaw, 2008).

Sun, et al. (2008) are of the opinion that learner computer anxiety, instructor attitude toward e-learning, e-learning course flexibility, e-learning course quality, perceived usefulness, perceived ease of use, and diversity in assessments are the critical factors affecting learners' perceived satisfaction. The four elements to be considered when developing e-learning are shown in Figure 2.1.

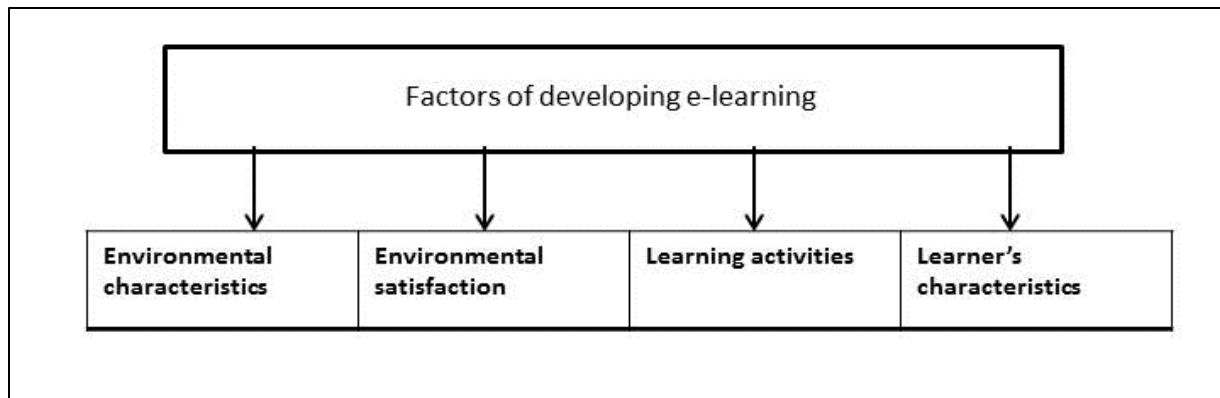


Figure 2.1: Factors used for developing e-learning: (Liaw, 2008)

Environmental Characteristics

These include the e-learning's system quality and type of multimedia instruction. In e-learning, environmental characteristics, such as synchronous or asynchronous interaction create a high-level communicative environment that allows learners not only to share information, but also to determine how to retrieve useful information. In an e-learning environment, learners and instructors are physically separated. Based on the activity theory, increased student engagement can increase the learning outcome (Liaw, 2008).

The interactions on the network are the main instructional components of the virtual classroom. The instructional materials (lesson notes) are the background material, from which discussions originate (Passerini & Granger, 2000).

Environmental Satisfaction

This enhances learners' perceptions of technology that might promote their participation in the learning processes. The learners' perceptions of the system might be the operating methods, system speed, and system quality (Liaw, 2008). The learners' satisfaction and confidence in the system enhances their learning experience.

Learning Activities

Learners and instructors can share their knowledge and experiences using learning activities. The constructivist theory assumes that learning activities in which learners play active roles, engage and motivate students' learning more effectively than learning

activities where learners are passive (Liaw, 2008). The factors that influence students' motivation to learn include future economic benefit, development of personal and professional identity, challenge and achievement, enjoyment and fun (Yuan & Powell, 2013).

Learners' Characteristics

Characteristics of the targeted population must be understood (Passerini & Granger, 2000). These characteristics, which include self-efficacy, self-directed behaviour and autonomy need to be identified. Learners' characteristics will influence learners' perceived satisfaction, perceived usefulness and e-learning effectiveness (Liaw, 2008).

Liaw (2008) conducted a research to investigate students' satisfaction, behavioural intentions and the effectiveness of the Blackboard e-learning system. The results indicated that perceived self-efficacy, multimedia instruction, and e-learning system quality influenced learners' perceived satisfaction. Perceived self-efficacy was the major factor. Learners indicated that they needed more interactive and communicative functions and activities.

2.2.2.4 E-learning and Information Communication Technologies

The development in internet technologies has strengthened the World Wide Web as the platform of choice to support e-learning and the learning process (Santally, et al., 2012). Computer based chats, video and audio conferencing have made it possible to provide for the interaction of learners and tutors both in synchronous and asynchronous ways, leading to a highly reduced significance of the distance issue.

Table 2.2 illustrates how technology has changed the modalities which affect the nature of interaction between the teacher, student and content as well as how the interactions and communications are mediated.

Table 2.2: Conceptual educational frameworks illustrating model, modality and underlying (educational) technology, (Santally,et al.2012)

| Conceptual Frameworks | | | |
|--|--|--|---------------------------|
| Traditional Education | Distance Education | E-/Online Education | model |
| Physical Classroom Face-to-face & Asynchronous Same time, same place | The manual Asynchronous Different Time/Place | Virtual Classroom Content Real time Asynchrony | modality |
| Chalk & Board Projector Markers | Paper/VHS/Radio/TV Telephone/Faxes | Digital Mobile Networks Multimedia/web 2.0 Knowledge Marts (www) Social Networks (www) | Educational Technology |

Technology has also changed the ways that content can be authored and presented to the learner and, thus, offering a wider choice of pedagogical design approaches (Santally, et al., 2012). Asynchronous e-learning (see Table 2.3), occurs when students begin and complete their training courses at different times according to their own schedule. Participants cannot be online at the same time. Asynchronous e-learning facilitates flexible learning (Hrastinski, 2008). Synchronous e-learning allows real-time interaction and raises a sense of community among learners (Dharmawansa, et al., 2013). Synchronous e-learning enables students to receive immediate responses (Hrastinski, 2008).

The web is used as a study tool because of the various options it offers: asynchronous discussion forums, synchronous discussions (text, voice and/or video) and animated illustrations and multimedia applications (Gal-Ezer & Lupo, 2002).

Table 2.3: Synchronous and asynchronous e-learning (Dharmawansa, et al., 2013)

| E-Learning types | Common features | Conducting ways |
|-------------------------|-------------------------------------|------------------------------|
| Asynchronous e-learning | Intermittent on-demand access | Message boards |
| | Previously recorded or pre produced | Discussion groups |
| | Just in time | Self-paced courses |
| | Individual or poorly collaborative | Computer aided system |
| | Independent learning | Podcasting |
| | Self-paced | Web-based training |
| Synchronous e-learning | Real-time | Shared whiteboard |
| | Live | Virtual classrooms |
| | Scheduled | Audio and Video Conferencing |
| | Collaborative | On-line chat |
| | Co-presence of learners | Application sharing |
| | Concurrent learning | Instant messaging |

The cognitive model of media choice proposed by Dennis and Robert (2005) theorises that asynchronous communication increases a person's ability to process information. The ability to process a message received from a sender is influenced by factors such as the intelligence to follow the argument, whether there is adequate information to understand the issue being discussed, and whether there is enough time to process and/or reprocess the information.

Dennis and Robert (2005) allege that a receiver has more time to comprehend a message that is sent through a low social presence medium. The receiver also has time to access more sources of information. Additional sources can be used to accompany the message received, e.g. in the case of an email message, web links and/or numerous documents may be attached to the email. The media that is low in social presence enables the receiver to process information repeatedly until he or she fully understands it. However, in asynchronous learning, learners feel isolated and not part of the learning communities. Synchronous learning is essential for collaborative learning (Hrastinski, 2008). Dennis and Robert (2005) claim that synchronous learning increases levels of commitment. It also increases psychological arousal (Kock, 2005).

2.2.2.5 E-learning and Human Computer Interaction

Human Computer Interaction is a crossroad of social and behavioural sciences and information technology. It is important in e-learning environment design. HCI can be used in defining conventions and ideas on how to build usable and effective systems from a user's point of view (Novák, et al., 2010). There is a need for more intuitive ways of interacting with the computer. In e-learning, the quality of interaction is of great importance as it influences the learning process by employing specific communication modalities (Gawande, 2009). HCI has a direct impact on users and how they perform their work (Maxwell, 2000). Some of the current technologies that are used are perceived as distant and lacking the face-to-face contact of a traditional classroom setting (Gawande, 2009).

HCI theories and methodologies can support the design of appropriate e-learning settings responding to the complex and rapidly changing requirements of both the academic and business contexts of our society (Dix, et al., 2006). From a technical point of view, it is already possible to implement interactions that exploit the perceptive abilities which so far have characterised human to human communication only (Gawande, 2009).

Emotion detection plays a key role in HCI. Affective applications can be used to detect negative emotions like boredom or anger which reduce cognitive effort and hinder the achievement of learning goals (Kaiser & Oertel, 2006). Providing educational access for all individuals is one of the main goals of e-learning. However, many e-learning systems have various features and options that may be complex for people with cognitive and learning disabilities.

A prototype e-learning system for people with cognitive and learning disabilities was created. The prototype was based on assistive technologies and its goal was to alleviate over-complexity by reducing the number of features presented to the user at any one time, and by retaining and enhancing crucial features without negatively affecting overall functionality. A student was asked to perform some tasks on the e-learning system. The student was able to accomplish all the tasks and reported

satisfaction with the interface (Wachowiak, et al., 2010). Andruseac, et al., (2013) developed an e-learning platform to provide long distance speech therapy and remote monitoring of patients with dyslexia. The platform was made up of an application for patients' management and a recovery module (RM). The RM is an interactive and multimedia software for the rehabilitation of dyslexic people. It has a component that is designed to help memory and to correct language. A patient sees a word and/or a picture on the system. The patient will say the word and then hear the word from the system. He will then compare his pronunciation with the correct one and try again. The module also helps patients articulate words, understand paragraphs read and execute instructions.

2.2.3 Distance Education Theories

The first attempt to define distance education and to articulate a theory was in 1972. This was later called the Theory of Transactional Distance. In this theory, it was stated that distance education is not simply a geographical separation of learners and teachers, but, more importantly is a pedagogical concept (Moore, 1993). Holmberg defined distance education as the various forms of study where students are not under continued, immediate supervision by tutors. Holmberg views distance education as an organised educational programme (Pyari, 2011).

Distance education theories have been derived from European or American models based on correspondence study. The development of theory in distance education is seen as crucial in its sustainability (Gakool-Ramdoo, 2008). It has been argued that there is need for a global comprehensive theory that can explicate all activities pertaining to distance education (Amundsen, 1993).

Distance education has been formalised as a discipline over the past three decades. A number of theoretical frameworks have been established in an attempt to encompass and explain the activities in distance education. As theorists have tried to position their thinking, there seems to have been a lot of clamour among scholars around what is the most appropriate or most comprehensive theory to explicate the activities within distance education (Gakool-Ramdoo, 2008). Prominent theories are shown in Table 2.4.

Table 2.4: A comparison of theoretical perspectives (Amundsen, 1993 as cited by Gakool-Ramdoo, 2008).

| Framework | Central concepts | Primary focus | Apparent influence |
|---|---|---|--|
| Peters – The Industrial Model | Industrial Post-industrial | Match between societal principles and values | Cultural sociology |
| Moore – Transactional Distance Theory | Transactional distance (dialogue, structure) Learner autonomy | Perceived needs and desires of the adult learner | Independent study |
| Holmberg – Theory of teaching in distance education | Learner autonomy, Non-contiguous communication Guided didactic conversation | Promotion of learning through personal and conversational methods | Humanist approach to education |
| Keegan - Theory of reintegration of the teaching and learning acts | Reintegration of teaching and learning acts | Recreation of interpersonal components of face to face teaching | Framework of traditional pedagogy |
| Garrison (Shale, Baynton) – A theory of communication and learner control | Educational transaction, Learner control, Communication | Facilitation of the educational transaction | Communication Theory – Principles of adult education |

There are similarities and differences in the theories shown in Table 2.4. The most comprehensive theory is the Transactional Distance Theory developed by Moore. The Transactional Distance Theory can encompass both organisational and transactional issues without losing sight of the learner, the institution, and the nation altogether (Gakool-Ramdoo, 2008). Moore's theory is classified by two variables, namely, the distance between teacher and learner and the amount of learner autonomy (Moore, 1993; Simonson, et al., 1999). Moore states that distance education is composed of two

elements. The first element is the provision of a two-way communication (dialogue). The greater the dialogue between a teacher and a student, the shorter the transactional distance between them (Birochi & Pozzebon, 2011).

The second element is the extent to which a program is responsive to the needs and goals of an individual student (Simonson, et al., 1999). In the second part of his theory, Moore addresses learner autonomy. Due to the gap between the teacher and the students, the students must take a high degree of responsibility and study independently (Moore, 1993; Simonson, et al., 1999).

Peters (Gakool-Ramdoo, 2008), developed the Industrial Model. He argues that distance education carries separate activities that can be optimised if the division of labour approach is utilised. According to Peters (2008), distance education is a product of the industrial society and he states that in order for students to be autonomous, they must be meta-cognitively, motivationally and behaviourally active participants in their own learning (Gakool-Ramdoo, 2008).

Holmberg's concept of distance education is that learning is more effective when carried out through a guided didactic conversation (Kelsey & D'souza, 2004). The instructor guides and motivates students to express their feelings, thereby promoting increased learning outcomes and interpersonal communication (Kelsey & D'souza, 2004). Holmberg's theory of distance education was based on seven postulates guided by characteristics of didactic conversation (Kelsey & D'souza, 2004). These included:

- i) interpersonal communication to encourage study pleasure and motivation
- ii) that such dialogue is supported by well-developed instructional materials and two-way communications
- iii) that motivation was important for the achievement of learning outcomes
- iv) that friendly conversations create feelings of personal relationship
- v) that communications within natural conversation are easily understood and remembered
- vi) that the conversation concept can be successfully translated for use by the media to distance students
- vii) that planning and guiding the curriculum were essential for distance education

Keegan (1993) states that distance education must replicate face-to-face educational transaction in order to compensate for the location of students, causing lack of eye to eye contact which is vital in education (Gakool-Ramdoo, 2008). According to Keegan (1993), a theoretical structure for distance education focusing on the reintegration of the teaching acts by which learning is linked to learning materials may compensate for lack of eye to eye contact with students. He differs from Moore and Holmberg, who view separation as an advantage and a challenge to the autonomous learner (Gakool-Ramdoo, 2008).

Garrison argues that a two-way communication between a learner and a teacher is imperative (Birochi & Pozzebon, 2011). He states that the variables of dialogue and debate should provide agents with a high level of interaction in communicational processes to enlarge educational transactions (Birochi & Pozzebon, 2011). Garrison states that this two-way communication should be supported by technology and managed in a manner that control over the transaction is negotiated between the teacher and the student (Gakool-Ramdoo, 2008).

2.2.4 Learning Theories

Individuals use different strategies to seek and process information, and different strategies will result in different levels of effectiveness for different individuals in different contexts (Chen & Macredie, 2002). Designers of educational materials must be aware of such differences and offer appropriate support, resulting in higher quality of learning (Chen & Macredie, 2002).

The design, implementation and evaluation of e-learning systems can be enhanced by considering a recognised learning theory which is appropriate to the domain (de Villiers, 2005). Siemens (2004) states that the three broad learning theories most utilised in the creation of instructional environments are behaviourism, cognitivism and constructivism.

2.2.4.1 Three Major Learning Theories

Behaviourism

Behaviourism equates learning with changes in either the form or frequency of observable performance (Ertmer & Newby, 1993). According to McLeod (2003), three assumptions behaviourists share about the learning process are:

- Observable behaviour rather than internal thought processes is the focus of study; in particular, learning is manifested by a change in behaviour.
- The environment shapes behaviour; what one learns is determined by the elements in the environment, not by the individual learner.
- The principles of contiguity (how close in time two events must be for a bond to be formed) and reinforcement (any means of increasing likelihood that an event will be repeated) are central to explaining the learning process.

The strength of instructional design grounded in behaviourism is that when there are specific goals to be met, the learner is focused clearly upon achieving those goals whenever there are cues to prompt the learner's behaviour (McLeod, 2003). Learning is achieved when a proper response is demonstrated following the presentation of a specific environmental stimulus. For example, when presented with a math flashcard showing the equation " $2 + 4 = ?$ ", the learner replies with the answer of "6." The equation is the stimulus and the proper answer is the associated response (Ertmer & Newby, 1993).

Cognitivism

In the late 1950s, learning theory began to make a shift away from the use of behavioural models to an approach that relied on learning theories and models from the cognitive sciences. Instructors, psychologists and educators began to understate observable behaviour and stressed, instead, more complex cognitive processes such as thinking, problem solving, language, concept formation and information processing (Ertmer & Newby, 1993). Cognitivism supports cognition, retention and transfer of knowledge. New knowledge should be integrated with prior learning, building new skills on previous knowledge (de Villiers, 2005). Cognition involves thinking (process) and

knowledge (content) which can be further broken down into storing, retrieving, transforming and manipulating information (Shamir, 2013). Siemens (2004) states that cognitivism often takes a computer information processing model which views learning as a process of inputs, managed in memory and coded for long term recall.

Constructivism

According to constructivism, learning is knowledge construction and interpretation that is accomplished through individual experience, maturity and interaction with one's environment (Lee & Lee, 2008). Learners can explore and undertake discovery learning by setting up learner-centric environments and activities. Constructivism aims to instil personal goals and active involvement within real-world situated learning, leading to application skills and transfer (de Villiers, 2005). It emphasises collaborative activities and learner research, for example project and problem-based learning (de Villiers, 2005).

Cognitivists and behaviourists believe that knowledge is mind-independent and can be "mapped" onto a learner. Constructivists also believe in the existence of the real world but contend that what we know of the world stems from our own interpretations of our experiences. Humans create meaning as opposed to acquiring it (Ertmer & Newby, 1993). The three stages of knowledge acquisition are introductory, advanced, and expert (Jonassen, 1991 as cited by Ertmer and Newby, 1993). Jonassen argues that constructive learning environments are most effective for the stage of advanced knowledge acquisition, where initial misconceptions and biases acquired during the introductory stage can be discovered, negotiated and, if necessary, modified and/or removed (Ertmer & Newby, 1993).

Jonassen agrees that introductory knowledge acquisition is better supported by more objectivistic approaches (behavioural and/or cognitive) but suggests a transition to constructivistic approaches as learners acquire more knowledge which provides them with the conceptual power needed to deal with complex and ill-structured problems.

2.2.4.2 Use of Theories in the Design of Learning Materials

The development of effective online learning materials should be based on proven and sound learning theories (Anderson, 2008). Early computer learning systems were designed based on a behaviourist approach to learning, which claims that observable behaviour indicates whether a learner has learned something or not. However, some researchers argue that not all learning is observable and hence there has been a shift from behaviourist to cognitive learning theories.

Cognitive theories see learning as an internal process and contend that the amount learned depends on the processing capacity of the learner. There has been a move towards constructivism, which claims that learners interpret the information and the world according to their personal reality, that they learn by observation, processing and interpretation, and then personalise the information (Cooper, 1993).

A recently proposed theory under discussion is connectivism (Siemens, 2004). Siemens (2004) is of the opinion that connectivism is the integration of principles explored by chaos, network, complexity and self-organisation theories. Due to the information explosion in the current age, learning is not under the control of the learner.

Siemens (2004) claims that we now need a theory for the digital age to guide the development of learning materials for the networked world. Educators should be able to adapt existing learning theories for the digital age, at the same time, using the principles of connectivism to guide the development of effective learning materials (Anderson, 2008).

Under a close analysis of the behaviourist, cognitivist, and constructivist schools of thought, many overlaps in the ideas and principles become apparent. The design of online learning materials can include principles from all three learning theories (Anderson, 2008). Kahiigi, Ekenberg, Hansson, Tusubira, and Danielson (2008) state that the theories coexist and complement each other during a learning process. It should be kept in mind, though, that the attainment of the learning concepts varies from one learner to another and the learning methods dictate the level of knowledge to be attained (Kahiigi, et al., 2008).

2.3 Mobile Learning

Mobile learning is the delivery of educational content where the sole technologies are handheld or palmtop devices. Mobile learning devices include mobile phones, smartphones, personal digital assistants (PDAs) and their peripherals. Mobile phones are portable, have advanced capabilities and can be used for situated learning. Situated learning is learning that takes place in the same context in which it is applied (Traxler, 2005).

Some mobile phones are equipped with components such as a keyboard, touch screen, built in camera and secure email facilities (Traxler, 2005). Educators are considering mobile devices for the delivery of study materials due to their spontaneous access to online resources and their low cost compared to desktop computers and notebooks. Mobile devices can be used alongside paper and pencil due to their small size. Research has revealed that there is higher knowledge retention in studying with paper and mobile phone compared to studying online with paper (Ozcelik & Acarturk, 2011).

Research on mobile phone usage at the Tswane University of Technology revealed that the students preferred mailing lists compared to blogs, on line management tools (Box.Net), WebCT (on line management system) and Twitter (micro blogging) for answering questions raised in class and receiving study materials, marks and other types of information (van Biljon & Dembskey, 2011).

2.3.1 Classification of Mobile Devices

The emergence of mobile phones has brought opportunities for online learning and collaboration. Mobile devices have become widely used as many people can afford them. Their use has gone beyond the traditional communication role. They can now be used to support teaching and learning (Mtega, et al., 2012). Users can access study materials and information virtually online (Hamm & Jones, 2011). Sales of e-books have gone up and the trend will not reverse (Biedert, et al., n.d.). The types of mobile devices include cell phones, smartphones and tablet PCs.

Cell phones and Smartphones

Cell phones also known as mobile phones are used to make and receive calls over a wide geographic area. They can be used for group discussions via text messaging, and since so many have cameras, are useful for photography-based projects as well. Students can also record themselves reading stories aloud for writers' workshops or practicing speeches (Edutopia, 2012). Mobile phones have low memory capacity and low data transfer rate.

Smartphones have functions that are similar to those of cell phones and computers. They can be used for web browsing, reading e-books and playing games (GCF, 2013). Some smartphones have a built-in mini keyboard on the front of the phone or a keyboard that slides in and out from behind the phone. Some have touch screens, where a user can press objects on the screen to make selections and enter text through an on-screen keyboard.

Others include a stylus, which is similar to a digital pen but smaller and has less functionality. Instead of calling someone's smartphone or cell phone, users often send messages to others by pressing buttons on their phone's keypad, keys on the mini keyboard, or images on an on-screen keyboard.

Many smartphones have keypads that contain both numbers and letters which enable the same keypad to be used to dial phone numbers. Smartphones usually also provide personal information management functions such as a calendar, an appointment book, an address book, a calculator, and a notepad. In addition to basic phone capabilities, a smartphone allows one to send and receive e-mail messages and access the Web. Some smartphones communicate wirelessly with other devices or computers.

Most of the smartphones function as portable media players and include built-in digital cameras which can be used to share photos or videos with others as soon the images are captured. A variety of applications software such as word processing, spreadsheet, and games, and the capability of conducting live video conferences can be offered by smartphones (CengageBrain, 2013).

Notebooks

Notebooks are more compact in form than laptops, with typically 10 inch screen sizes. They are thin and lightweight, but can have functions that are similar to those of average desktop computers. However, they have less powerful processors and cannot run multiple programs simultaneously. They can do the least processor-intensive tasks, like browsing the Internet, checking email, and using office programs (GCF, 2013).

Some notebook computers have touch screens, allowing users to interact with the device by touching the screen, usually with the tip of a finger. On a typical notebook computer, the keyboard is on top of the system unit, and the monitor attaches to the system unit with hinges. These computers are portable which allows users to transport them from place to place. Most notebook computers can operate on batteries or a power supply or both (CengageBrain, 2013).

E-book Readers

These are mainly designed for reading books, magazines and online news (Edutopia, 2012). E-book readers can store books and have access to dictionaries. These devices usually are smaller than tablet computers but larger than smartphones (CengageBrain, 2013). They have either an e-paper (electronic paper) display or an LCD (liquid crystal display) display.

The e-paper can only display in black and white. It is designed to look like a page in a book. Unlike LCD, it is not backlit, which makes text to be readable outdoors (GCF, 2013). It causes less eye strain. Videos or other applications cannot be used because e-book readers have a low refresh rate. The LCD display is the same type of screen as those of computers and laptops. It is more versatile than the e-paper display and can display colours but cannot be viewed outdoors. E-books can also be read on smartphones, tablets and cell phones (GCF, 2013).

Tablet Computers

Apple's iPad, the Galaxy and the Kindle Fire are some of the models of tablets. Tablet PCs have the same capability as e-book readers and more. They are nearly comparable to computers but are lighter (Edutopia, 2012). Learners can download and

use applications, browse the Internet, watch games, play movies, take videos and photographs (Edutopia, 2012). Tablets use the touch interface on the screen as their source of input. Users have the option of using the virtual keyboard which may not be easy to use than a laptop keyboard. They can write or draw on a tablet PC by pressing a finger or digital pen on the screen, and issue instructions by tapping on the screen (CengageBrain, 2013).

High sales of iPads reflect consumer reactions to the technologies used for accessing e-book content. This was reflected in the launch of the iPad which generated high sales on its launch day. This was accompanied by many downloads of e-books (Gibson & Gibb, 2010). In a research conducted by Hamm and Jones, 2001, the majority of online students claimed that they use the iPad for activities such as reading, checking email and playing games. The respondents agreed that they could use the iPad without any assistance (Hamm & Jones, 2011).

PDA

A personal digital assistant (PDA) is a mobile device that functions as a personal information manager. It is used for managing phone numbers, addresses, calendars, and other information. Today, smartphones combine the functionality of a PDA and a mobile phone. A PDA differs from a smartphone in that it usually does not provide phone capabilities and may not be internet enabled, support voice input, have a built-in camera, or function as a portable media player (CengageBrain, 2013). Most PDAs use the touch screen technology (GCF, 2013).

2.3.2 Designing Content for Mobile Learning

The following guidelines can be referred to when designing content and interfaces from the pedagogical standpoint (Grasso & Roselli, 2005).

Accessibility and Intuitiveness

The content created must be short and to the point. User disorientation must be avoided and the total number of interactions with the system must be kept low. The mobile application content must be in small consistent information in order to reduce the

learners' cognitive load. The content must be divided into small partials to enable learners to read easily. Only relevant content must be included (Hashim, et al., 2010).

Simplicity and Consistency

The user must not get trapped in links to the various sections, which should be activated in few steps. Learners must be guided to external content where they can explore further (Grasso & Roselli, 2005). Bullets must be used to make contextual information more concise. There must be similar information and action in the same positions. Each display must be presented in the same way, and the form and function should call to mind the menus of traditional computers.

The following must be considered for links and navigation objects;

Intuitiveness

User disorientation must be avoided and the total number of interactions with the system required must be kept low. When a user activates a link, the presentation of the resulting interface must correspond to his or her expectations (Grasso & Roselli, 2005).

Correspondence with Tasks, Scrolling and Flexibility

Each link must be associated with a given task. Each display must be filled with useful objects to avoid the need for frequent scrolling of the page (Grasso & Roselli, 2005). There must be a function for alternative display of function. These can be shortcuts keys (Hashim, et al., 2010).

Feedback and Cancel Functions

Clear, simple suggestions must be given for the main objects, allowing the user to turn them on and off (Hashim, et al., 2010). Visual and sound feedback must be provided after user interactions with the objects. A user must be allowed to turn them on and off (Grasso & Roselli, 2005) and options for correcting mistakes made during navigation must be provided (Grasso & Roselli, 2005). User help for all applications both online and offline must be provided. Various kinds of help such as error messages, requests for confirmation of critical operations, warnings about lengthy operations and a return to the initial state in the case of errors must be made available in applications (Grasso & Roselli, 2005).

Interaction Modes and Content Modes

The contents must be adaptable and independent of the various interaction modes. Users must be free to choose how they want to interact with the application (Grasso & Roselli, 2005). The varieties of colours, bold type and italics must not cause confusion between links and static contents. The contents and image resolution must be reduced, but not so much as to make them incomprehensible. Images of appropriate quality must be used rather than filling the screen with tiny icons (Grasso & Roselli, 2005).

Eye tracking technology can be used to track users' eye movements as they perform tasks on an application. The data collected from eye tracking can give an insight into how users interact with applications and examine the effectiveness of content design. The scanning and reading patterns revealed by eye tracking can be used to redesign the content layout.

2.3.3 Mobile Learning Theories

Instructors and developers of educational materials need a solid theoretical foundation for mobile learning in the context of distance education and guidance about how to utilise emerging mobile technologies and integrate them into teaching more effectively (Park, 2011). There is a need for a theory of mobile learning to re-conceptualise learning for the mobile age and to recognise the role of mobility and communication in learning (Sharples, et al., 2005). The current mobile learning theories are listed below.

Behaviourist

Activities that promote learning as a change in learners' observable actions are encouraged. In educational technology, computer-aided learning is the presentation of a problem (stimulus) followed by the contribution on the part of the learner of the solution (response). Feedback from the system then provides the reinforcement (Naismith, et al., 2004). 'Classtalk' (Dufresne, et al., 1996) and 'Qwizdom' (Qwizdom, 2013) are examples of classroom response systems in a mobile learning context. BBC Bitesize is an initiative to provide revision materials via mobile phones using Java game and SMS text messages (Naismith, et al., 2004).

Constructivist

Learning is an active process in which learners actively construct new ideas or concepts based on both their previous and current knowledge. Learners are encouraged to be active constructors of knowledge, with mobile devices now embedding them in a realistic context at the same time as offering access to supporting tools (Naismith, et al., 2004). The most compelling examples of the implementation of constructivist principles with mobile technologies come from a brand of learning experience termed 'participatory simulations', where the learners themselves act out key parts in an immersive recreation of a dynamic system.

Situated Learning

Situated learning theorises that learning can be enhanced by ensuring that it takes place in an authentic context. Mobile devices are especially well suited to context-aware applications simply because they are available in different contexts, and so can draw on those contexts to enhance the learning activity.

The museum and gallery sector has been on the forefront of context-aware mobile computing by providing additional information about exhibits and displays based on the visitor's location within them. Examples of mobile systems that situate learning in authentic contexts include the Ambient Wood (Rogers, et al., 2002) and MOBlearn (Lonsdale, et al., 2003).

Collaborative

Learning through social interaction is promoted by mobile learning. Collaborative learning is based on the role of social interactions in the process of learning (Naismith, et al., 2004). The conversation theory describes learning in terms of conversations between different systems of knowledge (Zurita & Nussbaum, 2004). Mobile devices can support mobile computer supported collaborative learning by providing another means of coordination without attempting to replace any human-human interactions such as online discussion boards which substitute face-to-face discussions (Corlett, et al., 2004).

Informal and Lifelong

Mobile learning supports learning outside a dedicated learning environment and formal curriculum (GSMA mLearning, 2012). Informal and lifelong learning recognises that learning happens all the time and is influenced both by our environment and the particular situations we are faced with. Informal learning may be intentional, for example, through intensive, significant and deliberate learning 'projects' or it may be accidental, by acquiring information through newspapers, TV friends and family (GSMA mLearning, 2012).

This concludes the discussion of the educational aspects of the literature review. The next sections discuss the human visual system and eye tracking in e-learning. Eye tracking can be used to improve the functionalities of educational systems.

2.4 Eye Tracking

2.4.1 The Human Visual System

The human visual system consists of two functional parts, the eye and part of the brain. The brain is responsible for the image processing whilst the eye functions as the biological equivalent of a camera. What our eyes perceive as a scene is determined by the light rays emitted or reflected from a scene. Light rays send electrical signals to the brain through the optic nerve (Ted, 2001).

The external parts of the eye that are visible in the eye socket are the sclera (the white part of the eye), the iris (the colour part of the eye), and the pupil located in the centre of the iris. The cornea is a protective transparent membrane, void of blood vessels, which protrudes toward the front of the eye and covers the iris (Morimoto & Mimica, 2005). Figure 2.2 shows a cross section of the eye. Light enters the eye through the cornea, then subsequently through aqueous humour, the iris, the lens, the vitreous humour before striking the retina.

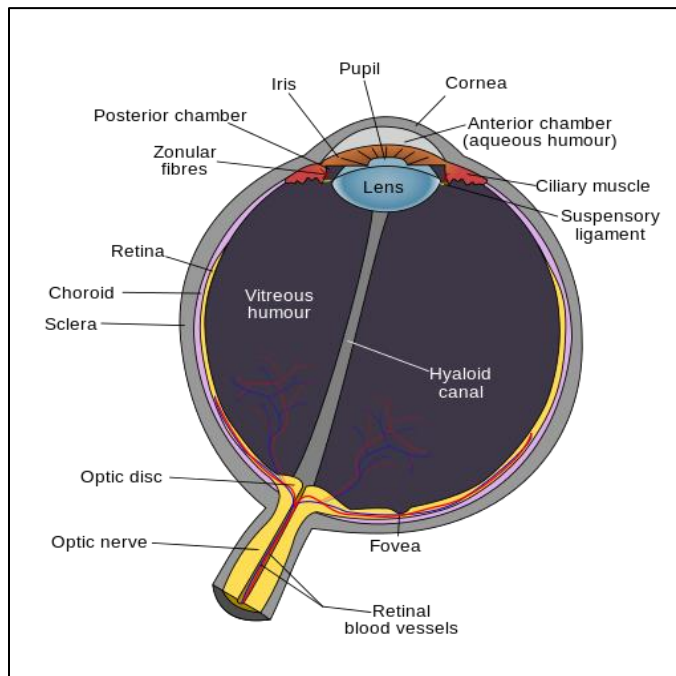


Figure 2.2: Schematic diagram of the human eye (Wikipedia, 2013)

The primary function of the cornea is to transmit and focus light into the eye (Willoughby, et al., 2010). The iris blocks excess light from entering the eye (Willoughby, et al., 2010). The pupil is located in the centre of the iris. It is for the entrance of light into the eye and changes size to control the amount of light into the eye (Hughes, n.d.).

The lens is located directly behind the iris and is used to focus light into the retina. The retina is light sensitive tissue that lies in the posterior segment of the eye and initiates processing of the image by

the brain. The photosensitive cells in the retina are known as rods and cones, and use the light to convert it into electrical signals that the optic nerve carries to the brain. The fovea is at the centre of the retina where the vision is most acute (Almeida, et al., 2011). During reading, when a fixated word is difficult to process, foveal attentional demands are high so that little attention is directed towards parafoveal words (Liversedge & Findlay, 2000).

Saccades are eye movements that reposition the fovea (Yang, et al., 2002). Fixations stabilise the fovea over an area of interest. They range in amplitude from the small movements made while reading, for example, to the much larger movements made while gazing around a room. Saccades are both voluntary and involuntary and last from 10-100 milliseconds.

They can be made voluntarily, but occur reflexively whenever the eyes are open, even when fixated on a target (Purves, et al., 2001). Saccades can also be made unconsciously. Saccadic eye movements are said to be ballistic because they are not

guided by sensory feedback. The saccade-generating system cannot respond to subsequent changes in the position of the target during the course of the eye movement. If the target moves again during this time, the saccade will miss the target, and a second saccade must be made to correct the error (Purves, et al., 2001).

Fixations often range between 200-300 milliseconds and are rarely shorter than 100 milliseconds (Cooper, et al., 2007; Cantoni, et al., 2012). Approximately 90% of viewing time is spent on fixations. During a fixation, the image is held approximately still on the retina; the eyes are never completely still, but always jitter using small movements called tremors or drifts (Cooper, et al., 2007). The trajectory between fixation points is generally called a scan path.

One of the major findings in eye movement reading research is that the information that is available on a single fixation is not limited to the currently fixated (foveal) word. Readers can acquire information from the upcoming parafoveal words before its subsequent fixation. Parafoveal review speeds up the reading time (Hand, et al., 2012). The perceptual span, the region of text from which useful information can be extracted is estimated to extend from three characters to the left of the fixation to around fourteen characters to the right of the fixation (Miellet, et al., 2009).

2.4.2 Definition of Eye Tracking

Eye tracking (Conati & Merten, 2007), is a process of electronically measuring the eye gaze or the position of the eyes. A device known as an eye tracker is used to measure the eye pupil positions, eye movement and provide detailed data about the users' visual attention on user interface elements (Manhartsberger & Zellhofer, 2005). In HCI, the analysis of eye movement data has been studied to evaluate usability issues and understand human performance (Conati & Merten, 2007). Table 2.5 shows the common eye tracking terms.

Table 2.5: Eye Tracking Terms

| <i>Term</i> | <i>Definition</i> |
|-------------------------------------|---|
| Eye tracking | It is a process of measuring eye gaze or eye movements |
| Fixation | A relatively stable eye in head position |
| Fixation duration | It is time taken by a person to fixate at a specific area of interest |
| Saccade | Rapid movements between fixations |
| Gaze duration | Cumulative duration of a series of consecutive fixations |
| Area of Interest | Area of a display or visual environment that is of interest to the research or design team and thus defined by them |
| Scan path | Spatial arrangement of a sequence of fixations |
| Gaze replay | Video presentation of a viewer's gaze path showing the scene seen by the viewer and the eye movements on that scene |
| Calibration | It is carried out before an eye tracking session. The eye tracker identifies the eye characteristics of an individual and uses them to estimate gaze point with high accuracy |
| Bright pupil eye tracking technique | Bright eye tracking technique is when an illuminator is placed close to the optical axis of the imaging device and causes the pupil to light up. |
| Dark pupil eye tracking technique | The dark pupil eye tracking technique is when the illuminator is placed away from the optical axis causing the pupil to appear black |

2.4.3 History of Eye Tracking

The study of eye tracking movements started as early as 1879 when Louis Émile Javal used a mirror on one side of a page to observe eye movements (Scherffig, 2005). He illustrated that our eyes do not move continuously along a line of text when reading, but make short movements, which he termed saccades. The first eye tracking devices that researchers built were invasive (Almeida, et al., 2011). The devices were in direct

contact with the cornea. Devices for tracking eye movements that were in direct contact with the eye included a blunt needle that was placed on a participant's upper eye lid, rubber balloons and eye caps. Slippage of these devices resulted in inaccuracy of test results. These devices caused discomfort for participants and participants could not read naturally. The first non-invasive equipment involving non-mechanical contact with the cornea was developed by Dodge and Cline in 1901 (Eachus, et al., 2008). The method involved reflecting a light from a cornea (Eachus, et al., 2008).

The advent of computer technology has enhanced the power of eye tracking equipment to record and process the huge volume of eye tracking data generated by eye movements (Eachus, et al., 2008). Eye tracking research in HCI has accelerated since the 1980s. Computer video screens and graphical user interfaces have enhanced eye tracking research (Eachus, et al., 2008). There have been technological advances with the internet, email, video conferencing and computer games consoles. Eye tracking helps answer questions about the usability of these complex interfaces (Almeida, et al., 2011; Eachus, et al., 2008).

2.4.4 Eye tracking Technologies and Application Areas

2.4.4.1 Eye tracking Technologies

Scleral Coil

The most accurate, but least user-friendly technology is the fixation of a sensor to the eye (Canessa, et al., 2012). The copper coil is embedded in a soft silicon annulus (Houben, et al., 2006). The subject wears a contact lens with two coils inserted. An alternate magnetic field allows the measurement of horizontal, vertical and torsional eye movements simultaneously.

The method is invasive but is still one of the most precise eye tracking systems. Due to their invasive nature, scleral search coils can only be used for a maximum duration of 30 to 60 minutes (Houben, et al., 2006). This technique can decrease the visual acuity, increase the intraocular pressure and has high risk of injuries (Canessa, et al., 2012).

Electro-oculography

This is one of the least expensive and simplest eye tracking technologies. The sensors are attached to the skin around the eyes to measure an electric field. The orientation of this field changes with the rotation of the eyes. The electrical changes are subsequently processed to relate them with the movements of the eyes. This obstructive method can only measure eye position relative to the head. In order to calculate the point of regard, a head tracker has to be used to measure the position of the head (Duchowski, 2007). The limitations of this technique is the contraction other than the eye muscles (like facial or neck) and eye blinking, that affect the electric potential related to eye movements (Canessa, et al., 2012).

Infrared Imaging

This is based on digital images of the front of the eye, acquired from a video camera and coupled with image processing and machine vision hardware and software. The visible and infrared spectrum imaging approaches are commonly used. It is also based on the geometric structure of the eye and on the tracking of its particular features: the pupil, the iris and the sclera. A benefit of infrared imaging is that the pupil, rather than the limbus, is the strongest feature contour in the image. Both the sclera and the iris strongly reflect infrared light while only the sclera strongly reflects visible light. Tracking the pupil contour is preferable given that the pupil contour is smaller and more sharply defined than the limbus. Furthermore, due to its size, the pupil is less likely to be occluded by the eyelids. The pupil and iris edge (or limbus) are the most used tracking features (Canessa, et al., 2012).

Optical Reflections

The camera based methods use optical features for measuring eye motion. Light, typically infrared (IR) is reflected from the eye and sensed by a video camera or some other specially designed optical sensor. The information is then analysed to extract eye rotation from changes in reflections. These are known as reflection based systems which include the photo-resistor measurement and the corneal reflection (Canessa, et al., 2012).

Corneal Reflection

The common technique used for measuring eye movement is the Pupil Centre Corneal Reflection (PCCR). A low power infrared light emitting diode (LED) mounted in the centre of a camera illuminates the eye causing visible reflections.

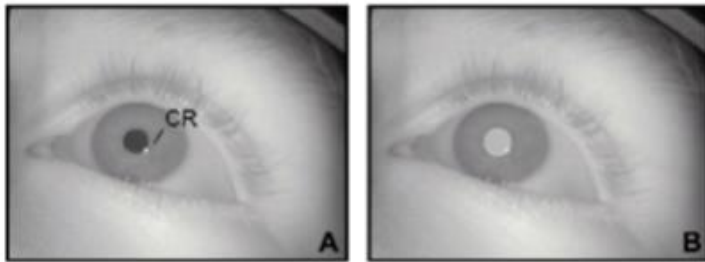


Figure 2.3: Sample eye showing the pupil and corneal reflections (glints). A) Dark pupil and corneal reflection. B) Bright pupil (Kowalik, 2011)

A camera or image sensors are used to capture the eye and these reflections (Canessa, et al., 2012; Kowalik, 2011). The image captured is used to identify the reflection of the light source on the cornea and on the pupil (see Figure 2.3). The vector formed by the angle between the cornea

and the pupil reflections, combined with other reflections is used to calculate the gaze point.

2.4.4.2 Eye Tracking Application Areas

Application areas of eye tracking include usability research and market research. User reaction to placement and variations of advertisements and products is eye tracked and analysed in order to design better products and advertisements (Morimoto & Mimica, 2005). In the automotive industry, eye tracking can be used to monitor driver fatigue or distraction. A controller triggers an alarm if the head position drops or if eyes close. In aviation, eye tracking can be used to monitor pilots' visual strategies, utilisation of information given by interfaces and the reaction time to take on information necessary up to the execution of a specific task. Eye movements can be tracked to detect neurological disorders while performing tasks like watching television. Eye tracking has been used to analyse games and film viewing. Assistive eye tracking technology which can be used to operate and control appliances by using eye movements is useful to

people with mobility impairments that are unable to control their body movement, speak, write, operate a computer or play video games.

2.4.5 Modern Eye Tracking

The two basic types of modern eye trackers used by researchers are the head mounted and the table mounted systems (Almeida, et al., 2011). Most of these systems use infrared light that is reflected from the cornea and the retina to obtain data on participants' eye movements (Cantoni, et al., 2012).

2.4.5.1 Head Mounted Eye Trackers

Head mounted eye trackers, as depicted in Figure 2.4, are worn by participants on the head. These portable eye trackers allow research to be conducted outside the laboratory. The headgear contains a camera and a video that record a participant's eye movements (Franchak, et al., 2010). Its infrared emitting diode allows for a dark pupil tracking approach.



1. SensoMotoric Instruments Eye Tracking Glasses
(SensoMotoric Instruments GmbH, 2013)



2. Tobii T120 Eye Tracker

Figure 2.4: Head and desk mounted eye trackers – Left: SensoMotoric Instruments Eye Tracking Glasses, Right: Tobii T120 Eye Tracker

Remote eye trackers estimate the point of regard on the screen whilst the head mounted eye trackers estimate the user's point of regard on the scene image (Mardanbegi & Hansen, 2011). Eye tracker glasses enable movements to be studied for real world activities such as in sports research, shopper research, usability research and many other scientific research areas (Tobii, 2012). Video-based eye tracker glasses include the *iView X HED* by SensoMotoric Instruments (see Figure 2.4), and *Mobile Eye* by Applied Science Laboratories (Vidal, et al., 2012). These systems are portable but require additional headgear and a laptop for video processing (Vidal, et al., 2012).

The Tobii Eye Tracker Glasses consist of a set of glasses and a small pocket-sized processing and data storage unit (Vidal, et al., 2012). The portable, mobile system is limited to eye movement recording at low frequency and only for up to one hour (Vidal, et al., 2012).

2.4.5.2 Desk Mounted Eye Trackers

Desk mounted eye trackers include the Tobii T120, Tobii X120 and the Eye Gaze 600 Series from LC Technologies. A desk mounted eye tracker, as the one seen in Figure 2.6, is integrated in the monitor and a participant sits in front of it. Desk mounted eye trackers limit the eye movement of a participant, restricting the participant to a localised area (Vertegaal, et al., 2006). A participant is given a specific task to undertake, such as reading from the computer screen. The eye tracker uses infrared light to monitor eye tracking and is invisible from the participant's perspective.

Modern eye trackers have software that provides calibration and analysis of test results. In the calibration procedure, a participant looks at calibration dots on the screen. The eye characteristics of the participant are captured and saved as a personal "profile", and can be re-used over an extensive period of time. The individual's eye characteristics are used to estimate the participant's gaze location on the screen during the eye tracking session. Areas of Interests (AOIs) are boxes of content that are defined to determine a user's attentiveness to them relative to other areas. Examples of statistics produced by an eye tracker on the AOIs include the number of fixations, fixation duration and number of mouse clicks. These statistics can be exported to statistics applications for analysis.

2.4.6 Eye tracking – Reading on Screen and Paper

Eye tracking studies of users when reading text on screen and on paper have been conducted in order to enhance online reading performance and comprehension. An e-learning system must be flexible, easy to navigate, consist of relevant content and have an appropriate layout design for its content (Ssemugabi & de Villiers, 2012).

In a study, participants were eye tracked while reading text in order to find out how typographical factors such as font type and font size affected their reading performance and comprehension. The fixation durations were longer for those who read text which was in smaller font sizes. Participants who read text in serif font took less time than those who read text in sans serif font (Beymer, et al., 2008). Manhartsberger and Zellhofer (2005) conducted an eye tracking study which revealed that participants scanned headlines in a web page on a screen. Participants took time to read normal text but spent less time reading headlines.

An experiment was conducted to find out how different text presentation modes on screen affect fixation duration, words read per minute, regressions etc. (Sharmin, et al., 2012). The presentation formats included a paragraph, sentences presented one by one, sentences presented in chunks of at most 30 characters and line by line presentation fitting the width of a computer screen. Participants read the most words per minute in a paragraph, followed by words in a sentence, words in a line and lastly words in chunks. The results showed that all the smaller units were associated with significantly longer average fixation duration and lower normalised fixation count than the relatively large units. It was more likely that smaller presentation units for the text brought ambiguity and, hence, the fixation duration increased for retrieval of the content's meaning.

On the other hand, larger sections of text represented clearer meaning of the context. The viewer could read the text without any interruption. Therefore, instead of paying great attention to any other place in the text, the reader pursued smooth reading with relatively short fixation duration. As a result, in automatic pacing, since the time for reading text in different formats was the same, a higher numbers of fixations appeared,

corresponding to shorter fixation durations. Regressions were observed more over chunks than with the paragraph format. Readers went back and forward often while reading chunks. On the other hand, the eyes followed a pattern of smooth reading with the paragraph format. Usually, people re-read more when there is ambiguity in the text (Sharmin, et al., 2012).

In a Norwegian school, a study that aimed to investigate the effect of technological interface on reading comprehension was conducted. Two groups of students read text on paper, while the other two groups read text in pdf format on computer screen. The findings showed that students who read on paper scored better than those who read text on screen (Mangen, et al., 2013).

Hefer (2013) eye tracked participants while reading short film subtitles in Afrikaans and in English. English was read faster by participants whose first language was Afrikaans and by those whose first language was English. Investigation on the navigation schemes and usability aspects of a web based Learning Management System (LMS), Moodle, was conducted through the use of an eye tracker. Navigation difficulties and elements that participants fixated on the screen were identified from the eye tracking results. Recommendations for improving its usability included the use of short sentences for difficult text, borders for text, use of enumerations for important points, use of pictures for interpretations and use of different colours for different semantic approaches (Rakoczi, 2010). The eye tracking patterns were used to redesign the user interface.

Siegenthaler, Wurtz, and Groner (2010) conducted an eye tracking study on the legibility and readability of paper and e-book readers. The results showed that the legibility of e-readers was comparable to that of paper books. Participants had the possibility of choosing the font size they liked. Older people chose a larger font size. E-readers, with the possibility of enabling users choose font size have better legibility than paper books (Siegenthaler, et al., 2010). However, the study showed that e-readers had usability problems. It was suggested that e-readers should have a more intuitive design with functions such as highlighting text, comment function and a fast search functions. The AdeLE (Adaptive e-learning with Eye Tracking) is a framework for adaptive e-

learning (Pivec, et al., 2006). It is a project developed by researchers at the University of Technology in Graz, Austria (Pivec, et al., 2006). The approach monitors user behaviour on a real-time eye tracking system for a more intensive research and improved understanding of cognitive processes (Pivec, et al., 2006). In an AdeLE-related study, forty students had to deal with texts of three difficulty levels under different conditions.

Eye movement parameters were applied to the data obtained from the study to understand user behaviour, that is, how a user searches for text, if the user skims through text, reads text once, reads text thoroughly, or just skips it (Pivec, et al., 2006). The results from the eye tracking data identified user behaviour and this was used for content adaptation. In order to personalise the content presentation, the learning style of a user must be identified (Pivec, et al., 2006). For example, in an e-learning course, a system may detect that a user is just skimming through the text. The system will consult the user if he or she already knows the details of the content. Depending on the answers provided to the system, the system may suggest to show abstracts from each chapter, content specific questions or suggest repeating the lecture (Pivec, et al., 2006).

Vergilino-Perez, et al. (2004) used eye tracking to record eye movements while participants were reading long words presented in isolation. The slope of the linear regression between first and second fixation positions was close to 1, which showed that the eyes were sent a particular distance further into the word, regardless of the initial fixation position. They concluded that the decision to refixate depends on both the length and frequency of a word.

Vergilino-Perez, et al. (2004) established that refixation saccades may be due to the correction of oculomotor errors caused by the eyes initially landing on a non-optimal position on the word. They argue that refixation saccades may also be due to cognitive processing difficulty during the first fixation. Low-frequency words are more often refixated than high-frequency words (Vergilino-Perez, et al., 2004).

Liu (2005) conducted a study on reading and discovered that screen based reading behaviour was characterised by more time on browsing and scanning, keyword

spotting, one-time reading, non-linear reading, and more reading selectively; while less time was spent on in-depth reading and concentrated reading.

2.4.7 Mobile Device Eye Tracking

Eye tracking of mobile devices can give invaluable insights into how users interact with mobile devices. Eye tracking has been difficult when testing the usability of handheld devices like smartphones, tablets and gaming devices. The handheld eye tracking set-ups allow limited hand and/or head movement. Set-ups using eye tracking monitors allow head movement, but have the handheld device attached to a fixed place, inhibiting natural handling and interaction, especially when the device is controlled using motion sensor (Heijden & Ginkel, 2011).



Figure 2.5: Mobile Device Eye Tracking SetUp - Tobii X120 Eye Tracker (Tobii Mobile, 2013)

Eye tracking can be done relatively easily on mobile devices using the Tobii X120 eye tracker together with the Mobile Device Stand (see Figure 2.5). The Mobile Device Stand is used to hold the X120 Eye Tracker upside down in a position which enables eye tracking during natural interaction with smart phones or tablet computers. The mobile

device is attached to Mobile Device Stand. A scene camera is adjusted to focus on the mobile device.

A study on reading interaction was conducted using the X120 eye tracker and mobile phones. Participants' touch and gaze data was recorded by the eye tracker while text on mobile devices. The participants' scrolling behaviour was identified. The results from the eye tracker indicated readers' preferred alignment of text (Biedert, et al., n.d.). Three types of readers were identified. These were full screen, line by line and block-wise

readers. The four full screen or page-wise readers read one page more or less completely and then scrolled so that the entire screen's content was replaced with new text. The next four readers who had line by line reading behaviour focused on a single or very few lines on the screen. They scrolled almost constantly to keep new information flowing into that preferred area. Ten readers, however, preferred mostly block-wise scrolling in which they changed only parts of the screen with each scrolling phase (Biedert, et al., n.d.). The average reading speeds of the participants ranged from 174 words per minute to 272 words per minute per session.

Computation of the estimated reading area for each participant was also done. Eye tracking studies of drivers having conversations on mobile devices while driving on the road have been conducted. An ASL 501 mobile eye-tracker which allows head movements was used to track participants' eye movements while driving. The study revealed that drivers' reactions were impaired when they spoke on mobile devices while driving (Strayer & Drews, 2007). The study also proved that in-vehicle conversations do not interfere with driving as much as mobile device conversations do.

According to Strayer and Drews (2007) drivers can synchronise the processing demands of driving with in-vehicle conversations than with mobile device conversations. In a separate study, a Tobii X120 eye tracker was used to analyse how young adults search for products on the web using smartphones. The results showed that the participants exhibited a top down viewing behaviour. Most of the participants looked at the first advertisement. The eye tracking results showed that the location of advertised items on a mobile phone had an impact on the amount of attention they received from the young adults (Djamasbi, et al., 2013).

In a study using a Tobii XL60 eye tracker, the participant's hands and handheld device were in a box. Users could see their hands and devices on an eye tracking monitor. Participants indicated that there was limited space due to playing the game using an iPhone with their hands and the handheld device inside the box. Participants had to look upward to the monitor and that caused them discomfort (Heijden & Ginkel, 2011).

Öquist and Lundin (2007) carried out an eye tracking study to identify the best text presentation format to use on a mobile device. They evaluated scrolling, paging, leading and rapid serial visual presentation in a repeated-measurement study. On mobile devices, scrolling is usually vertical and scroll bars are used to move from text to text. Paging presents text that is divided into pages that fit the screen. A joystick or arrow keys are used to move between pages. Leading scrolls the text horizontally on the screen at a speed that may be chosen by the user. Rapid Serial Visual Presentation presents text in chunks or few words at a time at a fixed location on the screen. The chunks are successively displayed at a pace that may be selected by a user.

The participants' eye movements were compared when reading on the different presentation formats. The reading speed, comprehension and task load were also compared when reading text presented in different formats. The results from the study showed that paging was the best format. Scrolling was found to be significantly slower than paging and leading. Leading was found to be efficient in terms of reading speed and comprehension.

2.4.8 Non-Eye Tracking Studies on Reading Text on Screen and Paper

In a Computer Based Instruction study (Morrison, et al., 1988), it was revealed that low density material was read faster, perceived as more efficient and selected more frequently than text presented in a high density format. Morrison, et al., (1988) also reports on another study where preferences for shorter sentences were noted. Complex sentences were split into single phrases. Morrison suggested that paragraphs be replaced with outline forms, sentences that summarise or amplify without giving new information be eliminated and information be presented in frames.

It is difficult to read dense text documents with no contrast and visual relief offered by graphics and careful page layout and typography (Krishnakumar & Jayakumar, 2011). Similar views were given by learners who favoured low density text. The students explained that low density text that provided sufficient contextual support reduced their reading time (Morrison, et al., 1989). However, a more recent study showed that some learners preferred middle to high density screens with actual lesson text (Ross, et al.,

1994). The explanations were that from an information-processing perspective, higher density screens tended to increase proximal contextual support for information by presenting main ideas and supporting explanations in the same frame (Ross, et al., 1994). The most commonly used fonts were compared for differences in reading effectiveness, reading time, perceptions of font legibility, font attractiveness, and general preference. After reading text on the screen, it was found that there were no significant differences in reading efficiency and between font types at any size.

Verdana was the most preferred font type, participants read it in the least time and it was perceived as being legible. The Times font type was the least preferred (Bernard, et al., 2002). Kolars, et al. (1981) compared two character densities: a line length of 70 characters containing characters of half the width of a line length of 35 characters (see Figure 2.6).

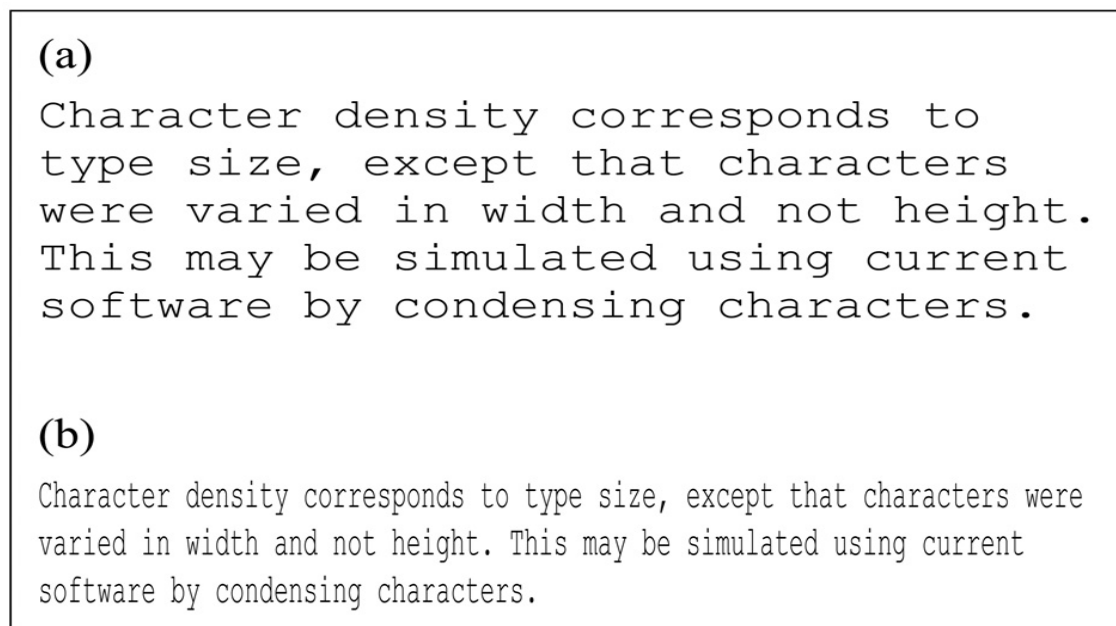


Figure 2.6: A simulation of different character densities used by Kolars et al. (1981).

Short extracts of about 300 words from Miller (1962), the Science of Mental Life, were read by twenty participants. Reading was found to be more efficient with the smaller characters, of which there were also more per line. The line with 70 characters per line had more fixations per line, but the total number of fixations was fewer. The number of

words acquired with each fixation was greater, the duration of each fixation longer and the overall reading time shorter.

The monospaced characters in Figure 2.6 (a) have a line length of about 35 characters; the characters in (b) are half the width and result in a line length of about 70 characters (Dyson & Kipping, 1997). An investigation into the effects of two reading speeds (normal and fast) and different line lengths on comprehension, reading rate and scrolling patterns was done. The results showed that a medium line length of 55 characters per line appears to support effective reading at normal and fast speeds. It was revealed that faster readers reading at their normal speed could recall more than slower readers. Very short and very long line lengths can slow down reading through disrupting the normal pattern of eye movements (Dyson & Haselgrove, 2001).

Proofreading performances on screen and paper using two different formats were compared. The two formats were the full screen display and a dual column display. The column display consisted of two vertical columns of text side by side. There were no differences in performance between twin-column and single-column presentation (Creed, et al., 1987).

A comparison of one and three columns was conducted by measuring the reading rate and comprehension (Dyson & Kipping, 1997). The text was displayed in 10 point Arial with 12 point interlinear spacing. Eighteen participants each read texts in three conditions: a single column (about 80 characters per line) with either scrolled or paged movement and a three column paged format (about 25 characters per column). Participants read the single paged column faster than the other two formats, with no differences in comprehension. However, it was found out that faster reading of the data was only found with the younger age group tested (18 – 24 year olds). Those older than 25 years showed no differences in the reading rate across the formats. Matthíasdóttir and Halldorsdottir (2007) discovered that students who were experienced computer users found it convenient to read books rather than electronic books. Students read faster on books than on screen.

Holzinger, et al. (2011) compared the use of a computer screen and paper for reading medical reports. Participants read diagnosis reports, and differences in reading speed and accuracy were investigated. No differences in reading speed when reading on paper or on screen were noted. There were also no significant differences in comprehension. They concluded that electronic screens match the visual quality of paper, and there are no differences in visual productivity between both media in real work settings. However, participants stated that paper was still their preferred reading medium.

2.5 E-learning Media Usability

E-learning media must integrate and embed usability, accessibility, cost, readability and legibility considerations.

2.5.1 Usability

Usability is a key issue in HCI as it is the aspect that is used to measure the quality of a user interface (Razzaq & Heffernan, 2008). The International Standards Organisation defines usability as: "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (25010:2011, 2013). Usability in learning is defined as the effectiveness, efficiency and satisfaction with which users can achieve specified learning goals in a particular environment or with a particular tool or learning resource (Cooper, et al., 2007).

According to Ssemugabi and De Villiers (2012), the evaluation of educational software should investigate its usability, interaction and website design, pedagogical effectiveness, learning content and how well users are supported during learning. Learning is classifying or categorising new knowledge and experiences (Siemens, 2006).

2.5.2 Accessibility of E-learning Systems

Accessibility is determined by the flexibility of the e-learning system to meet the needs and preferences of all users (Cooper, et al., 2007). E-learning makes it possible for

students to study with local and international institutions (Best, 2005) and provides institutions with continued permanent links with their students. E-learning may enable students to interact with instructors and other students through the use of discussion forums, blogs, emails, and other facilities (Cantoni, et al., 2004). Electronic media is accessible and flexible but students must have specific technological skills in order to use it (Best, 2005). Without the routine structures of a traditional class, students may miss deadlines (Blocher, et al., 2002). It is difficult for instructors to detect students' non-verbal immediacy behaviours, such as emotions, over the Internet (Marks, et al., 2005). It is essential that mobile websites that have e-learning material are always available and accessible.

It is important that the server which contains the learning materials is always up. E-books have more flexibility, accessibility and availability than paper books. Libraries have reached a critical mass in e-book numbers creating more access and usage opportunities (Jeong, 2012). The traditional paper based print media is familiar and accessible if learners are literate (Kizito, 2003).

Accessibility must include users with various forms of disabilities. These disabilities are sensory (for example, hearing and vision), motor (for example, limited use of hands) and cognitive impairments (Lazar, et al., 2004). Assistive technologies such as screen readers, voice recognition, pointing devices, alternate keyboards and refreshable Braille displays (Lazar, et al., 2004) can be used by disabled users. Web Content Accessibility Guidelines (WCAG) can be followed by developers in order to make their websites accessible to all people (Caldwell, et al., 2004).

Laabidi, et al., 2014 developed an e-learning system that provides people with disabilities with adaptive and personalised learning experiences that are tailored to their particular educational needs and personal characteristics. The MoodleAcc+ application is a version of the platform Moodle. In the application, if a visually impaired user selects his type of disability, the appropriate auditory components will be presented in his course, if a colour blind student selects his type of disability, colour images will be replaced by grey images in the presented course and Braille settings will be presented in the course for blind students.

Resources with a lower level of accessibility are less usable for individuals. Conversely, improved accessibility for disabled users promotes usability for all (Cooper, et al., 2007). Accessibility and usability, while distinct entities are interlinked and cannot be viewed or applied in isolation. An improvement in accessibility may not always result in an improvement in usability (Yates, 2005). It is sometimes a trade-off between the two.

Sites that are developed to meet accessibility standards are generally, but not always, usable due to the similarity between concepts shared by both accessibility and usability, such as the inclusion of appropriately contrasting colour schemes and the exclusion of non-browser compliant elements such as JavaScript on web pages (Yates, 2005). In instances where a site conforms to accessibility standards, the site may not be constructed in an intuitive fashion that is easy to navigate and, so, may not pass usability tests (Yates, 2005). Websites developed to conform to both usability and accessibility standards support the creation of web environments which perform their functions more effectively and provide an enhanced experience for the user (Yates, 2005).

2.5.3 Cost

E-learning is initially costly to launch, and converting the content requires special skills. Other costs include editing, reviewing and formatting the content for an electronic medium. The study material is uploaded on a server for online access and students do not have to attend classes. Classroom learning incurs costs such as overhead costs, and real estate costs. The number of students in a classroom is limited.

The production of paper learning materials is cheap (Kizito, 2003). Print media is generally suited for complex and semantically rich content (Merkt, et al., 2011). However, it is more expensive to update the content in paper based learning material than in electronic learning material. There are, thus, clear advantages to finding effective ways in which content-rich material can be designed for screen based delivery.

2.5.4 Readability

Pikulski (2002) defines readability as the level of ease or difficulty with which text material can be understood by a particular reader who is reading that text for a

particular purpose. In HCI, displays designed for visual information must consider visual comfort which is the ease with which information can be read from the screen (Zuffi, et al., 2007). In the opinion of Finnegan (2006), readability is the match of the reading skill and the reading level. Efficient readability requires good legibility of the displayed text. Legibility refers to the visual properties of a character or a symbol, determining the ease with which it can be recognised (Zuffi, et al., 2007).

An experiment was conducted to examine the effect of web-page text and background colour combination on readability, retention, aesthetics and behavioural intention. The findings were that colours with greater contrast ratio generally lead to greater readability (Hall and Hanna, 2004; Legge, Lubin and Luebker, 1987; as cited by Zuffi, Brambilla, Beretta and Scala, 2007).

Designers of e-learning materials must consider the effect of reading online, as online reading is different from book reading (Matthíasdóttir & Halldorsdottir, 2007). On the screen, sentences can fill the width of the monitor and are often too wide. Students who learn online require appropriate comprehension skills to master the content read. E-learning programs are mainly text based. Success in reading text is dependent on an individual's reading skills and prior knowledge (Al-Seghayer , 2007). Text that is easy to be read by someone may be very difficult for another person. Reading skill must equal or exceed readability to ensure comprehension and learning. Course designers must ensure that courses are constructed and delivered at an appropriate level for the target audience (Finnegan, 2006).

2.5.5 Legibility

Legibility refers to the visual properties of a character or a symbol determining the ease with which it can be recognised. Legibility is influenced by text dimension and text font. It is generally recognised that high luminance contrast between foreground and background colours enhances legibility (Zuffi, et al., 2007).

Nielsen (1999) mentions four ways that can make online content more legible. These are:

- i) Use high contrast background colours. Black on white background is the easiest to read.
- ii) Do not enhance your background with designs and textures.
- iii) Use reasonable fonts like Verdana and Times New Roman.
- iv) Use static text. Words that blink or move are very hard to read.

2.6 Conclusion

In the education sector, e-learning is increasingly being used for delivering educational materials. Eye tracking can be used to discover how the learning process occurs. The eye tracking results can be used to identify students' learning preferences, which can be used for content adaptation. The eye tracking technology assists designers of online study materials analyse eye movements of users and evaluate e-learning study materials.

The development of effective online learning materials should be based on learning theories. A combination of theories for developing online learning materials may be used. As research progresses, new theories that should be used in developing online materials are evolving. Learning theories influence the learning process. Mobile learning theories include situated, informal and lifelong learning. New technologies have the potential to transform learning. E-learning developers must integrate the new technologies in learning to enhance the quality of learning.

Study material designers must also consider the usability components when developing study materials. These are efficiency, memorability, satisfaction, learnability, error reduction and recovery. Efficiency is concerned with task completion in relation to user productivity, in particular time expended (Buchanan & Salako, 2009). Learnability refers to the capability of the system to enable users feel that they can productively use the system right away and quickly learn new functions (Buchanan & Salako, 2009).

Memorability is how easy it is to remember a system feature once learned and the effort required to reuse the system feature after not having used it for some time (Kotzé & Renaud, 2008). Satisfaction is the comfort and acceptability of the user-system interaction process, as well as the effects on other people affected by its use (Kotzé &

Renaud, 2008). Learners must be able to use the system with accuracy without making undue errors, and if errors are made, they should be able to recover from them with minimal disruption (Kotzé & Renaud, 2008).

CHAPTER 3

METHODOLOGY

3.1 Introduction

A methodology is a collection of goal-oriented, problem solving techniques governed by a set of principles, beliefs and procedures that prescribe what to do and how to do things (Mohan & Ahlemann, 2013). This chapter presents the research design and methodology employed to achieve the research objectives. Section 3.2 discusses the research purpose, experimental paradigm, research context and methods used in the study and limitations associated with those methods. Section 3.3 discusses the qualitative and quantitative methods used in the study. In this research, the emphasis was on the quantitative research, although some qualitative data collection and analysis were done for triangulation purposes. The hardware and software used for experiments are described in section 3.4. Section 3.5 discusses the limitations of the study. The next section 3.6 discusses the ethical procedures that were followed. The last section, 3.7 is the conclusion.

3.2 Research Design

A research design is the conceptual structure within which the research is conducted. It comprises of the blue print of collection, measurement and analysis of data. According to Durrheim (2002), a research design consists of the research purpose, paradigm, context and techniques.

3.2.1 Research purpose

The research purpose and research questions are the suggested starting points for developing a research design because they provide important clues about the substance that a researcher aims to access (Wahyuni, 2012). The purpose of this study was to compare the reading patterns of university students on three different platforms

(as identified below), using eye tracking. According to Durrheim (2002), the research purpose consists of the objects of the study and the research approach.

3.2.1.1 Objects of the study

The subject of investigation were students who were registered for the INF1520 module and their reading patterns on paper, computer screen and mobile device.

3.2.1.2 Research Approach

According to Durrheim (2002), the basic types of research are:

- a) exploratory, descriptive and explanatory research
- b) applied and basic research
- c) qualitative and quantitative research

Exploratory studies are used to make preliminary investigations into relatively unexplored areas of research. Descriptive studies describe phenomena accurately through narrative type descriptions, classification or measuring relationships. Explanatory research aims to understand phenomena by discovering and measuring causal relations (Durrheim, 2002). An important element of explanatory research is identifying and controlling variables in the research. A variable is a characteristic of a phenomenon that can be observed or measured. An independent variable is the variable that the experimenter manipulates to determine its effects on the dependent variable.

This research was exploratory and descriptive. The researcher explored the eye gaze pattern differences of students reading the same content on paper, computer screen and on mobile device. It gave detailed descriptions of students' reading patterns with the aid of eye tracking data. The research also sought and described guidelines that could be derived from the differences of the eye tracking patterns of students when they read the same content on the different platforms with respect to the design of online delivery of course content.

Basic research is conducted solely for the purpose of gathering information and building on existing knowledge. Applied research is designed to solve practical problems of a

society (Durrheim, 2002). The findings from applied research have a practical implementation within a society rather than just gaining knowledge. This research was applied as it analysed the differences of eye tracking patterns when reading on three different platforms with the ultimate aim to improve the quality of study material for ODL.

Quantitative researchers collect data in the form of numbers and use statistical types of data analysis. They collect data in the form of written, spoken language or observations and analyse the data by identifying and categorising themes (Amaratunga, et al., 2002; Durrheim, 2002). Qualitative researchers rely on their beliefs and a variety of understandings in describing, interpreting and explaining phenomena of interest (Warfield, 2005). Triangulation is the use of more than one method, mainly qualitative and quantitative methods in studying the same phenomenon for the purpose of increasing study credibility (Hussein, 2009). In this research, we used mainly quantitative methods to analyse the reading patterns of students, and some qualitative methods for triangulation purposes.

3.2.2 Paradigm

As Wahyuni (2012) states, a research paradigm is a set of fundamental assumptions and beliefs as to how the world is perceived, which then serves as a thinking framework that guides the behaviour of the researcher. Paradigms determine the methodology used in research and help researchers in the collection of data, analysis and interpretation of it.

Bhattacharjee (2012) notes that positivism, based on the works of French philosopher Auguste Comte (1798-1857), holds that science or knowledge creation should be restricted to what can be observed and measured. Positivists believe that different researchers observing the same factual problem will generate a similar result by using statistical tests and applying a similar research process (Wahyuni, 2012). The positivist approach has a strong tendency to produce applicable knowledge that is externally valid (Kim, 2003).

Interpretivists seek to understand values, beliefs and meanings of social phenomena thereby obtaining a deeper understanding of cultural activities and experiences of the

people they study (Kim, 2003 as cited by Smith and Heshusius, 1986). Knowledge is comprised of multiple sets of interpretations that are part of a context and researchers must understand the people they study and tactfully apply their conceptions of those being studied (Kim, 2003). Bhattacharjee (2012) states that within the interpretivist paradigm researchers study social order through the subjective interpretation of participants involved.

In this study, quantitative methods were employed to analyse eye tracking results obtained from the experiments and qualitative methods were used to enhance interpretation of the results, thus the study was based on both the positivist and the interpretivist paradigms.

3.2.3 Context

The researcher must define the environment and conditions under which the research will take place. The positivist research controls and manipulates the context of the research. The experimenters also manipulate certain aspects of the situation to determine if the participants' behaviour will be influenced by the manipulation. Qualitative researchers prefer a naturalistic enquiry that is non-obstructive and does not manipulate and control features of the research context (Durrheim, 2002). The researcher may not even be known to participants. Researchers consider if their physical presence will influence the behaviour of participants.

This research was conducted in the context of the University of South Africa (UNISA). South Africa is a developing country, with low literacy rates which impede knowledge and skills acquisition. UNISA offers courses through ODL, thereby enabling continued learning for people who cannot physically attend classes because of time or distance. South Africa is a multilingual society with a notable digital divide and UNISA considers the diversity of the people when designing study materials. This research aimed to enhance the readability of computer screen and mobile based e-learning material and, thereby, improve ODL.

The experiments were held in the usability laboratory at UNISA. This study environment was chosen as it was in Pretoria and the location of the laboratory was convenient for

most of the participants living in Johannesburg or Pretoria. All participants were students that had registered for the INF1520 module and were computer literate.

3.3 Research Techniques

This section describes the techniques used in the execution of the research. The discussion is split into three categories: sampling, data collection methods and analysis.

3.3.1 Sampling

Sampling is the selection of a subset of individuals to estimate the characteristics of the whole population. The logic of using a sample is to make inferences about some larger population from a small one (Berg, 2001). A sample is a representative subset of the target population (Kitchenham & Pfleeger, 2002). Sampling is used because data from every member of the population is impossible, too costly or impractical to collect. The size of a sample must be large enough to allow the researcher to make inferences about the population, but it also depends on the type of study conducted and on practical constraints (Durrheim, 2002).

Many alternative ways can be used to select a sample. These may be grouped into probability and non-probability techniques. Probability sampling involves random selection of elements in which each element has an equal chance of being selected. Probability sampling designs are used when the representativeness of the sample is of importance in the interest of wider generalisability (Zeepedia, 2013). When time, cost or other factors become critical, non-probability sampling is used.

In this research, convenience sampling, which is also called opportunity sampling, was used. It is the selection of participants from the population using non-random procedures. Convenience sampling is a non-probability sampling technique that involves obtaining responses from people who are available and willing to take part (Kitchenham & Pfleeger, 2002). Available and accessible students who were registered for the INF1520 module took part in the study. An invitation email was sent to all students that had registered for the module. The laboratory was at the University of

South Africa's main campus in Pretoria; hence only students who lived in Pretoria or Johannesburg were able to participate.

Participant Profile

Selecting participants is an important task in the research process. Participants are chosen based on the information that the researcher wants to obtain. The participants in this study were students that had registered for the INF1520 module for the first time and were therefore not yet familiar with the text content to be read during the eye tracking study.

A total of thirty participants took part in the study. Seventeen were male and thirteen were female. One participant was below the age of 20, eleven were between the ages of 21 and 25, eleven participants were between the ages of 26 and 3 and only one participant was aged between 30 and 40. Fifteen participants stated that they had average computer skills; thirteen reported they had high level computer skills and two stated that they had very high level computer skills. Almost all participants reported using computers and/or mobile devices for receiving and sending emails, downloading music and for communicating using Facebook and Twitter.

Twenty three of the participants reported reading university supplied printed material as one of their methods of study. One of the methods of study used by eight students was downloading and printing study material. Seventeen students stated that they downloaded study material to read on computer while six read downloaded educational material on mobile phone.

Twelve students mentioned that they read university supplied printed material and downloaded study material to read on computer. Six students reported that they read university supplied printed material and downloaded study material to read on mobile. Those that read university supplied printed material and downloaded study material to read on computer and on mobile phone were six. The participant profile is shown in Table 3.1. The list of the participants who took part in the experiments is shown in Appendix A.

Table 3.1: Participant Profile

| | Age (years) | | | | | | Computer Skills | | | | | Computer Use | | | | | Cell phone Use | | | | | Reading Method | | | |
|-----|-------------|----------------------------|-------|-------|-------|----------|-----------------|-----|---------|------|-----------|----------------------|---------------------|----------------|---------------------------|---------|----------------------|---------------------|----------------|---------------------------|---------|--------------------------------------|-----------------------------------|--|--|
| | Below 20 | 21-25 | 26-30 | 30-40 | 40-50 | Above 50 | Very Low | Low | Average | High | Very High | Receive, Send Emails | Online applications | Download music | Games, Facebook , twitter | myUnisa | Receive, Send Emails | Online applications | Download music | Games, Facebook , twitter | myUnisa | University Supplied printed material | Download study material and print | Download study material and read on computer | Download study material and read on mobile |
| M1 | | X | | | | | | | | X | | X | X | X | X | X | X | X | | X | | X | | | |
| M2 | | | | X | | | | | | X | | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| M3 | | | X | | | | | | | X | | X | X | | X | X | | | | | | X | | X | X |
| M4 | | X | | | | | | | X | | | X | X | X | X | X | X | X | | | | X | | | |
| M5 | | | | | X | | | | | X | | X | X | X | X | X | X | X | | X | | X | | | |
| M6 | X | | | | | | | | | X | | X | X | X | X | X | X | X | X | X | X | X | | X | |
| M7 | | | | X | | | | | | X | | X | X | | X | X | X | X | | X | X | | | X | |
| M8 | | X | | | | | | | X | | | X | X | X | X | X | X | X | | X | | X | X | X | X |
| M9 | | | X | | | | | | X | | | X | X | X | X | X | X | | | X | | X | X | X | X |
| M10 | | X | | | | | | | | X | | | X | | X | | | | | X | X | X | X | X | |
| P1 | | | X | | | | | | X | | | X | X | X | X | X | X | X | X | X | X | | | X | |
| P2 | | X | | | | | | | X | | | X | X | X | X | X | X | X | X | X | X | X | | | |
| P3 | | | X | | | | | | X | | | X | X | X | X | X | X | X | X | X | X | X | | | |
| P4 | | | X | | | | | | | | X | X | X | | | X | X | | X | X | X | | | X | |
| P5 | | | X | | | | | | | X | | X | X | | | X | X | X | | | X | | X | | |
| P6 | | | X | | | | | | X | | | X | X | X | X | X | X | X | X | X | X | X | | X | X |
| P7 | | | | X | | | | | | | X | X | X | | | X | X | | | | | X | | | |
| P8 | | | | X | | | | | | X | | X | X | X | X | | X | | | X | | X | | X | |
| P9 | | X | | | | | | | | X | | X | X | X | X | X | X | X | X | | | X | | X | |
| P10 | | | | X | | | | | | X | | X | X | X | X | X | X | X | X | X | | | | X | |
| S1 | | | | X | | | | | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| S2 | | X | | | | | | | X | | | X | X | X | X | X | X | X | X | X | X | X | | | |
| S3 | | X | | | | | | | X | | | X | X | | X | X | X | X | X | X | X | X | | | |
| S4 | | | X | | | | | | | X | | X | X | | X | X | X | X | | X | X | X | X | X | X |
| S5 | | X | | | | | | | X | | | X | X | X | X | X | X | X | X | X | X | X | | | |
| S6 | | | X | | | | | | X | | | X | X | X | | X | | | | | | X | | X | |
| S7 | | | X | | | | | | X | | | X | | | | | X | | | X | | X | | | |
| S8 | | | X | | | | | | X | | | X | X | | | X | X | X | X | X | | X | | | |
| S9 | | X | | | | | | | X | | | X | | | | X | | X | | | X | | X | | |
| S10 | | X | | | | | | | | X | | X | | X | | X | | | X | | X | | | X | |
| KEY | M* | Mobile device participants | | | | | | | | | | | | | | | | | | | | | | | |
| | P* | Paper participants | | | | | | | | | | | | | | | | | | | | | | | |
| | S* | Screen participants | | | | | | | | | | | | | | | | | | | | | | | |

3.3.2 Data Collection Methods

The use of various data collection methods and triangulation is critical in obtaining in-depth understanding of a phenomenon. Data collection methods used in this study included eye tracking experiments, observation, and questionnaires.

3.3.2.1 Experiment Design

i) Introduction

The main method for collecting data was through eye tracking. Eye tracking is a technique that measures the location and the sequence of eye movements. An eye tracker is a device that records eye movements and eye fixations. As was discussed in subsection 2.4.1, eye tracking has been studied to evaluate usability issues and understand human performance (Conati & Merten, 2007). This method was used to record participants reading on paper, screen and on a mobile device.

Eye movements can be divided into fixations and saccades. Fixations are low-velocity eye movements that correspond with an individual staring at a point (Wei, et al., 2009). Saccades are rapid eye movements occurring between fixations (Manhartsberger & Zellhofer, 2005). In this research, we used the fixation points and the sequences of the points to determine the linearity of the saccades. The differences of fixation points were used to calculate the saccade lengths. The time taken to read text was the total of all the saccades' duration.

ii) Advantages of Eye Tracking

Eye tracking is less obstructive than the think aloud protocol. The eye gaze is a very good indicator of visual attention (Lucassen & Schraagen, 2011). Eye tracking measures conscious and unconscious behaviour and provides quantitative data about a participant's cognitive processes (Eger, et al., 2007). A major validity problem using conventional usability methods arises when testing subjects in an artificial environment such as a usability laboratory. Subjects are aware of the test situation and may provide wrong data. Self-report measurements, like thinking aloud protocols or questionnaires may produce biased data. Eye tracking reveals higher validity in data compared to the conventional methods (Sciessl, et al., 2003).

iii) Drawbacks of Eye Tracking

The eye tracking systems require extensive calibration procedures to ensure accurate results. The use of the eye tracking apparatus is time-consuming. The software and equipment are relatively expensive. Some participants cannot be tested if they have long lashes, wear lenses or eye glasses (Ross, 2009; Janes, 2009). Therefore the number that eventually gets tested is smaller than the number that could be tested using other methods.

iv) Eye Tracking in this Study

Participants were required to read a section of the INF1520 study guide that dealt with graphical user interfaces. There were three groups of participants. The first group was assessed while reading the text on paper. The second group was assessed while reading on a computer screen. The third group was eye tracked while reading the text on a mobile device.

The text read by participants was an extract from the INF1520 study guide and was one page in length. The page consisted of nine paragraphs. The total number of words in the page was 429. All the nine paragraphs were defined as Areas of Interests (AOIs). Statistics was produced by the eye tracking software on the AOIs. The researcher chose the graphical user interfaces topic which consisted of factual and informational text from which participants could answer a number of content questions afterwards. The text read by participants is shown in Figure 3.1.

4.1 Introduction

In this unit we discuss a small selection of topics that are associated with interaction design. INF3720 – the third level module on HCI – covers the topic of interaction design in detail. Here we look at the following:

- the different forms that interfaces of interactive systems can take,
- some specific interaction design techniques
- an overview of the evaluation of interactive systems.

4.2 Interface Types

Preece et al. (2007) give an overview of the different types of interfaces. Following Preece et al., we provide a brief description of eleven of these.

4.2.1 Advanced Graphical Interfaces

The term graphical user interface (GUI) refers to any interactive system that uses pictures or images to communicate information. This is an extremely wide definition. It includes keyboard-based systems that only use graphics to present data. It also includes walk-up and use systems where users only interact by selecting portions of a graphical image.

The strength of GUIs is the way they support interaction in terms of (Shneiderman, 1998):

- **Visibility:** Graphical displays can be used to represent complex relationships in data sets that would not, otherwise, have been apparent. This use of graphics is illustrated by the bar charts and graphs that were introduced in the section on requirements elicitation.
- **Cross-cultural communication:** It is important that designers exploit the greatest common denominators when developing interaction techniques. Text-based interfaces have severe limitations in a world market. Graphical interaction techniques are not so limited. In particular, ISO standards for common icons provide an international graphics language ('lingua franca').
- **Impact and animation:** Graphical images have a greater intuitive appeal than text-based interfaces, especially if they are animated. The use of such techniques may be beneficial in terms of the quality and quantity of information conveyed. It may also be beneficial in improving user reactions to the system itself.

Some weaknesses of GUIs are:

- **Clutter:** There is a tendency to clutter graphical displays with a vast array of symbols and colours. This creates perceptual problems and makes it difficult for users to extract the necessary information. Graphical images should be used with care and discretion if people are to understand the meanings associated with the symbols and pictures.
- **Ambiguity:** Graphical user interfaces depend upon users being able to associate some semantic information with the image. In other words, they have to know the meaning of the image. From our earlier discussion, they have to interpret the mappings. A user's ability to do this is affected by their expertise and the context in which they find the icon.
- **Imprecision:** There are some contexts in which graphical user interfaces simply cannot convey enough

Figure 3.1: Page read by participants

The researcher first introduced herself, thanked the participants for their attendance and explained to them what the research was about. Participants completed the consent forms and the pre-test questionnaires. The pre-test questionnaires were designed to collect participants' profile data and consisted of closed questions, see Appendix E. The researcher briefly explained the function of the eye tracker and the eye tracking process. After the eye tracking session, the participants answered questions on the questionnaire. Appendix F shows the comprehension questions that were answered by one of the participants.

Set-up for the three platforms

The specific set-up for the three platforms was as follows:

i) Reading Text on Mobile Device

The Tobii X120 consists of the X120 eye tracker and a mobile device stand (see Figures 2.5 and 3.2). The eye tracker is optimised to track eye movements from below. Therefore, it must be positioned below the stimulus that is to be studied. If the eye tracker is placed below a mobile device, the participant's hand would obstruct the eye tracker's field of view while interacting with the mobile device. Therefore, in this study, the eye tracker was placed above the mobile device in an upside down position (Tobii, 2012). The chair that participants sat on was height-adjustable to accommodate different participants' heights and ensure that the stimulus and the participant's eyes were at the same level.

The mobile device, an iPad2, was attached to the mobile eye tracker's stand with sticky tape. A scene camera, attached to a flexible arm protruding from the device stand was adjusted in different ways for different participants to avoid obstruction when reading. During calibration, participants were requested to focus on calibration points in the consecutive order specified by the numbers on the calibration plate. Participants had to scroll vertically when reading from the mobile device since the whole page could not be displayed because of the small size of the screen.



Figure 3.2: Tobii X120 and iPad

The Tobii Mobile Device Stand mounts the eye tracker, mobile device and scene camera. Participants can rotate the device holder between portrait and landscape modes during testing. The setup also allows for freehand movement testing. Instead of mounting the device, the participant may hold the mobile device in his hand and lean it against the setups' surface. The scene-camera is flexible and can be mounted on either side of the stand (Tobii Mobile, 2013).

ii) Reading Text on the Computer Screen

In this case, the T120 eye tracker was used for eye tracking. The T120 eye tracker has an integrated monitor and camera and, therefore, enables on-screen eye tracking, which made the eye tracking set up easy (see Figure 3.3). Calibration involved the participant's eyes following a red dot to specific points on the screen. The main task was for participants to read the text on a page of the study guide which was displayed on the eye tracker monitor.



Figure 3.3: Reading text on Tobii T120 eye tracker (*Included with the permission from the subject*)

iii) Reading Text on Paper

The X120 eye tracker was also used to track students reading on paper. The set-up was almost identical to the mobile device set-up, except that a study guide was used instead of the iPad. Also, it was placed on the table instead of on the mobile device stand so that participants could read naturally. The scene camera was adjusted to focus on the study guide placed below the eye tracker. After the calibration, participants read a single page from the study guide.

3.3.2.2 Observations and Video Recordings

i) Introduction

Observation, an ethnographic research method, is viewed as an ancient method of “collecting data first-hand” (Baker, 2006). It is stated that Aristotle used observational

techniques in his botanical studies on the island of Lesbos and that Charles Darwin used observations of animal and marine life at the Galapagos Islands to help him formulate his theory of evolution that he describes in *On the Origin of Species* (Baker, 2006; Driscoll, 2010).

ii) Types of Observation

Observation is used as a research method in two distinct ways – structured and unstructured. In positivistic research *structured observation* is a discrete activity whose purpose is to record physical and verbal behaviour. Its schedules are predetermined using taxonomies developed from known theory. In contrast, *unstructured observation* is used to understand and interpret cultural behaviour. Observers using unstructured methods usually begin the observation with no predetermined notions as to the discrete behaviours that they might observe. The observers may have some ideas as to what to observe, but these may change over time as they gather data and gain experience in the particular setting (Mulhall, 2002).

In an unstructured observation the researcher may adopt a number of roles from complete participant to complete observer, whereas in structured observation the intention is always to 'stand apart' from that which is being observed. These two different stances reflect the two paradigms through which these methods arise. 'Structured observers' are attempting to remain objective and not contaminate the data with their own preconceptions, whereas 'unstructured observers' carrying with them the tenets of the naturalistic paradigm would contend that it is impossible to separate researcher from 'researched'. Pretzlik (1994) claims that the two types of observation may be used in the same study.

iii) Advantages of Observation

Participant observation is one of the qualitative methods that provide a deeper understanding of social phenomena than data obtained from purely quantitative methods. The information obtained from observation must not be influenced by past behaviour, future intentions or attitudes of participants.

One of the advantages of the video recordings is permanence. One can play, pause and restart the video recordings and, thereby, gain a level of understanding which is not possible during real-time observation (Haidet, et al., 2009). Observation also captures the whole social setting in which people function, by recording the context in which they work. It is also valuable because it informs about the influence of the physical environment (Mulhall, 2002). A disadvantage is that video analysis is time consuming and, therefore, cannot be performed on large samples. Researcher bias may result in selective observation, selective recording of information, or the subjective interpretation of situations (Baker, 2006). Therefore, the observer must address the issue of validity and reliability in observation.

iv) Observation in this Study

In this research, video recordings were made while the participants were reading the text on different platforms. The behaviour and activities of participants while reading text were observed from the gaze replay.

3.3.2.3 Questionnaires

i) Introduction

A questionnaire or survey (Vitale, et al., 2008; Kaptein & Avelino, 2005) is a highly structured data collection technique designed to extract information from respondents (Antony & Antony, 2006). The objective is to translate the researcher's information requirements into a set of specific questions that respondents are willing and able to answer. Combining closed-ended and open-ended questionnaires is a mixed methods research that has gained popularity due to its potential to capture the benefits of both quantitative and qualitative data collection and analysis at a relatively low cost to the researcher (Erickson & Kaplan, 2000).

ii) Advantages of Questionnaires

According to Kaptein and Avelino (2005), the main advantages of questionnaires are;

- Efficiency. A questionnaire is an economical and a quick method of collecting information and well suited for extracting information from larger groups of people.

- Confidentiality. Respondents provide reliable information only if they are confident that the information they divulge will not later be used against them. A questionnaire can guarantee anonymity.
- Comparability. Quantitative data generated by a questionnaire can easily be compared with data from other groups of respondents where the same questionnaire has been used.

iii) Use of Questionnaires in this Study

Questionnaires, shown in Appendix E, were used in this study to collect data. Pre-test questionnaires were designed to collect the participants' profile data. These were composed of closed questions. The post-test questionnaire consisted of open-ended questions based on the content of the text read. These were intended to examine the participants' comprehension after reading the text content.

The advantage of the questionnaires was that participants could read the questions more than once before answering them. However, some participants could not understand questions from the questionnaire and expected explanations from the researcher.

3.3.3 Data Analysis

Data analysis is the process of applying statistical or logical techniques to describe, illustrate and evaluate data. Both quantitative and qualitative methods were used in this study.

3.3.3.1 Quantitative Data Analysis

Quantitative data is analysed using statistical procedures. Statistics involves the gathering and evaluation of numerical data for making inferences from the data. According to Durrheim (2002), the stages of quantitative data analysis are data preparation, coding data, entering data and cleaning data (see Figure 3.4).

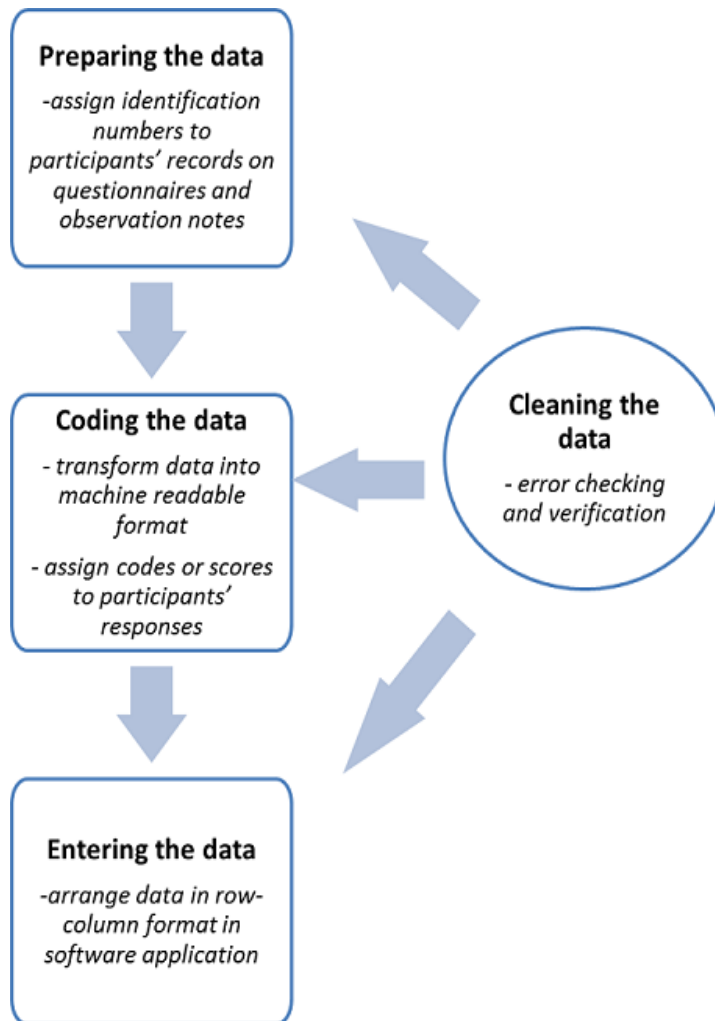


Figure 3.4: Steps in quantitative data analysis

Steps in quantitative data analysis

Step 1: Preparing the Data

Quantitative data are the raw materials of research and consist of lists of numbers that represent scores on variables (Durrheim, 2002). The data is obtained through measurement. Raw data is unordered, contains errors and missing values and must be processed and transformed into machine-readable format. In this research, raw data sources included the pre-test, post-test questionnaires and eye tracking data exported from Tobii Studio™.

Step 2: Coding the Data

A set of rules is applied to the data to transform it from one form to another. Information from a questionnaire is transformed into meaningful format that can be read by a computer. Items from the questionnaire used in the study were transformed into numbers. For example, the low computer skill was given a score of 1, average skill a score of 2 and high skill, a score of 3. After reading text, participants answered comprehension questions from the post-test questionnaires. The responses were assigned scores depending on their accuracy. The scores of all the items were added together to give a summed score for each questionnaire (Durrheim, 2002). Summed scores provided a reliable measure of an individual's performance from a questionnaire.

Step 3: Entering the data

Numerical data from the questionnaire must then be input into a computer application in a format that can be interpreted by a statistical computer package. In this study, data for each subject was entered in a computer application in rows and columns to represent scores on specific variables (Durrheim, 2002). Labels entered into the computer were the same as those on the questionnaires. This enabled the researcher to refer back to the original questionnaire when checking for data input errors. The Tobii Studio™ manual was used to understand the meanings of column headings in the statistics file exported into Microsoft Excel®.

Step 4: Cleaning the data

Cleaning the data involves checking and correcting errors in data. This must be done before statistical analysis can be performed. In this study, the researcher selected a random sample of 10% of cases and checked if the data was entered correctly. Data was re-entered for a few cases that had errors. The researcher checked columns for invalid codes and corrected them. Incorrect computer functions were also corrected, for example, if the variance function was used instead of the standard deviation function.

Statistical data analysis

After the data has been cleaned and is in a machine-readable format, it may be analysed statistically. There are two main types of data analysis: descriptive analysis and inferential analysis.

Descriptive Analysis

Data analysis begins with the calculation of descriptive statistics for the research variables. This is a summary of various aspects about the data that gives details about the sample and provides information about the population from which the sample was drawn (Larson, 2006). Frequency statistics are the main descriptive statistics used with discrete variables. These include counts, proportions of the total number of observations and cumulative frequencies for successive categories of ordinal variables (Larson, 2006). Descriptive statistics for continuous variables fall into three categories: location statistics, dispersion statistics and shape statistics.

Location statistics include the mean, median and mode. Dispersion statistics include the standard deviation, range and variance. Shape statistics examples are skewedness and kurtosis (Larson, 2006). In this study, calculations included the mean, range, variance and standard deviation of fixation duration and saccade length on different platforms. The total, average and variance of comprehension scores for three groups of participants were calculated. These groups were participants that read text content on a mobile device, participants that read text on computer screen and those that read text on paper.

Inferential Data Analysis

Inferential statistics are used to draw conclusions about populations on the basis of data obtained from samples. Inferential statistics can be used to estimate population parameters and to test hypotheses. It can be split into parametric and non-parametric tests. Non parametric techniques focus on the order or ranking of scores and ignore the numerical properties of numbers at interval and ration scales (Terre Blanche & Durrheim, 2002).

An example of non-parametric tests for the measure of central tendency is the median, which is the score in the middle of a ranked data set. The mean is a parametric estimate of central tendency because it takes the numerical value of scores into consideration by using mathematical operations. Inferential tests used in this study included the Analysis of Variance (ANOVA), which was used to test if the differences of saccade length and

linearity, fixation duration and fixation count for the three groups of participants was dependable or might have happened by chance (Durrheim, 2002).

3.3.3.2 Qualitative Data Analysis

Qualitative research does not seek to quantify data (Pope, et al., 2000). Qualitative data is descriptive, appearing mostly in conversational or narrative form (Terre Blanche & Kelly, 2002). It can also come in observations of a person's behaviour.

Data

The eye tracking software produced three different visualisations of eye tracking data (gaze replay, heat map and gaze plot). The researcher used the gaze replay to observe how participants read text on the different platforms. The eye trackers recorded the eye gaze as it moved along in the scene seen by the participant. The movement of the gaze in the scene was indicated by a gaze cursor.

Steps in Qualitative Data Analysis

Step 1: Familiarisation and Immersion

Immersion usually involves repeated reading of the data in an active way – searching for meanings and patterns (Braun & Clarke, 2006). It is important for the researcher to know the data well enough to know its content and the type of interpretations that the data can support (Terre Blanche & Kelly, 2002). In this study, the researcher watched the gaze replay and made notes in preparation for the formal analysis.

Step 2: Inducing Themes

A theme is created when similar issues and ideas expressed by participants are brought together by the researcher into one category (Terre Blanche & Kelly, 2002). When generating themes, the researcher must think in terms of processes, functions, tensions and contradictions and must have a reasonable number of themes that may have sub-themes under each. The researcher must try different types of themes before settling for the final ones but must not lose focus of what the study is about and most of the themes should relate directly that.

In this study, the researcher identified themes after watching the gaze replays. Examples of theme labels were, 'how do the eye tracking patterns differ when participants read the same content on paper and on a computer screen' and 'on which platform were the most regressions'.

Step 3: Coding

Coding, also known as indexing, is marking different sections of the data as being instances of, or relevant to, one or more themes (Terre Blanche & Kelly, 2002). The researcher might code a phrase, a line, a sentence or a paragraph that pertains to the themes under consideration. Coding can be done manually or through a software programme (Braun & Clarke, 2006). In this research, data was broken down into labelled, meaningful pieces and grouped under the theme labels in a spreadsheet.

Step 4: Elaboration

Elaboration is exploring the newly organised material to identify similarities and differences in the data that may lead to new insights (Terre Blanche & Kelly, 2002). In this study, the researcher observed differences and similarities when reading on different platforms. The researcher watched the movement of the cursor in the gaze replay videos.

Step 5: Interpretation and Checking

Checking and fixing the final interpretation must be carried out. A researcher's role in the study must be reflected. The researcher's personal involvement might influence the collection of data and interpretation. The researcher's previous experiences in what might have influenced the interpretation of the gaze such as reading, data collection and analysis replays.

Synthesis and making sense of the data entail exploring relationships between categories, looking for patterns and relationships and mapping the interpretations to the findings (Wong, 2008). The qualitative data analysis process is shown in Figure 3.5. In this study, the researcher had to confine to the research findings and not use a speculative approach to the participants' responses. Contradictions, over-interpretation and irrelevant data were checked for correction.

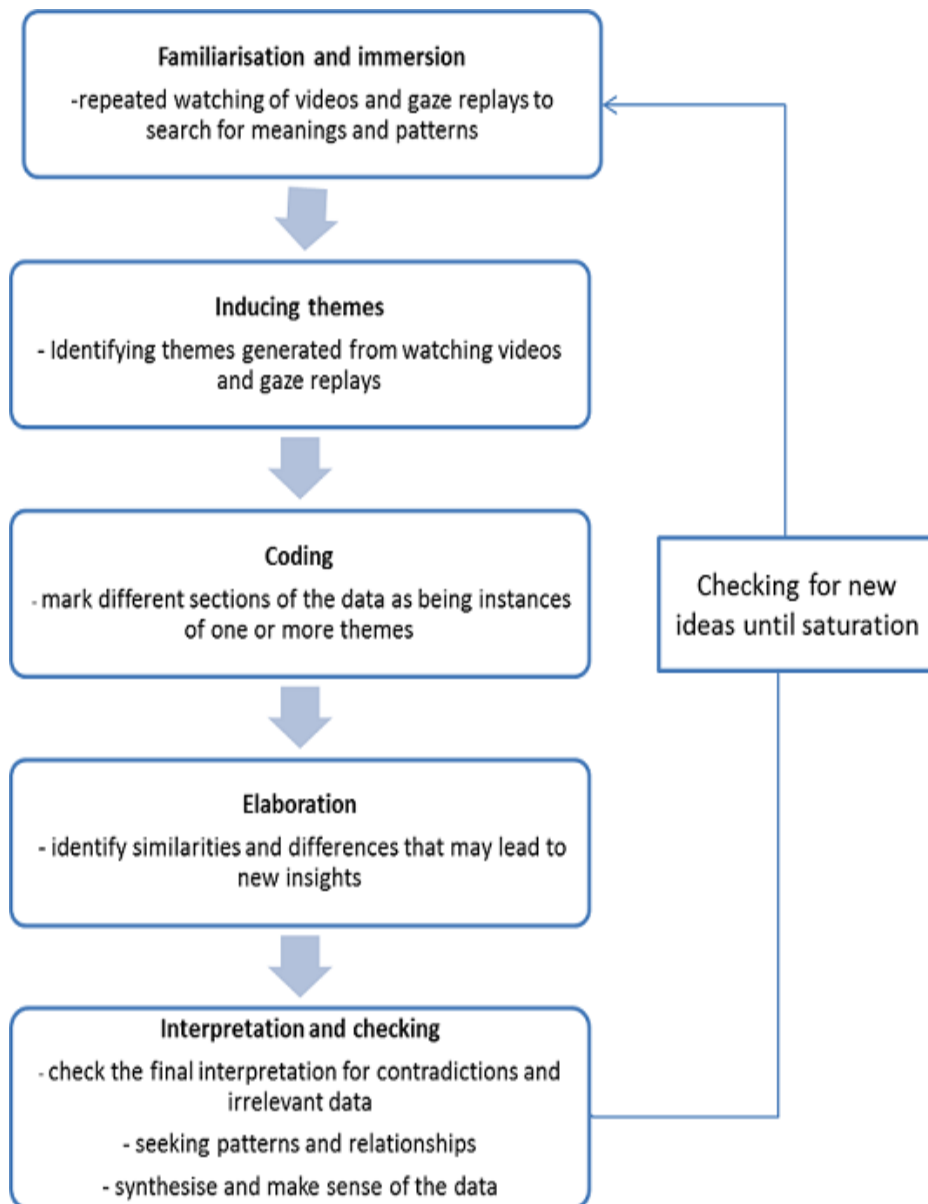


Figure 3.5: Qualitative data analysis process

3.4 Research Instruments

3.4.1 Eye Tracking Equipment

Eye Tracking Hardware

Two different types of Tobii eye trackers were used for this study. The Tobii T120 eye tracker was used to record how participants studied on computer screen while the Tobii X120 eye tracker was used for the eye tracking of participants reading on paper and on

mobile devices. Both eye trackers have an accuracy of 0.5 degrees, a drift that is less than 0.3 degrees, sampling frequency of either 60 or 120 Hz and use infrared diodes to generate patterns on a participant's eyes. The frame rate of 120Hz provides twice as many data points and is more precise.

These reflection patterns and other visual data are collected by image sensors (Tobii, 2012). Complex mathematics is used to calculate the position of the participant's eye ball and finally the gaze point on the screen (Tobii, 2012). The Tobii T120 eye tracker is integrated in a 17-inch TFT monitor and designed for all types of eye tracking studies where the stimuli can be presented on the monitor, from packaging to advertisements to reading text (Tobii, 2012). Figure 3.3 shows a picture taken of a participant reading on a T120 eye tracker.

Eye trackers need to be calibrated in order to map the participant's eyes to a position in screen space. During calibration, both bright and dark pupil techniques are used and the most suitable one is chosen automatically. These techniques are used to determine the eye position. The bright pupil eye tracking technique is when an illuminator is placed close to the optical axis of the imaging device and causes the pupil to light up. The dark pupil eye tracking technique is when the illuminator is placed away from the optical axis causing the pupil to appear black (Tobii, 2012).

The Tobii X120 eye tracker, a stand-alone eye tracker, requires an external monitor and is used for eye tracking studies relative to any surface. It allows head movements and provides a distraction-free test environment (Tobii, 2012). Mobile devices are smaller than computer screens and are usually held close to the participant during interaction, making observation difficult. Special equipment is needed to capture the screens and keys of mobile devices. The Tobii X120 eye tracker can be used with a mobile device stand for the eye tracking of mobile devices (Biedert, et al., n.d.).

Eye Tracking Software

Tobii Studio™ allows researchers to record and analyse eye tracking tests. Eye tracking sessions can be observed in real time. The recordings can be replayed. Graphical visualisations, for example, heat maps and gaze plots are created. These provide a tool

for qualitative analysis and presentation. The software supports the calculation of key eye tracking metrics in addition to tables and graphs to enable quantitative analysis and interpretation as well as display of results. In order to calculate any eye tracking metric, Areas of Interest (AOIs) must be defined. All the metrics in Tobii Studio™ rely on AOIs. Raw eye tracking data for all participants can be exported to text, spreadsheet or to an analysis application. In this study, the researcher exported statistical data to Microsoft Excel® (see Figure 3.6).

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|----|------------|--------|------------------------|----------------|------------|----------------|----------------|------------|------------|--------------|--------------|--------------|---------------|
| | ExportDate | Studio | StudioProjectNa | FixationFilter | GazeEventD | FixationPointX | FixationPointY | GazePointX | GazePointY | EyePosRightY | EyePosRightZ | ValidityLeft | ValidityRight |
| 2 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 1149 | 466 | 222 | 126 | 266 | 191.54 | 417.25 | 0 | 0 |
| 3 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 366 | 501 | 225 | 22 | 252 | 194.67 | 424.06 | 0 | 0 |
| 4 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 716 | 132 | 248 | 493 | 252 | 193.67 | 421.36 | 0 | 0 |
| 5 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 916 | 197 | 248 | 448 | 243 | 194.29 | 420.11 | 0 | 0 |
| 6 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 466 | 258 | 244 | 349 | 237 | 194.52 | 420.35 | 0 | 0 |
| 7 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 233 | 313 | 241 | 289 | 240 | 193.82 | 420.70 | 0 | 0 |
| 8 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 167 | 352 | 203 | 249 | 274 | 191.95 | 420.52 | 0 | 0 |
| 9 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 983 | 380 | 237 | 222 | 226 | 192.28 | 421.80 | 0 | 0 |
| 10 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 133 | 434 | 236 | 139 | 236 | 192.29 | 422.14 | 0 | 0 |
| 11 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 366 | 387 | 237 | 188 | 255 | 192.40 | 422.24 | 3 | 1 |
| 12 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 550 | 429 | 240 | 131 | 253 | 192.52 | 422.08 | 0 | 0 |
| 13 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 1366 | 473 | 232 | 106 | 250 | 192.66 | 422.33 | 0 | 0 |
| 14 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 167 | 539 | 231 | 13 | 245 | 193.43 | 424.26 | 0 | 0 |
| 15 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 333 | 137 | 252 | 470 | 212 | 193.45 | 424.93 | 0 | 0 |
| 16 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 217 | 164 | 229 | 527 | 243 | 191.97 | 427.06 | 4 | 0 |
| 17 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 1033 | 201 | 247 | 417 | 240 | 188.66 | 435.96 | 0 | 0 |
| 18 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 683 | 250 | 247 | 368 | 212 | 195.89 | 411.86 | 0 | 0 |
| 19 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 600 | 310 | 247 | 290 | 222 | 194.79 | 405.56 | 0 | 0 |
| 20 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 183 | 368 | 245 | 225 | 230 | 191.52 | 401.50 | 0 | 0 |
| 21 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 300 | 337 | 247 | 255 | 218 | 191.96 | 401.78 | 0 | 0 |
| 22 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 267 | 294 | 247 | 313 | 254 | 192.34 | 401.38 | 0 | 0 |
| 23 | 2013/04/16 | 3.1.2 | Mobile Devices - Tobii | Fixation | 150 | 349 | 245 | 242 | 217 | 193.40 | 402.30 | 0 | 0 |

Figure 3.6: Statistics file exported to Microsoft Excel®

The exported statistics file has columns named *Validity Left* and *Validity Right*. These show the validity of the gaze data. If a participant's eye gaze is found and the tracking is good, the validity code is 0. If the eye gaze cannot be found, then the validity code is 4. Invalid data must be filtered out before data analysis is carried out. In this study, the

validity codes of 0 for both the left and right eyes were chosen. Incorrect codes that were not 0 were excluded.

3.4.2 Reliability and Validity of the Research Instruments

Validity and reliability are widely used as criteria for the evaluation of the method used. Evaluation of whether data is valid and reliable is a key element in applying research findings. The researcher used both qualitative and quantitative methods for triangulation purposes.

Validity

Validity refers to whether a research instrument truly measures what it is intended to measure (Joppe 2000; as cited by Golafshani, 2003). The researcher analysed participants' behaviour, using the gaze replay, in order to locate areas of inconsistency. Areas of inconsistency may lead to validity problems within a study.

Calibration was carried out at the beginning of each session. Calibration enables the identification of a participant's eye characteristics so as to estimate the gaze point with high accuracy. Eye tracking produces precise eye tracking data, i.e. fixations and saccades. The exported statistics file also includes areas where the eye gaze was lost (see Figure 3.5). The areas are indicated by a validity column whose values range from 0 to 4. If validity is 0, it implies that the gaze point was computed with high accuracy. If validity is 4, it indicates that the eye tracker was unable to locate the participant's eye gaze.

The areas that the eye tracker was not able to measure were not included in the data analysis. The eye tracker used in this study allows reasonable amounts of head movement and participants' pupils to dilate without invalidating calibration. A pilot study enabled the researcher to identify potential problems that could occur during the actual study and rectify them. The pilot study was used to validate that the text to be read by participants was clear. During the pilot study, calibration problems were experienced for people reading on paper. The researcher had to re-position the study guide and re-adjust the scene camera arm.

Reliability

Reliability refers to the stability, equivalence and consistency of a research instrument from one assessment to another (Cook & Beckman, 2006; van Saane, Sluiter, Verbeek, & Frings-Dresen, 2003). In other words, if the same results can be produced under a similar method, then the instrument is considered reliable.

The data from the pre-test questionnaire was easily quantifiable as it consisted of closed questions. The post-test questionnaire consisted of open ended questions. The researcher ensured that the comprehension questions in the post questionnaires were the same for participants reading on the three different platforms. The researcher was in attendance and explained the meaning of technical terms from questions in the open ended questionnaires. Responses given by participants were short, definite and explicit and did not require subjective interpretation.

The gaze replay was given to an experienced researcher for re-coding. The researcher also scored the participant's responses to the comprehension questions. Comparisons of the rater's interpretations with those of the researcher were carried out and the results were similar.

3.5 Limitations

Some participants looked off the screen while reading, which resulted in the eye tracker failing to locate their eye gaze on the screen area. A validity filter was used to exclude the incorrect data. Other participants did not answer comprehension questions in detail. Some of the responses were irrelevant thus making the comparisons and statistical analysis to be difficult. Some participants could not be calibrated when reading on paper using the X120 eye tracker and were requested to read on the computer screen instead.

3.6 Ethical Procedures

3.6.1 Ethical Considerations

Researchers conducting tests must abide to principles, laws and regulations that outline legal and ethical obligations regarding testing in respect of the rights and welfare of

research participants. In this study, ethical principles of honesty, objectivity, validity, confidentiality and respect for participants' emotional wellbeing were adhered to.

3.6.2 Permission to Conduct Research

Institutions must ensure that all ethical review mechanisms are in place before allowing research to take place (Chilengi, 2009; Terre Blanche & Durrheim, 2002). For this study, an application to conduct research was made to the university's research ethics committee. The research ethics committee at the University of South Africa reviews and grants permission to do research when ethics standards need to be met. The document that was sent to the ethics committee seeking permission to conduct the study is shown in Appendix B. A written approval to conduct the eye tracking study was granted by the committee (see Appendix C).

3.6.3 Consent Forms

An ethical experiment must have participants' informed consent. Participants who agreed to participate in the study were given an overview of the research. They signed the consent forms to signify their acknowledgement and were informed they could withdraw from the experiment at any time. An example of the consent form appears in Appendix D.

3.6.4 Confidentiality

Privacy is concerned with the exclusion of various persons or groups from knowing certain aspects or data from an individual's life. In this research, participants were required to submit private identifiable information. The participants' personal data was made accessible only to the researcher and the supervisors. In all other reporting of the research, identifying data, which may allow the identification of participants, was masked and anonymous codes were used instead. The participants' identity will not be published in any reports or publications without their consent.

3.7 Conclusion

The chapter discussed the research methodology followed in the research reported in this dissertation. It explained the selection of the sample and how the data was

collected from participants and experiments. It described the hardware and software used in experimental set up. Ethical procedures that were followed when collecting the data were discussed. The next chapter describes how the data that was collected is analysed.

CHAPTER 4

DATA ANALYSIS

4.1 Introduction

The previous chapter discussed the methods used to collect data from participants. This chapter discusses the analysis of the collected data and the results. The goal was to compare the similarities and differences of reading patterns on three platforms, which were the mobile device, computer screen and paper. Data for participants reading on the platforms was collected and is described in the chapter. This chapter presents the techniques employed in the quantitative data analysis and the processes taken to analyse qualitative data. The findings presented demonstrate the similarities and differences of reading patterns on the platforms.

The chapter has the following sections:

Section 4.2 discusses the data collected and section 4.3 discusses how the quantitative data was analysed. Section 4.4 presents the qualitative data analysis and section 4.5 summarises the results.

4.2 Data

4.2.1 Exported Statistics File

The raw eye gaze data for all participants was exported to Microsoft Excel®. In an exported eye tracking statistics file, each data point is identified by a timestamp which represents the time when the data was collected and “x”, “y” coordinates which indicate fixation points. Two gaze points are assigned the same fixation if they are within a pre-defined minimum distance from each other. Short fixations are discarded (Tobii White Paper, 2010).

A fixation filter filters out raw eye tracking data. Tobii has two types of fixation filters, the Tobii Fixation Filter and the IVT-Filter, (Velocity Threshold Identification) filter. The Tobii Fixation Filter produces raw data for fixations and is not optimal for saccade

identification. The fixation filter used in this study was the IVT-Filter which is based on the eyes' angular velocity and operates on eye movement data rather than gaze point pixel locations. It has a noise reduction function which reduces noise in eye tracking data and a gap-fill-in function that fills in data where valid data is missing (Tobii IVT Filter, 2012). This implies that more of the eye gaze data can be classified correctly into three event types: fixations, saccades and unclassified. The IVT-Filter provides information regarding both fixations and saccades in the eye gaze data.

The *Unclassified* column indicates areas where the eye tracker lost the participant's eye gaze. The data indicated by the *Unclassified* column is filtered out of the statistics. The exported statistics data was the source of most of the data used in data analysis. In the study, the eye tracker recorded ten participants reading text on paper, ten reading on computer screen and ten reading on the mobile device. The purpose of the study was to identify the differences in the reading patterns on the platforms.

4.2.2 Responses to Comprehension Questions

Data was also obtained from comprehension responses in the open ended questionnaires. Scores were allocated according to the accuracy of the responses. One of the questionnaires with answers is shown in Appendix F.

4.2.3 Gaze Replay

A gaze replay provided a dynamic visualisation of the gaze recording. It replayed the gaze path overlaid on top of the stimuli. Figure 4.1 shows a still image of a gaze replay for a participant who read on paper. The red dots indicate a participant's current eye position. The gaze replay was reviewed after the eye tracking tests were conducted and the insights of the tests were noted (see Appendix G).

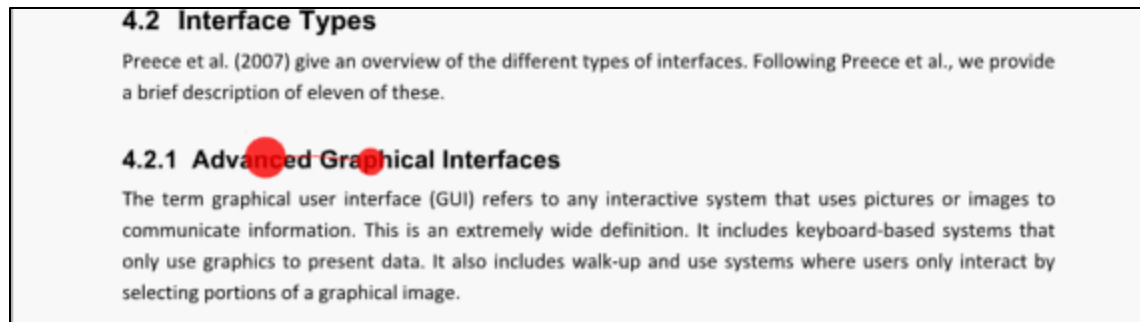


Figure 4.1: Gaze Replay

Qualitative information regarding the experiments was derived from the gaze replay. This was used for data interpretation. Appendix H shows the heat map and gaze replay for students who read text on computer screen and on mobile device.

4.2.4 Analysis of Exported Statistical Data

The exported raw data was filtered using validity codes from the Validity Left and Validity Right columns. The following steps were followed in the preparation of data for analysis (Durrheim, 2002).

4.2.4.1 Preparing the Data

Data consists of lists of numbers that represent scores on variables (Terre Blanche & Durrheim, 2002). The raw data for this study consisted of data obtained from the results of eye tracking and the answers from open ended questionnaires. These measurements included the session recording time, pupil and eye positions from the screen or display areas, location points and the duration of fixations and saccades.

Validity codes were used to filter out eye tracking data where the eye gaze of a participant was lost. The raw data in the exported statistics file has columns named *Validity Left* and *Validity Right*. These show the validity of the gaze data. If the eye gaze for both eyes was recorded, the validity code is 0. If the eye gaze cannot be found, then the validity code is 4. In this study, the researcher filtered out data whose validity codes were not 0 from both columns. Table 4.1 contains the explanations of the validity codes.

Table 4.1: Validity Codes

| <i>Code</i> | <i>Code Description</i> |
|-------------|---|
| 0 | Data for the relevant eye has been recorded. There is no confusion between left and right eye. |
| 1 | The system has only recorded one eye and estimated whether the recorded eye is left or right. The other eye is given code 3. |
| 2 | One eye has been recorded but there is no guarantee if it is the left or right eye |
| 3 | The gaze data is incorrect or corrupted. |
| 4 | The gaze data is missing or definitely incorrect. If the gaze data on both eyes is 4 and the next is 0, then it might mean there was a blink. |

Table 4.2 lists some of the gaze event data types that were in the exported statistics file. These were used in the quantitative data analysis of this study.

Table 4.2: Gaze Event Data Types (TobiiRelease, 2012)

| Gaze Event Data | Description | Format |
|-------------------|---|-------------------------------------|
| SaccadeIndex | This gaze event data represents the order in which a saccade event was recorded. This index is an auto-increment number and starts from 1. | Count |
| FixationIndex | Represents the order in which a fixation event was recorded. This index is an auto-increment number starting with 1. | Count |
| GazeEventType | This is a type of eye movement event which is classified by the fixation filter settings applied during the gaze data export. | Fixation Saccade Unclassified |
| GazeEventDuration | Duration of an eye movement event. | Milliseconds |
| FixationPointX | This is a horizontal coordinate of the fixation point on the media. This column is empty if <ul style="list-style-type: none"> fixation is outside the media media is covered no media is displayed This column is affected by the settings in the Fixation Filter Tab | Pixels |

| | | |
|----------------|---|--------|
| FixationPointY | Vertical coordinate of the fixation point on the media. This column is empty if <ul style="list-style-type: none"> • fixation is outside the media • media is covered • no media is displayed This column is affected by the settings in the Fixation Filter Tab | Pixels |
|----------------|---|--------|

Data about the media used is also included in the exported statistics file. This consists of the media name, width, height, position and resolution. In this study, the data was filtered to separate fixation data from saccade data. Fixation data was used to calculate fixation duration and fixation count whilst saccade length and the linearity of saccades were calculated from saccade data.

4.2.4.2 Coding the Data

Raw data must be converted to meaningful numerical format. Codes are precise and are the medium of communicating information in a quantitative analysis (Sivesind, 1999 as cited by Bazeley, 2002). In this study, codes were created for each participant. The eye tracking data and comprehension scores were assigned to individual participant codes.

4.2.4.3 Entering the Data

The participants' eye tracking data was exported from Tobii Studio™ into Microsoft Excel® in a tabular format. The comprehension scores data from the questionnaires were input into the spreadsheet for computation and analysis. The participants' methods of study were also input into the spreadsheet for analysis.

4.2.4.4 Cleaning the Data

The data consisted of the eye tracking results and responses from the questionnaires. Calculations were carried out on the eye tracking data. These calculations were revisited to ensure that they were accurate. Participants' responses from questionnaires and calculation scores that were input into the computer were checked for errors.

Comparisons were made between raw data from questionnaires to the data that was input into the computer.

4.3 Quantitative Data Analysis

4.3.1 Fixation and Saccade Duration

One aim was to determine if there were differences in the reading duration on different platforms. Saccades are a result of fixation intervals. The fixation and saccade duration were calculated from the raw exported data. The exported statistics file presented the fixation and saccade duration per participant in milliseconds (ms). The researcher converted the figures in milliseconds to figures in minutes and seconds.

Procedure

A fixation and saccade duration example is shown in Figure 4.2. The fixation duration at the all fixation points was added together. The total duration was the combination of fixation and saccade duration.

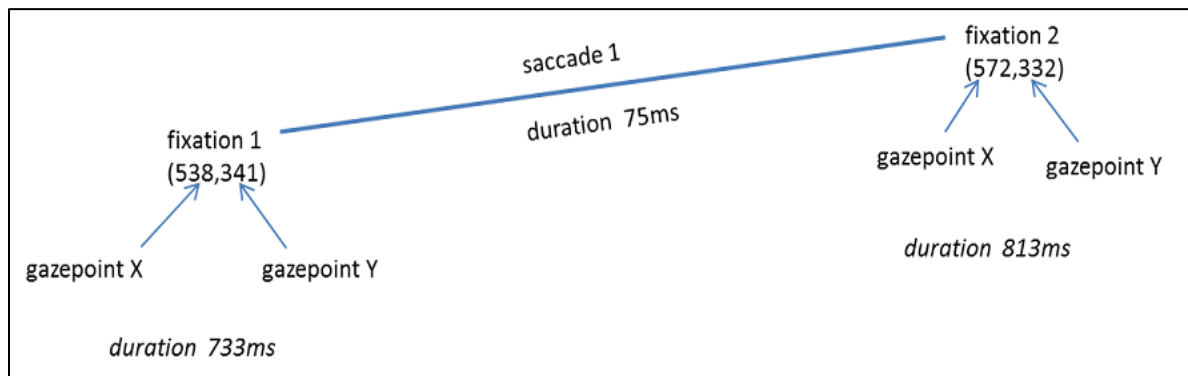


Figure 4.2: Total fixation

The duration for fixations and saccades was converted from milliseconds to minutes and seconds (see Table 4.3).

Table 4.3: Fixation and saccade duration on the three platforms

| Participant (<i>different group for each platform</i>) | Mobile | | Paper | | Screen | |
|---|--------------|--------------|--------------|--------------|--------------|--------------|
| | Fixation | Saccade | Fixation | Saccade | Fixation | Saccade |
| P1 | 03:59 | 01:05 | 01:39 | 00:23 | 03:25 | 01:05 |
| P2 | 02:33 | 01:00 | 01:57 | 00:30 | 02:27 | 00:36 |
| P3 | 04:09 | 00:41 | 03:11 | 00:30 | 06:15 | 00:59 |
| P4 | 04:02 | 01:01 | 05:19 | 00:33 | 03:44 | 01:27 |
| P5 | 01:11 | 01:21 | 02:25 | 00:50 | 03:18 | 01:07 |
| P6 | 02:44 | 01:12 | 02:18 | 01:03 | 02:57 | 00:59 |
| P7 | 02:29 | 00:56 | 02:15 | 00:21 | 03:52 | 00:55 |
| P8 | 03:31 | 00:53 | 02:51 | 00:21 | 02:49 | 00:38 |
| P9 | 02:38 | 01:15 | 01:58 | 00:43 | 02:37 | 00:34 |
| P10 | 02:33 | 01:01 | 03:21 | 00:35 | 02:31 | 00:45 |
| <i>Mean</i> | <i>02:59</i> | <i>01:02</i> | <i>02:43</i> | <i>00:35</i> | <i>03:24</i> | <i>00:55</i> |

The total duration of fixations was more than the total duration of the saccades. The total duration in minutes and seconds, per participant is shown in Table 4.4.

Table 4.4: Mobile, screen and paper duration

| Participant | Duration | Participant | Duration | Participant | Duration |
|----------------|--------------|-------------|--------------|-------------|--------------|
| Mobile P1 | 05:04 | Screen P1 | 04:30 | Paper P1 | 02:02 |
| Mobile P2 | 03:33 | Screen P2 | 03:03 | Paper P2 | 02:27 |
| Mobile P3 | 04:50 | Screen P3 | 07:12 | Paper P3 | 03:41 |
| Mobile P4 | 05:03 | Screen P4 | 05:11 | Paper P4 | 05:51 |
| Mobile P5 | 02:31 | Screen P5 | 04:25 | Paper P5 | 03:15 |
| Mobile P6 | 03:56 | Screen P6 | 03:58 | Paper P6 | 03:21 |
| Mobile P7 | 03:26 | Screen P7 | 04:47 | Paper P7 | 02:35 |
| Mobile P8 | 04:24 | Screen P8 | 03:27 | Paper P8 | 03:12 |
| Mobile P9 | 03:53 | Screen P9 | 03:11 | Paper P9 | 02:41 |
| Mobile P10 | 03:34 | Screen P10 | 03:16 | Paper P10 | 03:56 |
| <i>Average</i> | <i>04:01</i> | | <i>04:18</i> | | <i>03:18</i> |

Participants who read on paper took the shortest time with an average of 03:18 minutes (see Figure 4.3).

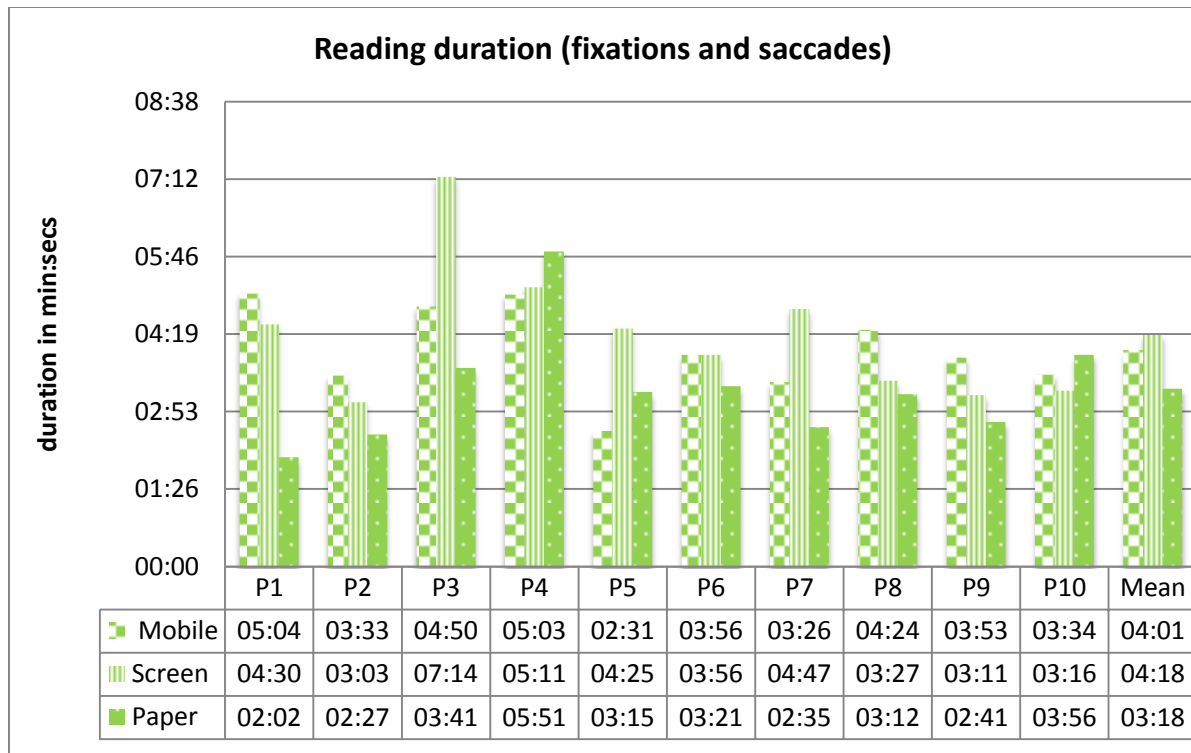


Figure 4.3: Fixation and saccade duration

Participants who read on mobile device and those who read on screen had an average fixation duration of 4:01 and 4:18 minutes respectively.

Results

Test for Normality

The Shapiro-Wilk test for normality was used to test if the duration data was normally distributed. To ensure the accurate inferences about a sample, parametric tests, e.g. ANOVA, must be used for normally distributed data and non-parametric tests, e.g. Kruskal-Wallis for data that is not normally distributed. Table 4.5 shows the results of the normality test.

Table 4.5: Shapiro-Wilk test for Normality (Saccade Duration)

| Tests of Normality | | | | | | | |
|--------------------|--------|---------------------------------|----|-------------------|--------------|----|-------|
| | Group | Kolmogorov-Smirnov ^a | | | Shapiro-Wilk | | |
| | | Statistic | Df | Sig. | Statistic | Df | Sig. |
| Duration | Mobile | 0.145 | 10 | .200 [*] | 0.938 | 10 | 0.526 |
| | Screen | 0.162 | 10 | .200 [*] | 0.865 | 10 | 0.088 |
| | Paper | 0.182 | 10 | .200 [*] | 0.874 | 10 | 0.111 |

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The significance figures were all greater than 0.05. The significance value for the mobile device was 0.526, screen was 0.088 and paper was 0.11. This meant that the data was not significantly different from a normal distribution. The mean for the mobile, screen and paper were 4:01, 4:18 and 3:18 minutes respectively as shown in Table 4.6. The minimum duration values for the mobile, screen and paper were 2:31, 3:03 and 2:02 minutes respectively. The maximum values were 5:04, 7:14 and 5:51 minutes for mobile, screen and paper respectively.

Since the data was normally distributed, the One Way Analysis of Variance, (ANOVA) was used to test if the differences in duration when reading on different platforms were significant.

Table 4.6: Descriptives for Saccade Duration

| | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|--------|----|-------|----------------|------------|----------------------------------|-------------|---------|---------|
| | | | | | Lower Bound | Upper Bound | | |
| Mobile | 10 | 04:01 | 00:58 | 00:22 | 03:09 | 04:57 | 02:31 | 05:04 |
| Screen | 10 | 04:18 | 01:18 | 00:29 | 03:32 | 05:56 | 03:03 | 07:14 |
| Paper | 10 | 03:18 | 01:16 | 00:29 | 02:09 | 04:29 | 02:02 | 05:51 |
| Total | 30 | 04:02 | 01:16 | 00:17 | 03:27 | 04:37 | 02:02 | 07:14 |

The p-value was 0.11, which was more than the alpha level of 0.05 (see Table 4.7). This meant that there were no statistically significant differences in duration among the groups of participants that read on mobile, paper and computer screen.

Table 4.7: ANOVA One Way Test for Duration

| | Sum of Squares | Df | Mean Square | F | Sig. |
|----------------|----------------|----|-------------|-------|-------|
| Between Groups | 23:42 | 2 | 11:51 | 2.332 | 0.116 |
| Within Groups | 30:12 | 27 | 28:21 | | |
| Total | 53:53 | 29 | | | |

The number of words read per minute per section was calculated and is shown in Appendix I. The page that was read by participants consisted of seven sections. The participant's reading speed for the whole page was calculated. The average speed for participants who read on paper was 141 words per minute. Those who read on mobile device had an average speed of 111 words per minute. Participants who read on computer screen had an average of 106 words read per minute.

4.3.2 Fixation Count

A fixation count is the total number of fixations a participant has on a predefined Area of Interest (AOI) (Albert & Tedesco, 2010). All the paragraphs in the page read by participants were defined as AOIs. The fixation counts were calculated as the number of fixations located in each paragraph. If a participant's eye gaze shifts from the AOI during the recording and returns to the same media element, then the new fixations on the media will be included in the calculations of the metric (Tobii Manual, 2010).

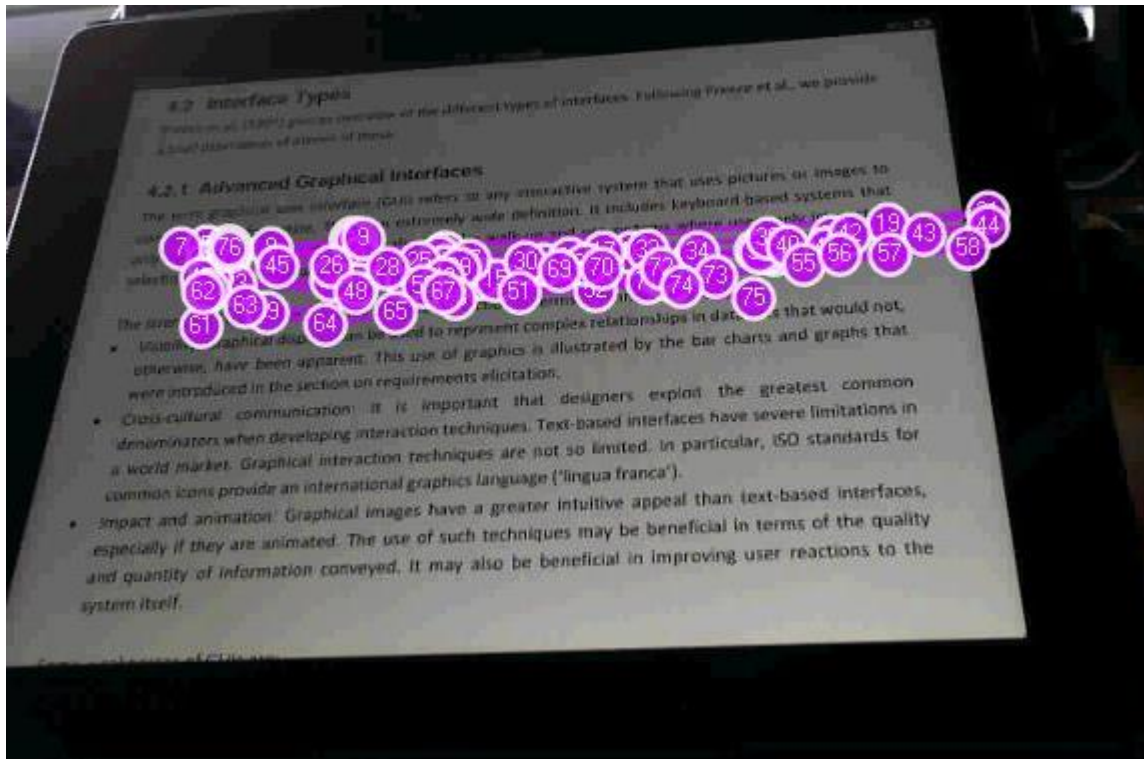


Figure 4.4: Gaze plot on mobile device

The dots in a gaze plot show the positions and sequences of fixations. Figures 4.4 and 4.5, respectively, show gaze plots on a mobile device and on paper.

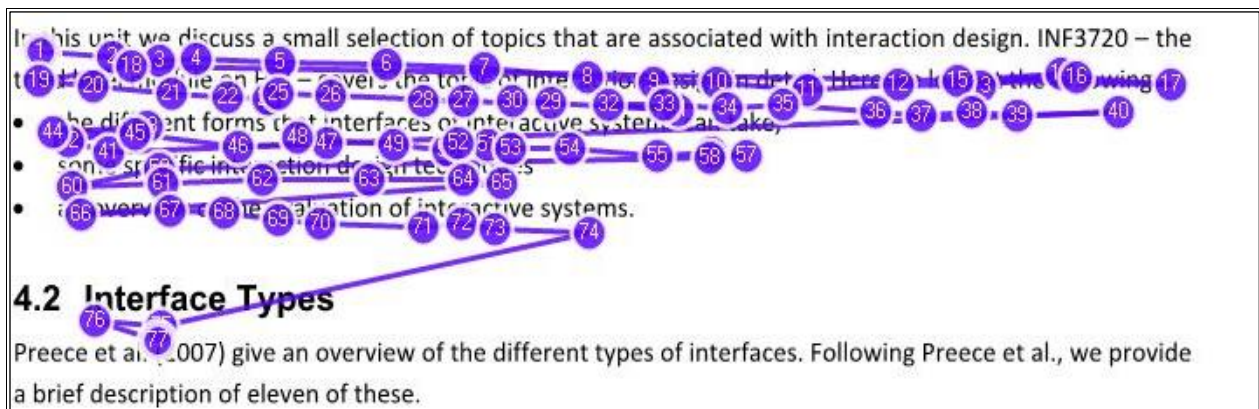


Figure 4.5: Gaze plot on paper

The number of fixations per paragraph was generated by Tobii Studio™. The figures show the gaze plot with fixation numbers. Participants who read on computer screen

had the most fixation counts. Those who read on paper had the least fixations. The total fixations on all the paragraphs read are shown in Table 4.8.

Table 4.8: Fixation Count

| Participant | Fixation Count | Participant | Fixation Count | Participant | Fixation Count |
|---------------|----------------|-------------|----------------|-------------|----------------|
| Mobile P1 | 286 | Screen P1 | 266 | Paper P1 | 178 |
| Mobile P2 | 232 | Screen P2 | 331 | Paper P2 | 219 |
| Mobile P3 | 333 | Screen P3 | 293 | Paper P3 | 202 |
| Mobile P4 | 171 | Screen P4 | 343 | Paper P4 | 302 |
| Mobile P5 | 319 | Screen P5 | 256 | Paper P5 | 450 |
| Mobile P6 | 303 | Screen P6 | 388 | Paper P6 | 133 |
| Mobile P7 | 313 | Screen P7 | 334 | Paper P7 | 469 |
| Mobile P8 | 401 | Screen P8 | 352 | Paper P8 | 305 |
| Mobile P9 | 351 | Screen P9 | 614 | Paper P9 | 403 |
| Mobile P10 | 511 | Screen P10 | 463 | Paper P10 | 491 |
| <i>Mean</i> | 322 | | 364 | | 315 |
| <i>Totals</i> | 3220 | | 3640 | | 3152 |

The fixation indices and coordinates in the eye tracking data were used to identify forward passes and regressions. Participants who read on screen had the most fixation counts. Forward passes are eye movements that move forward after a fixation. Backward passes are eye movements that cause the eyes to regress rather than move forward. Regressions may be caused by a cognitive event (Boland, 2004).

The average number of forward passes on mobile device was 226. Participants who read on screen had an average of 256 forward passes and those who read on paper had an average of 241 forward passes (see Table 4.9).

Table 4.9: Forward Passes and Regressions

| Participant (different group for each platform) | Mobile | | Screen | | Paper | |
|--|----------------|-----------------|----------------|-----------------|----------------|-----------------|
| | Forward Passes | Backward Passes | Forward Passes | Backward Passes | Forward Passes | Backward Passes |
| Participant 1 | 193 | 93 | 207 | 59 | 107 | 71 |
| Participant 2 | 189 | 43 | 249 | 82 | 173 | 46 |
| Participant 3 | 255 | 78 | 196 | 97 | 159 | 43 |
| Participant 4 | 132 | 39 | 253 | 90 | 237 | 65 |
| Participant 5 | 256 | 63 | 155 | 101 | 388 | 62 |
| Participant 6 | 239 | 64 | 290 | 98 | 114 | 19 |
| Participant 7 | 237 | 76 | 211 | 123 | 353 | 116 |
| Participant 8 | 222 | 179 | 252 | 100 | 209 | 96 |
| Participant 9 | 243 | 108 | 406 | 208 | 296 | 107 |
| Participant 10 | 297 | 214 | 339 | 124 | 370 | 121 |
| Mean | 226 | 96 | 256 | 108 | 241 | 75 |

The percentages of forward passes were 70% for participants that read on mobile device, 76% for those that read on paper and 70% for the ones that read on computer screen.

Results

Test for Normality

The Shapiro-Wilk normality test results are shown in Table 4.10.

Table 4.10: Test for Normality - Fixation Count

| Group | | Kolmogorov-Smirnov ^a | | | Shapiro-Wilk | | |
|--|--------|---------------------------------|----|-------|--------------|----|-------|
| | | Statistic | Df | Sig. | Statistic | df | Sig. |
| fixation_count | mobile | 0.176 | 10 | .200* | 0.954 | 10 | 0.717 |
| | screen | 0.245 | 10 | 0.091 | 0.847 | 10 | 0.053 |
| | Paper | 0.168 | 10 | .200* | 0.918 | 10 | 0.341 |
| *. This is a lower bound of the true significance. a. Lilliefors Significance Correction | | | | | | | |

The significance figures of 0.717 for mobile device, 0.053 for computer screen and 0.341 for paper indicate that the fixation count data was not significantly different from a normal distribution. The average fixation count for mobile device was 322, screen had an average of 364 fixation counts and paper had an average of 315 (see Table 4.11).

Table 4.11: Descriptives for Fixation Count

| | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|--------|----|------|----------------|------------|----------------------------------|-------------|---------|---------|
| | | | | | Lower Bound | Upper Bound | | |
| Mobile | 10 | 322 | 92 | 29 | 256 | 388 | 171 | 511 |
| Screen | 10 | 364 | 106 | 34 | 288 | 440 | 256 | 614 |
| Paper | 10 | 315 | 131 | 41 | 221 | 409 | 133 | 491 |
| Total | 30 | 334 | 109 | 20 | 293 | 375 | 133 | 614 |

The One Way ANOVA was used to determine if there were statistically significant differences in the fixation counts (see Table 4.12).

Table 4.12: ANOVA test for Fixation Count

| | Sum of Squares | df | Mean Square | F | Sig. |
|----------------|----------------|----|-------------|-------|-------|
| Between Groups | 13972.27 | 2 | 6986.133 | 0.568 | 0.573 |
| Within Groups | 332139.6 | 27 | 12301.47 | | |
| Total | 346111.9 | 29 | | | |

The p-value was 0.573 which implies that there were no statistically significant differences in fixation counts on the different platforms.

4.3.3 Saccade Length

The raw eye tracking data includes the X and Y coordinate points. These can be used to calculate the length of saccades. The length interval used was one pixel. The

Euclidean formula, shown in Figure 4.6, is similar to the Pythagorean formula and was used to calculate the saccade length between two fixation points.

$$\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Figure 4.6: Distance between two points

The Tobii T120 eye tracker has a resolution of 1280 X 1024 pixels and a 17 inch monitor, i.e. 43cm. Therefore it had 30 pixels per cm. The researcher calculated the number of pixels per cm for the Tobii T120 eye tracker using the resolution and the screen size of the eye tracker.

The media that was used for eye tracking participants who read on paper and on mobile device had 36 and 34 pixels per cm respectively. The saccades' length in cm is shown in Table 4.13.

Table 4.13: Saccade Length

| | Mobile (cm) | | Screen (cm) | | Paper (cm) |
|------------|-------------|------------|-------------|-----------|------------|
| Mobile P1 | 633 | Screen P1 | 930 | Paper P1 | 385 |
| Mobile P2 | 462 | Screen P2 | 1282 | Paper P2 | 463 |
| Mobile P3 | 434 | Screen P3 | 944 | Paper P3 | 240 |
| Mobile P4 | 393 | Screen P4 | 1325 | Paper P4 | 402 |
| Mobile P5 | 391 | Screen P5 | 2613 | Paper P5 | 383 |
| Mobile P6 | 331 | Screen P6 | 482 | Paper P6 | 1404 |
| Mobile P7 | 277 | Screen P7 | 511 | Paper P7 | 336 |
| Mobile P8 | 241 | Screen P8 | 1058 | Paper P8 | 661 |
| Mobile P9 | 504 | Screen P9 | 1659 | Paper P9 | 707 |
| Mobile P10 | 556 | Screen P10 | 482 | Paper P10 | 644 |
| Average | 422 | | 1129 | | 563 |

The average saccade length of the eye movements of participants who read on mobile device, computer screen and on paper were 422cm, 1129cm and 563cm respectively.

Results

Test for Normality

The Shapiro-Wilk was used to test if the data was normally distributed. The results, shown in Table 4.14, show a significance of 0.008 for paper saccade length which was less than 0.05. This indicates that the distribution was significantly different from a normal distribution.

Table 4.14: Test for Normality: Saccade Length

| Group | | Kolmogorov-Smirnov ^a | | | Shapiro-Wilk | | |
|----------------|--------|---------------------------------|----|-------------------|--------------|----|------|
| | | Statistic | Df | Sig. | Statistic | df | Sig. |
| saccade_length | mobile | .099 | 10 | .200 [*] | .983 | 10 | .981 |
| | screen | .182 | 10 | .200 [*] | .873 | 10 | .109 |
| | Paper | .232 | 10 | .135 | .781 | 10 | .008 |

The Kruskal-Wallis, a non-parametric test was used to find out if there were statistically significant differences in the saccade length on different platforms (see Table 4.15).

Table 4.15: Kruskal-Wallis test for Saccade Length

| Null Hypothesis | Test | Sig. | Decision |
|---|---|------|----------------------------|
| The distribution of saccade_length is the same across all categories of the group | Independent-Samples Kruskal-Wallis Test | .003 | Reject the null hypothesis |

The p-value was 0.003, which was less than the alpha value of 0.05. The p-value indicated that there were statistically significant differences in the saccades length of screen, paper and mobile device. The saccade length for computer screen was the longest. The mobile device saccade length was the shortest.

4.3.4 Comprehension Scores

After reading the text, students had to answer five comprehension questions from the open ended questionnaires. The questionnaire consisted of five questions (see Appendix E).

Table 4.16: Comprehension Scores

| Participant | Scores | Participant | Scores | Participant | Scores |
|-------------|--------|-------------|--------|-------------|--------|
| Mobile P1 | 93% | Paper P1 | 80% | Screen P1 | 70% |
| Mobile P2 | 73% | Paper P2 | 93% | Screen P2 | 97% |
| Mobile P3 | 73% | Paper P3 | 67% | Screen P3 | 63% |
| Mobile P4 | 53% | Paper P4 | 93% | Screen P4 | 50% |
| Mobile P5 | 60% | Paper P5 | 100% | Screen P5 | 64% |
| Mobile P6 | 95% | Paper P6 | 80% | Screen P6 | 97% |
| Mobile P7 | 40% | Paper P7 | 80% | Screen P7 | 57% |
| Mobile P8 | 53% | Paper P8 | 87% | Screen P8 | 60% |
| Mobile P9 | 73% | Paper P9 | 60% | Screen P9 | 40% |
| Mobile P10 | 67% | Paper P10 | 80% | Screen P10 | 100% |
| Mean | 68% | | 85% | | 71% |

The questions were allocated an equal weighting of 3. Scores were given per question upon answering it correctly (see Table 4.16). The total scores per participant were then converted to percentages. The comprehension scores were compared for all the three groups.

Results

Test for Normality

The Shapiro-Wilk was used to test if the data was normally distributed. The significance values were greater than 0.05. This indicated that the comprehension scores data was not significantly different from a normal distribution (see Table 4.17).

Table 4.17: Test for Normality - Comprehension Scores

| Group | | Kolmogorov-Smirnov ^a | | | Shapiro-Wilk | | |
|---------------|--------|---------------------------------|----|-------|--------------|----|------|
| | | Statistic | Df | Sig. | Statistic | df | Sig. |
| Comprehension | mobile | .187 | 10 | .200* | .947 | 10 | .637 |
| | paper | .234 | 10 | .127 | .939 | 10 | .539 |
| | screen | .208 | 10 | .200* | .889 | 10 | .166 |

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The average comprehension scores for mobile, screen and paper were 0.68, 0.71 and 0.82 respectively (see Table 4.18).

Table 4.18: Descriptives for Comprehension Scores

| | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Minimum | Maximum |
|--------|----|------|----------------|------------|----------------------------------|-------------|---------|---------|
| | | | | | Lower Bound | Upper Bound | | |
| Mobile | 10 | 0.68 | 0.1741 | 0.05506 | 0.5555 | 0.8045 | 0.4 | 0.95 |
| Paper | 10 | 0.82 | 0.12092 | 0.03824 | 0.7335 | 0.9065 | 0.6 | 1 |
| Screen | 10 | 0.71 | 0.21112 | 0.06676 | 0.547 | 0.849 | 0.4 | 1 |
| Total | 30 | 0.73 | 0.17827 | 0.03255 | 0.6661 | 0.7992 | 0.4 | 1 |

The One Way ANOVA was used to find out if there were statistically significant differences in comprehension scores. The p-value as shown in Table 4.19 was 0.163. There were no statistically significant differences in comprehension scores among the groups of participants who read on mobile device, paper and those who read on screen.

Table 4.19: One Way ANOVA Test for Comprehension Scores

| | Sum of Squares | Df | Mean Square | F | Sig. |
|----------------|----------------|----|-------------|-------|-------|
| Between Groups | 0.116 | 2 | 0.058 | 1.944 | 0.163 |
| Within Groups | 0.806 | 27 | 0.03 | | |
| Total | 0.922 | 29 | | | |

4.3.5 Linearity of the Saccades

Studies on deviations of saccade trajectories as a measure have increased. A saccade does not take the shortest route in terms of a straight line between the starting point and the endpoint, but shows a trajectory which is slightly curved. The strength of a saccade deviation is a measure of the amount of attention allocated to any particular location in space (van der Stigchel, 2010).

Linearity is the measure of deviation from a straight line. In this study, the researcher tested the linearity of eye movements of participants on the read a sentence shown in Figure 4.7.

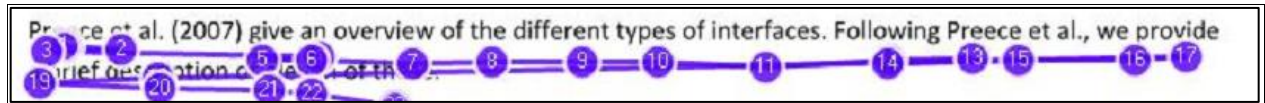


Figure 4.7: Sentence extracted for linearity testing

RStudio was used to calculate linearity. Distances from the fixation points to the straight line were calculated and added together. The sum of the distances was then divided by the distance of the straight line to obtain the linearity and index values, see an illustration in Figure 4.8.

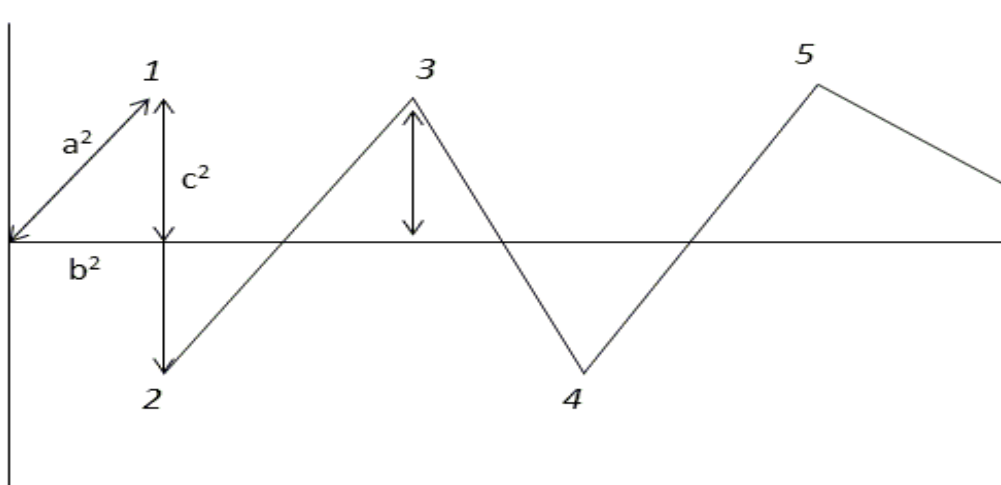


Figure 4.8: Linearity of Saccades

A comparison of the number of forward and backward passes on the sentence that was tested for linearity is shown in Table 4.20. A regression is the backward movement of the eye to previously read words. The regressions on the sentence that was read were relatively small.

Table 4.20: Forward and Backward Passes on Sentence Read

| | Paper | | Computer Screen | | Mobile Device | |
|---|----------------|-------------|-----------------|-------------|----------------|-------------|
| Participant (<i>different group for each platform</i>) | Forward Passes | Regressions | Forward Passes | Regressions | Forward Passes | Regressions |
| P1 | 7 | 2 | 7 | 0 | 7 | 2 |
| P2 | 9 | 0 | 10 | 1 | 9 | 2 |
| P3 | 6 | 1 | 8 | 0 | 13 | 7 |
| P4 | 5 | 1 | 9 | 4 | 9 | 6 |
| P5 | 8 | 0 | 8 | 3 | 9 | 0 |
| P6 | 9 | 2 | 12 | 2 | 11 | 1 |
| P7 | 10 | 5 | 7 | 1 | 4 | 5 |
| P8 | 12 | 4 | 10 | 7 | 5 | 5 |
| P9 | 3 | 8 | 3 | 7 | 6 | 6 |
| P10 | 1 | 4 | 7 | 5 | 6 | 7 |
| <i>Mean</i> | 7 | 1 | 9 | 2 | 10 | 3 |

The index values indicate the degree of linearity (see Table 4.21).

Table 4.21: Index values per platform

| Media | N Rows | Sum(sum Distance) | Range(x) | INDEX |
|-------|--------|-------------------|----------|---------|
| M1 | 6 | 1688.75 | 468 | 3.60843 |
| M2 | 7 | 1692.8 | 362 | 4.67624 |
| M3 | 8 | 502.841 | 208 | 2.4175 |
| M4 | 5 | 669.856 | 476 | 1.40726 |
| M5 | 7 | 496.529 | 222 | 2.23662 |
| M6 | 7 | 1176.43 | 364 | 3.23195 |
| M7 | 6 | 1229.97 | 607 | 2.02631 |
| M8 | 6 | 919.023 | 430 | 2.13726 |
| M9 | 7 | 1468.03 | 416 | 3.52893 |
| M10 | 6 | 756.06 | 460 | 1.64361 |
| P1 | 6 | 1165.97 | 419 | 2.78274 |
| P2 | 5 | 280.757 | 242 | 1.16015 |
| P3 | 5 | 536.149 | 501 | 1.07016 |
| P4 | 9 | 268.073 | 213 | 1.25856 |
| P5 | 5 | 234.126 | 229 | 1.02238 |
| P6 | 10 | 313.646 | 232 | 1.35192 |

| | | | | |
|-----|---|---------|-----|---------|
| P7 | 7 | 394.167 | 117 | 3.36895 |
| P8 | 6 | 688.597 | 371 | 1.85606 |
| P9 | 5 | 176.109 | 84 | 2.09654 |
| S1 | 8 | 725.554 | 124 | 5.85124 |
| S2 | 7 | 634.572 | 258 | 2.45958 |
| S3 | 7 | 2378.29 | 584 | 4.07241 |
| S4 | 7 | 1864.8 | 617 | 3.02237 |
| S5 | 9 | 639.386 | 299 | 2.13841 |
| S6 | 8 | 428.805 | 189 | 2.26881 |
| S7 | 8 | 699.409 | 342 | 2.04505 |
| S8 | 7 | 649.396 | 124 | 5.23707 |
| S9 | 8 | 454.36 | 347 | 1.30939 |
| S10 | 8 | 558.631 | 159 | 3.5134 |

The means for the index values are shown in Figure 4.22. The paper participants had a mean of 1.77, the mobile mean was 2.69 and the mean for screen was 3.19. A straight line, (linear line) has a value of 1. This indicates that participants who read on paper had had more linear eye movements (mean value for paper was 1.77). The densities or distribution of the index values are shown in Appendix J.3.

Table 4.22: Means for One Way Anova - Linearity

| Level | Number | Mean | Std Error | Lower 95% | Upper 95% |
|--------------|--------|---------|-----------|-----------|-----------|
| Test1-Mobile | 10 | 2.69141 | 0.36493 | 1.9413 | 3.4415 |
| Test2-Paper | 9 | 1.77416 | 0.38467 | 0.9835 | 2.5649 |
| Test3-Screen | 10 | 3.19177 | 0.36493 | 2.4417 | 3.9419 |

Std Error uses a pooled estimate of error variance

The variances in the linearity data are shown in Appendix J.2. The significance of the differences in linearity was calculated using the Analysis of Variance and the Welch's test. Table 4.23 shows the results of the Analysis of Variance test.

Table 4.23: Analysis of Variance for Linearity

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|----------|----|----------------|-------------|---------|----------|
| Media | 2 | 9.711144 | 4.85557 | 3.6461 | 0.0402* |
| Error | 26 | 34.62497 | 1.33173 | | |
| C. Total | 28 | 44.33612 | | | |

The Analysis of Variance value was 0.0402, which was less than 0.05. The Welsh's test is shown in Table 4.24.

Table 4.24: Welch's Test for Linearity

| F Ratio | DFNum | DFDen | Prob > F |
|---------|-------|--------|----------|
| 4.166 | 2 | 16.957 | 0.0338* |

The Analysis of Variance and the Welch's test values were less than 0.05. This implies that there were significant differences in linearity when reading on the platforms. The detailed differences in the linearity are explained in Tables 4.25 and 4.26.

Table 4.25: Connecting Letters Report

| Level | | | Mean |
|---|---|---|-----------|
| Test3-Screen | A | | 3.191774 |
| Test1-Mobile | A | B | 2.6914106 |
| Test2-Paper | | B | 1.7741628 |
| <i>Levels not connected by same letter are significantly different.</i> | | | |

The Connecting Letters Report shows that there were no significant differences in linearity between the screen and the mobile (letter A appears in screen row and in mobile row). There were also no significant differences in linearity between mobile and paper (letter B appears in both mobile and paper rows). However there were significant

differences in linearity between screen and paper (letter A in screen row, letter B in paper row, letters not similar).

Table 4.26: Ordered Differences Report

| Level | | Difference | Std Err Dif | Lower CL | Upper CL | p-Value |
|--------------|--------------|------------|-------------|----------|----------|---------|
| Test3-Screen | Test2-Paper | 1.417611 | 0.530229 | 0.10005 | 2.73517 | 0.0331* |
| Test1-Mobile | Test2-Paper | 0.917248 | 0.530229 | -0.4003 | 2.23481 | 0.2134 |
| Test3-Screen | Test1-Mobile | 0.500363 | 0.516087 | -0.7821 | 1.78279 | 0.6022 |

The significant difference in linearity between screen and paper is indicated by the p-value, 0.0331 which was less than 0.05. Further studies may test multiple sentences for linearity.

4.3.6 Computer and Mobile Device Use for Learning

The aim was to determine the current use of computers and mobile devices for learning. Students indicated their use of computers and mobile devices for educational purposes in closed questions that were in the pre-test questionnaire (see Table 4.27).

Table 4.27: Current Use of Computers and Mobile Devices

| | Receive, Send Emails | Online applications | Download music | Games, Facebook, twitter | myUnisa |
|-------------------|----------------------|---------------------|----------------|--------------------------|---------|
| Mobile Device Use | 83% | 70% | 50% | 73% | 57% |
| Computer Screen | 97% | 90% | 63% | 73% | 90% |

83% of the students reported using mobile devices for sending and receiving emails. Those who indicated using computers for sending and receiving emails were 97%. More students reported reading online applications on computer screen than on mobile device. 70% currently read their online applications on mobile device compared to 90% of students that read online applications on computer screen. More students use the

computer screen for downloading and reading notes that are on myUnisa. 57% of the students read notes from myUnisa on mobile device compared to 90% who currently read on computer screen. The results indicate that the majority of students currently use computers than mobile devices for reading educational materials.

4.4 Qualitative Data Analysis

This section discusses the results from the gaze replay. The researcher watched a replay of each participant's eye gaze data and identified differences in reading patterns on paper, computer screen and on mobile device. The elaboration process produced insights that emerged as a result of the differences and similarities in the reading patterns. These insights may be used in designing e-learning materials that are suitable for reading on computer screen or on mobile device.

Results

1. Intensive reading

Evidence

The gaze replay showed mainly horizontal eye movements with many fixations (shown by gaze cursor) per line relative to the number of words at that line. Most students had fixations that covered more than half of each sentence. Participants spent a larger share of time reading than navigating.

2. There were more regressions on screen and mobile device than on paper

Evidence

The gaze cursor reflected the gaze path. The examined gaze replay was used to gain insight of participants' reading patterns. Most of the eye movements were in a forward direction. All participants who read on the three platforms revisited words or sentences. Participants that read on paper had the least regressions of words and sentences. A number of participants who read on mobile device or on screen re-read the entire text again. Few participants who read on paper re-read the entire text.

3. Skipping of words was similar when reading on paper, screen or mobile device

Evidence

The gaze replay showed that there were no fixations over some words. Participants fixated mostly on content words (nouns and verbs), rather than on function words (prepositions and conjunctions). When observing the gaze replay, the fixation circles were bigger on content words, which meant that the longer duration was on those words. Skipping of words was similar on all the platforms.

4. The readers' initial fixations were at the left of a word for text read on all platforms

Evidence

The initial fixations were to the left of the centre of a word on all the different platforms. Words that appeared less frequently were fixated most and were less skipped.

4.5 Conclusion

Generally, participants that read on paper performed better than those that read on computer screen or on mobile device. The summary is shown in Table 4.28.

Table 4.28: Reading Summary

| | Paper | Computer Screen | Mobile Device | Significance of differences on paper, mobile or screen |
|----------------|--------|-----------------|---------------|--|
| Comprehension | Best | Medium | Least | Insignificant |
| Duration | Least | Most | Medium | Insignificant |
| Linearity | Most | Least | Medium | Significant |
| Fixation Count | Least | Most | Medium | Insignificant |
| Saccade Length | Medium | Most | Least | Significant |

The results of this study showed that there were similarities and differences in eye movements of all the participants who read on the different platforms. Participants who read on paper took less time than those who read on computer screen or on mobile device. Paper readers had the least fixation counts and the most scores in comprehension. Most participants who read on the different platforms regressed within sentences and across the paragraphs. Those who read on paper had the least

regressions. Eye movements of participants who read on paper were more linear and more ordered than those of participants who read on screen or on mobile device.

The insights from the study are listed below;

1. The length of the saccades for participants who read on computer screen was the longest. The mobile device participants' saccades were the shortest. The inferential tests proved that there were significant differences in the length of the saccades of participants who read on the different platforms.
2. The saccades of participants that read on computer screen had the biggest deviations in terms of linearity. The eye movements of participants that read on paper had more linearity. The analysis showed that the differences in linearity when reading on the platforms were significant.
3. Participants who read on paper had the most comprehension scores. However the analysis proved that the differences in comprehension for those who read on paper, mobile device or computer screen were insignificant.
4. Most fixation counts were during screen reading. The participants that read on paper had the least fixation counts. Further analysis proved that the differences of the fixation counts on the three platforms were insignificant.
5. Participants who read on paper took the least time to read the entire page. The inferential analysis proved that the differences in the duration when reading on paper, mobile device or computer screen were insignificant.
6. Participants who read on paper had the least regressions. None of them re-read the entire page again. After reading the entire page, few of the participants that read on mobile device or on screen regressed to the beginning of the page again.
7. More students currently use computers than mobile devices to read downloaded notes or access educational materials from myUnisa.
8. The gaze replay showed mainly horizontal eye movements on all platforms. At least half of each of the sentences was read by most of the participants regardless of platform.

CHAPTER 5

DISCUSSION OF THE FINDINGS

5.1 Introduction

The purpose of this research was to enhance the usability of content-rich computer and mobile based e-learning material. This chapter discusses and summarises the major and also any additional findings of the study in relation to the objectives of the research and the literature reviewed in Chapter 2. More participants reported reading notes from the university supplied printed materials than from downloaded notes.

Most of the students that downloaded educational materials read them on computer screen. The results indicated that there were differences in duration, number of fixations (fixation count), comprehension, saccade length and linearity of the saccades when reading on the different platforms. Nevertheless, the results showed that the differences in duration, comprehension and fixation count were insignificant. The differences in saccade length and linearity of saccades were significant. Section 5.2 discusses the results of the eye tracking experiments and their implications. Section 5.3 presents the conclusion.

5.2. Discussion of Results

5.2.1. Fixation Duration

Results

The figures revealed that there were differences in the fixation duration taken by participants when they read text on the different platforms. The mean fixation duration taken by participants that read on paper was 2:43 minutes, those that read on mobile device had a mean of 2:59 minutes and the mean fixation duration taken by computer screen readers was 3:24 minutes. This suggests that participants found it easier to read on paper than on mobile device or computer screen. These findings are substantiated by existing literature that suggests that people are more comfortable and experienced

when reading on paper than on screen (Zaphiris & Kurniawan, 2001; Hak Joon & Joan, 2013).

5.2.2 Saccade Duration

Results

This experiment was designed to calculate the saccades duration per participant using the raw eye tracking data. The total saccade duration for participants who read on paper was the least. The mean saccade duration taken by participants who read on mobile device was 1:02 minutes, participants who read on paper had mean saccade duration of 0:35 minutes and participant who read on screen had a mean of 0:55 minutes. Saccade duration increases with time on task (McGregor & Stern, 1996). In this experiment, participants that read on computer screen and those who read on mobile device had more fixation counts than those that read on paper.

5.2.3 Total Duration

Results

The experiment was designed to test if there were differences in the total duration when reading on paper, screen or mobile device. Participants who read on paper completed in the shortest time. Those that read text on the computer screen had the most reading duration. A One Way ANOVA was used to test if the differences in the duration were significant. The p-value was 0.11, which was more than the alpha level of 0.05. This meant that there were no statistically significant differences in duration when they read on mobile, paper and computer screen.

Existing literature suggests that though people still prefer reading on paper, the differences when reading on paper and screen are declining because of the improvement in screen display technology. Ergonomics is one of the most significant factors in making electronic text less effective than printed text (McGrail, 2007; Woody & Daniel, 2010). Students can now easily read text on tablet PCs like they are holding a book (Dundar & Akcayir, 2012). Tablet PCs are ergonomic. Users can also change the font size of characters on display.

Implications for Design

Designers of e-learning materials must find ways of making reading from the screen less straining. According to Muter and Maurutto (1991), the differences when reading on paper and screen cause different reading experiences on media. These include the differences in distance between the reader and the media, angle of the reading material, character shape, resolution, characters per line, lines per page, words per page, inter-line spacing, left justification versus full justification, margins, posture of the reader, familiarity with the medium and contrast ratio between characters and background, posture of the reader and familiarity with the medium.

A column layout may be used for designing e-learning materials to be read on screen. Reading is slightly faster for text in two columns (Dyson, 2004). Baker (2005) provides evidence that left justified text is read faster than full justified text.

5.2.4 Fixation Count

Results

This study was designed to calculate the number of fixations taken by participants when they read on the different platforms. Participants that read on computer screen had the most fixation counts and those that read on paper had the least. The average fixation count for screen was 364, mobile was 322 and paper was 315. Visual effort is determined using measures based on eye gaze data namely: fixation counts and durations (Sharif & Maletic, 2010). Higher numbers of fixations and longer fixation durations may be related to difficulty in processing text (Reitbauer, 2008).

The screen had the most regressions. The average regressions for the computer screen were 108, participants who read on paper had an average of 75 regressions and those that read on mobile device had an average of 96 regressions. However the inferential statistics showed that the differences in fixation count on the platforms were statistically insignificant ($p = 0.573$). The gaze replay analysis revealed that most fixations for all participants landed on content words.

Implications for Design

Dyson (2004) reports that “Kolers, et al., 1981...found that single spacing required more fixations per line and reading time was longer. The results concluded that double line spacing was faster than single line spacing.”. A high number of regressions may be caused by users' decline of sense of orientation when reading long lines of text (single wide columns) online, most probably resulting in a bigger chance of getting lost and having to re-read the same words (Zaphiris & Kurniawan, 2001). Designing text in columns may improve readability and reduce the number of regressions.

5.2.5 Saccade Length

Results

Fixation and saccade points were used to calculate the length of saccades for each participant who read either on paper, mobile device or on computer screen. Participants who read on the computer screen had the longest total saccade length. The screen eye movements had a mean saccade length of 1129 cm, the mean for the paper saccade length was 562 cm and the mean saccade length for the mobile device was the least with 422 cm.

The Kruskal-Wallis, a non-parametric test was used to find out if there were statistically significant differences in the saccade length on different platforms. The p-value was 0.003, which was less than the alpha value of 0.05. This indicated that there were statistically significant differences in the saccade length of participants that read on screen, paper and on mobile device. There is a consistent relationship among the saccade's size, speed and duration. Thus the larger the saccade the longer its duration (Leigh & Kennard, 2004).

Implications for Design

Designers must take into account that the computer screen size is bigger than the size of paper or the size of mobile device. Dyson (2004) reported that longer sentences with more words are read faster than shorter ones. The optimal length must be between 50 and 70 characters per line and adding more may no longer improve the reading rate.

5.2.6 Comprehension

Results

The participants' overall comprehension was compared among students who read on paper, mobile device and on computer screen. Participants who read on paper obtained the most comprehension scores. The mean comprehension scores obtained by participants who read on paper were 84.71, those read on mobile device had a mean of 67.57 and the participants who read on screen had a mean of 71.14.

Existing literature suggests that people who read text on paper have more comprehension than those that read on screen (Mangen, et al., 2013; Hak Joon & Joan, 2013). Most people are now knowledgeable of technologies that provide the ability to annotate text online. They are also aware of new screens that have lower flicker rates and less glare, and of new lightweight laptops and tablet PCs but still prefer to read on paper (Spencer, 2006).

The ANOVA analysis revealed that the p-value was 0.163, which was more than the alpha level of 0.05. This meant that there were no statistically significant differences in the comprehension scores when reading on mobile, paper or on computer screen. Literature suggests that the comprehension differences when reading on paper and screen are declining. People are now accustomed to reading text on the screen. The quality of screens, i.e. flicker rate and contrast quality have improved.

According to Dundar and Akcayir (2012), tablet PCs are effective tools for reading electronic texts. The availability, display quality and ergonomics of tablet PCs have positive effects on students. Students can easily read text by orienting an iPad like a book. Tablet PCs can be used in horizontal or vertical position, which positively affects reading because rotating a tablet PC to a horizontal position provides a wider reading area.

Moreover, students are able to adjust the size of the text, allowing them to read more comfortably. Students can easily read a text by placing a tablet PC on their desktop, whereas looking at a monitor for an extended period could be tiresome. The findings in this study suggest that tablet PCs can be an effective solution for the ergonomic and

physical problems of reading electronic texts. Tablet PCs are more user friendly than other types of displays (CRT and LCD).

Implications for Design

Comprehension when reading on computer screen or mobile device must be improved. Paging through online text improves navigation and generally results in better comprehension than scrolling (Baker, 2005). In order for students to understand the text read, e-learning materials may make use of tool tips, an electronic dictionary to explain terminology. The e-learning materials must also allow students to take notes digitally.

5.2.7 Linearity

Results

The fixation coordinates from the eye tracking data were used to calculate linearity. RStudio, open access software was used to test linearity. The results showed that eye movements of participants that read on paper had more linearity. Reading on screen and mobile device was less linear. A thematic change may cause higher cognitive load and reduce inference building. Linear and narrative text seems to be suitable for learning and enhance focused attention more than nonlinear and non-narrative encyclopaedic texts (Zumbach & Mohraz, 2008).

Implications for Design

Text in multi columns may improve linearity. Linearity has implications on cognitive load. The optimal length of characters per line must be considered to avoid a decrease in linearity.

5.2.8 Use of paper, computers and mobile devices for educational purposes

Most students read university supplied printed materials than notes downloaded on computers or mobile devices. The percentages of students who use computers and mobile devices were calculated. Students currently use computers more than mobile devices for reading downloaded notes.

5.3 Conclusion

The results of this study indicate that the majority of students currently read their notes from the university supplied printed materials. Downloaded notes are read more on computer screen than on mobile device. The literature review and the results of this research point out that although people still prefer to read on paper, the differences in duration and comprehension when reading on paper, computer screen or on mobile device are decreasing. In this study there were no significant differences in comprehension, fixation duration and saccade duration. There were significant differences in saccade length and linearity of saccades.

Due to the development in technologies, i.e. improved screen designs for computers and mobile devices, the readability of text on computer screens and mobile devices has improved. People have more experience in reading from screens. E-readers have annotation, highlighting features and other functions. The screen sizes of the new tablet PCs are similar to the width of paper which makes reading on tablet PCs favourable. Öquist and Lundin (2007) contend that readability on small screens is a bottleneck for mobile information access and small improvements in readability of text can lead to marked improvements in usability.

Students can easily read text by orienting an iPad like a book. Tablet PCs allow users to view content in either horizontal or vertical mode by rotating the device. This positively affects reading because rotating a tablet PC to a horizontal position provides a wider reading area (Dundar & Akcayir, 2012). Moreover, students are able to adjust the size of the text, allowing them to read more comfortably. The next chapter, Chapter 6 discusses the recommendations for designing content rich material based on the research findings.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter presents findings and recommendations that have been derived from the study. The study sought to find out the differences of reading patterns on paper, computer screen and on mobile device in order to optimise the design of computer based and mobile based learning material using eye tracking. The study made use of qualitative and quantitative methods to extract comprehensive data that could answer the research questions. The results enabled the researcher to draw conclusions about the data collected and make recommendations for future practice and study. Section 6.2 summarises the major research findings, section 6.3 provides the recommendations based on the research findings. The limitations of the study are discussed in section 6.4. Section 6.5 discusses the future work. Section 6.6 is the conclusion section and focusses on the core findings based on the objectives of the study.

6.2 Major Findings

The main questions were:

How can we optimise the design of computer based and mobile based e-learning material using students' eye tracking patterns when studying how students interact with the paper based HCI study guide and the electronic version of the study guide respectively? In order to answer the main question, the researcher had to answer the sub questions below.

6.2.1 How do the eye tracking patterns of students differ when they read the same content on paper, on a computer screen and on a mobile device respectively?

Eye tracking experiments were conducted to analyse the differences of reading patterns on paper, computer and on mobile device. The inferential statistical analysis revealed that there were no significant differences in duration, fixation count and comprehension

when reading on the different platforms. There were significant differences in the saccades' length and linearity.

6.2.2 How do students use computers and mobile devices for learning?

Participants were requested to give details of how they use computers and mobile devices for educational purposes. The majority of the students still read from the university printed material. More students reported using computers than mobile devices for downloading and reading notes.

Mobile devices learning theories include behaviourist, constructivist, situated, collaborative, informal, lifelong and coordination (see Section 2.3.3). Students reported that they engaged in collaborative activities to share resources through short message services, emails, Facebook, and Twitter. Lifelong learning is supported by mobile devices as learning materials are readily accessible regardless of location or time (Naismith, et al., 2004). Due to their portability, mobile devices promote ongoing, continuous development. People continually enhance their knowledge and skills and participate in a process of continuing vocational and professional development (Sharples, 2000). Some students also revealed that they play games on their computers and on mobile devices.

6.3 Recommendations

Paper has good readability and understandability. Based on the findings from the study, the following recommendations are suggested.

6.3.1 How should paper based material be adapted for delivery on a computer screen?

Recommendation 1

In this study, the saccade length for participants who read on computer screen was the longest. E-learning designers must avoid designing text that runs across the entire screen. Some readers feel overwhelmed by strings of words that stretch all the way across their screen. The optimal characters per sentence must be considered for more linear reading. The ideal measurement for displaying text on screen is the 50% column

“rule”, with an optimal length of characters per line in a column (SHIFT eLearning, 2013). Enough white space must be kept between the columns. Text split into columns improves comprehension and reduces the reading duration (Dyson, 2004).

Recommendation 2

The eye tracking experiments used in this study did not cater for students with disabilities. To attain accessibility for all, the online content must also be available to all users including those with disabilities. E-learning designers must incorporate assistive technologies such as screen readers, screen magnifiers, voice-recognition software, scanning software, audio presentations for the visually impaired, switches and mouse devices (Gilmore, 2004).

E-learning systems must provide people with disabilities with adaptive and personalised learning experiences that are tailored to their particular educational needs and personal characteristics (see Section 2.5.2). In the MoodleAcc+ application, if a visually impaired user selects his type of disability, the appropriate auditory components will be presented in his course, if a colour blind student selects his type of disability, colour images will be replaced by grey images in the presented course and Braille settings will be presented in the course for blind students.

Recommendation 3

E-learning designers must check the readability of pages on a few major screen resolutions. Designers must ensure that the page displaying the content is readable under different resolutions. Multiple columns must be checked if they are viewable for users whose screens have a lower resolution.

Recommendation 4

Comprehension when reading text on computer screen can also be improved by making use of tool tips that are linked to the relevant words or phrases, to explain technical or scientific terms used in the text area.

Recommendation 5

Paging must be used for text to be read on a computer screen as it results in better comprehension than scrolling (Baker, 2005).

6.3.2 How should paper based material be adapted for delivery on a mobile device?

Recommendation 1

In this study, participants had to scroll up and down in order to read the content. Some scrolled to read previously read text. Other page navigation options must be made available to users. E-learning material designers may use paging to link pages for users who would want to avoid scrolling. This can improve flexibility and reduce the reading duration (Öquist & Lundin, 2007).

Recommendation 2

Although students with disabilities did not take part in the study, assistive technologies and adaptive e-learning platforms must be used to ensure that online content is accessible to all users.

Recommendation 3

As seen from the results, reading text on paper was faster. A person reading on paper can choose positions suitable depending on the luminance from the environment. In order to achieve that for mobile devices, the devices must all automatically adjust their luminance in accordance with brightness of their surroundings.

Recommendation 4

Mobile devices must automatically adjust font size depending on the dimensions of the device as devices differ in sizes. Users must also be given option to change the font size.

Recommendation 5

The document types chosen by e-learning developers must be supported by mobile devices so as to eliminate the incompatibility of software problem.

Recommendation 6

Mobile devices must support fragmented reading. Jakob Nielsen recommends the use of shorter sentences and shorter paragraphs, use of more white space and bulleted lists (Nielsen, 1997).

6.3.3 How do students currently use computers and personal mobile devices for educational purposes?

Recommendation

More students currently use computers than mobile devices to read notes online. Students must be educated on the potential use of computers and mobile technology for learning. These include;

- information on collaborative tools and resources that are available on myUnisa
- electronic book tools that enable students to highlight sections of digitized books
- the capability to annotate directly on Web documents or pages

Online educational materials must be accessible to all students and also viewable in mobile format.

6.4 Limitations of the Study

Only thirty students took part in the study. These were students that had registered for the INF1520 module and lived in Johannesburg or Pretoria. The study did not include students with disabilities. Future research may include a larger number of students, disabled or able bodied drawn from various departments and regions. The study was conducted at the usability laboratory. Students may read differently under the duress of reading in controlled research laboratory.

6.5 Future Work

E-learning designers must provide tools and not just content. They can make use of video, audio, and animation to support their learning and communication. Video stories from experts and audio footages with questions may be used in mobile learning to help students remember the content.

This study aimed to enhance the readability of the INF1520 study guide. UNISA e-learning material designers may in future use the recommendations for the INF150 to design computer screen and mobile based content rich learning material for other modules. A research that involves students with disabilities must be carried out in order

to understand the complex issues, interactions and disabled learners' requirements for accessible e-learning, compatible assistive technologies and effective learning support. Equal access to on-line learning must be available to all students.

6.6 Conclusion

This primary objective of this study was to optimise the usability of content rich e-learning material. The secondary objectives were to identify the differences of reading patterns on paper, computer screen and on mobile device and derive guidelines with respect to the design of content rich online learning material. The researcher also had to obtain information on how students currently use computers and mobile devices for learning.

The eye tracking experiments and observations identified the similarities and differences of reading patterns on different platforms. More students currently use computers than mobile devices for reading their educational materials. Greater equivalence in computer and paper based tasks is being achieved today than a decade ago due to the developments in display screens and the advent of new types of mobile devices (Noyes & Garland, 2008).

In this study, the learning theories and design principles were paramount in addressing the objectives of the study. Recommendations based on the results of the study were given on how computer screen and mobile based learning materials can be designed.

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APPENDICES

Appendix A: Attendance List

| <i>Participant</i> | <i>Platform</i> | <i>Date</i> | <i>Time</i> |
|--------------------|---------------------------------|------------------------------------|-------------|
| Pilot Study | Mobile device, Paper and Screen | 7 th of February, 2013 | 08:00 AM |
| Pilot Study | Mobile device, Paper and Screen | 8 th of February, 2013 | 08:00 AM |
| M1 | Mobile device | 13 th of February, 2013 | 09:00 AM |
| M2 | Mobile device | 12 th of February, 2013 | 09:00 AM |
| M3 | Mobile device | 13 th February, 2013 | 03:00 PM |
| M4 | Mobile device | 12 th of February, 2013 | 08:00 AM |
| M5 | Mobile device | 13 th of February, 2013 | 10:00 AM |
| M6 | Mobile device | 12 th of February, 2013 | 09:00 AM |
| M7 | Mobile device | 13 th of August, 2013 | 09:00 AM |
| M8 | Mobile device | 15 th of August, 2013 | 10:00 AM |
| M9 | Mobile device | 15 th of August, 2013 | 10:00 AM |
| M10 | Mobile device | 16th of August, 2013 | 10:00 AM |
| P1 | Paper | 12th of February, 2013 | 10:00 AM |
| P2 | Paper | 12 th of February, 2013 | 01:00 PM |
| P3 | Paper | 12 th February, 2013 | 09:30 AM |
| P4 | Paper | 13 th of February, 2013 | 10:30 AM |
| P5 | Paper | 12 th February, 2013 | 02:00 PM |
| P6 | Paper | 13 th of February, 2013 | 09:00 AM |
| P7 | Paper | 13th of August, 2013 | 11:00 AM |
| Pilot Study | Mobile device, Paper and Screen | 8 th of August, 2013 | 09:00 AM |
| P8 | Paper | 22nd of January, 2014 | 10:00 AM |
| P9 | Paper | 24th of January, 2014 | 09:00 AM |
| P10 | Paper | 24th of January, 2014 | 10:45 AM |
| S1 | Screen | 15 th of February, 2013 | 10:00 AM |
| S2 | Screen | 12th of February, 2013 | 12:30 PM |
| S3 | Screen | 13 th of February, 2013 | 10:00 AM |
| S4 | Screen | 12 th of February, 2013 | 10:30 AM |
| S5 | Screen | 16 th of August, 2013 | 10:00 AM |
| S6 | Screen | 16th of August, 2013 | 11:30 AM |
| Pilot Study | Mobile device, Paper and Screen | 21 st of January, 2014 | 09:00 AM |

| | | | |
|-----|----------------------------|-----------------------|----------|
| S7 | Screen | 22nd of January, 2014 | 11:00 AM |
| S8 | Screen | 23rd of January, 2014 | 10:30 AM |
| S9 | Screen | 23rd of January, 2014 | 12:00 PM |
| S10 | Screen | 22nd of January, 2014 | 11:30 AM |
| KEY | | | |
| M* | Mobile device participants | | |
| P* | Paper participants | | |
| S* | Screen participants | | |

Appendix B: Ethical Clearance Form

**UNIVERSITY OF SOUTH AFRICA
COLLEGE OF SCIENCE, ENGINEERING AND TECHNOLOGY**

ETHICAL CLEARANCE APPLICATION FORM

Date: 2013/01/14

PLEASE NOTE THAT THE FORM MUST BE COMPLETED IN TYPED SCRIPT. HANDWRITTEN APPLICATIONS WILL NOT BE CONSIDERED.

| |
|------------------------------------|
| SECTION 1: PERSONAL DETAILS |
|------------------------------------|

| | | |
|-----------|---|--|
| 1.1 | Full Name and Surname of Applicant: | BONGEKA MPOFU |
| 1.2 | Title (Ms/ Mr/ Mrs/ Dr/ Professor/etc.): | Ms |
| 1.3 | Student Number (where applicable): | 49131699 |
| | Staff Number (where applicable): | |
| 1.4 | School: | School of Computing |
| 1.5 | College: | College of Science, Engineering and Technology |
| 1.6 | Campus: | Pretoria Main Campus |
| 1.7 | Existing Qualifications: | BSc Honours |
| 1.8 | Proposed Qualification for Project: (In the case of research for degree purposes) | MSc in Computing |
| 2. | Contact Details | |
| | Telephone Number | 011 3482927 |
| | Cell. Number | 0726389145 |
| | e-Mail address | bongielondy@yahoo.com |
| | Postal address (in the case of students and external applicants) | P.O Box 74519 TURFFONTEIN,JOHANNESBURG |

3. SUPERVISOR/ PROJECT LEADER DETAILS

| NAME | TELEPHONE NO. | EMAIL | SCHOOL / INSTITUTION | QUALIFICATIONS |
|----------------------------|---------------|---------------|----------------------|----------------|
| 3.1 Prof Helene Gelderblom | 012 429 6631 | geldejh@unisa | UNISA | PhD (UNISA) |
| 3.2 Mr Tobie van Dyke | 012 429 6676 | vdyktj @unisa | UNISA | |

SECTION 2: PROJECT DESCRIPTION

Please do not provide your full research proposal here: what is required is a short project description of not more than two pages that gives, under the following headings, a brief overview spelling out the background to the study, the key questions to be addressed, the participants (or subjects) and research site, including a full description of the sample, and the research approach/ methods

| | |
|---|---|
| 2.1 Project title | USING EYE TRACKING TO OPTIMISE THE USABILITY OF CONTENT RICH E-LEARNING MATERIAL |
| 2.2 Location of the study (where will the study be conducted) | UNIVERSITY OF SOUTH AFRICA |
| 2.3 Objectives of and need for the study (Set out the major objectives and the theoretical approach of the research, indicating briefly, why you believe the study is needed.) | The main objective of the study is to optimise the usability of content-rich computer and mobile based e-learning material. |
| 2.4 Questions to be answered in the research (Set out all the critical questions which you intend to answer by undertaking this research.) | Main question: How can we optimise the design of computer based and mobile based e-learning material using students' eye tracking patterns when studying the paper based |

| | |
|----------------------------------|---|
| | <p>HCI study guide and the electronic version of the study guide respectively?</p> <p>Sub-questions:</p> <p>How do the eye tracking patterns of students differ when they read the same content on paper and on a computer screen respectively?</p> <p>How do the eye tracking patterns of students differ when they read the same content on a mobile device and on a computer screen?</p> <p>How should paper based material be adapted for delivery on a computer screen and on mobile device?</p> |
| 2.5 Conflict of Interest: | N/A |

2.5 Research approach/ methods

(This section should explain how you will go about answering the critical questions which you have identified under 2.4 above. Set out the approach within which you will work, and indicate in step-by-step point form the methods you will use in this research in order to answer the critical questions).

Find attached a copy of questions to be used in the interview. The interviews will be an informal and semi-structured.

2.6 Proposed work plan

Set out your intended plan of work for the research, indicating important target dates necessary to meet your proposed deadline.

| STEPS | DATES |
|-------------------------------------|--------------------------|
| 1. Experiments in the usability lab | February 2013 |
| 2. Data Analysis | March 2013 to April 2013 |
| 3. Writing up of results | May 2013 – October 2013 |

SECTION 3: ETHICAL ISSUES

The UNISA Ethics Policy¹ applies to all members of staff, graduate and undergraduate students who are involved in research on or off the campuses of UNISA. In addition, any person not affiliated with UNISA who wishes to conduct research with UNISA students and/or staff is bound by the same ethics framework. Each member of the University community is responsible for implementing this Policy in relation to scholarly work with which she or he is associated and to avoid any activity which might be considered to be in violation of this Policy.

All students and members of staff must familiarize themselves with AND sign an undertaking to comply with the University's "Code of Conduct for Research" (the policy can be accessed at the following URL: http://cm.unisa.ac.za/contents/departments/res_policies/docs/ResearchEthicsPolicy_apprvCounc_21Sept07.pdf).

QUESTION 3.1

| Does your study cover research involving: | YES | NO |
|--|-----|----|
| Adults | √ | |
| Persons who are intellectually or mentally impaired | | √ |
| Persons who have experienced traumatic or stressful life circumstances | | √ |
| Persons who are HIV positive | | √ |
| Persons highly dependent on medical care | | √ |
| Persons in dependent or unequal relationships | | √ |
| Persons in captivity | | √ |
| Persons living in particularly vulnerable life circumstances | | √ |

If "Yes", indicate what measures you will take to protect the autonomy of respondents and (where indicated) to prevent social stigmatisation and/or secondary victimisation of respondents. If you are unsure about any of these concepts, please consult your supervisor/ project leader.

Participant's identity will not be revealed. In cases where photographs of usability testing are to be published in the dissertation or in ensuing conference papers and journals articles, the researcher will request for specific permission from the participants.

¹ The URL for this is:

http://cm.unisa.ac.za/contents/departments/res_policies/docs/ResearchEthicsPolicy_apprvCounc_21Sept07.pdf

QUESTION 3.2

| Will data collection involve any of the following: | YES | NO |
|--|-----|----|
| Access to confidential information without prior consent of participants | | √ |
| Participants being required to commit an act which might diminish self-respect or cause them to experience shame, embarrassment, or regret | | √ |
| Participants being exposed to questions which may be experienced as stressful or upsetting, or to procedures which may have unpleasant or harmful side effects | | √ |
| The use of stimuli, tasks or procedures which may be experienced as stressful, noxious, or unpleasant | | √ |
| Any form of deception | | √ |
| Any use of materials harmful to human beings | | √ |

If "Yes", to any of the previously mentioned explain and justify. Explain, too, what steps you will take to minimise the potential stress/harm.

Participants will be shown the e-learning material to be read. To set them at ease, the researcher will inform the participants, before the experiment is carried out, that it is not their proficiency or ability being tested, but the usability of the e-learning material.

QUESTION 3.3

| Will any of the following instruments be used for purposes of data collection: | YES | NO |
|--|-----|----|
| Questionnaire | √ | |
| Survey schedule | | √ |
| Interview schedule | | √ |
| Psychometric test | | √ |
| Other/ equivalent assessment instrument | √ | |

If "Yes", attach copy of research instrument. If data collection involves the use of a psychometric test or equivalent

assessment instrument, you are required to provide evidence that the measure is likely to provide a valid, reliable, and unbiased estimate of the construct being measured as an attachment. If data collection involves interviews and/or focus groups, please provide a list of the topics to be covered/ kinds of questions to be asked as an attachment. Explain the withdrawal or discontinuation criteria of respondents.

All participants will be asked to complete a basic demographic questionnaire to establish their age, level of education and level of computer experience. Participants will be observed while using the software in the School of Computing's usability laboratory. Each participant will be required to complete a questionnaire that will consist of comprehension questions related to the text participants will read. Evaluation questions relating to their reading experience will also be included.

QUESTION 3.4

| Will the autonomy of participants be protected through the use of an informed consent form, which specifies (in language that respondents will understand): | YES | NO |
|--|------------|-----------|
| The nature and purpose/s of the research | √ | |
| The identity and institutional association of the researcher and supervisor/project leader and their contact details | √ | |
| The fact that participation is voluntary | √ | |
| That responses will be treated in a confidential manner | √ | |
| Any limits on confidentiality which may apply | √ | |
| That anonymity will be ensured where appropriate (e.g. coded/ disguised names of participants/ respondents/ institutions) | √ | |
| The fact that participants are free to withdraw from the research at any time without any negative or undesirable consequences to themselves | √ | |
| The nature and limits of any benefits participants may receive as a result of their participation in the research | √ | |
| Is a copy of the informed consent form attached? | √ | |

If not, this needs to be explained and justified, also the measures to be adopted to ensure that the respondents fully understand the nature of the research and the consent that they are giving.

QUESTION 3.5

Specify what efforts been made or will be made to obtain informed permission for the research from appropriate authorities and gate-keepers (including caretakers or legal guardians in the case of minor children)?

Participants will be required to sign a consent form.

QUESTION 3.6

STORAGE AND DISPOSAL OF RESEARCH DATA/SAMPLES:

Please note that the research data should be kept for a period of at least five years in a secure environmental safe location by arrangement with your supervisor. In the case of samples will the samples be destroyed?

How will the research data be disposed of? Please provide specific information, e.g. shredding of documents incineration of videos, cassettes, etc.

After 5 years data will be disposed of as follows:

- Permanent deleting of files
- Shredding of hard copy documents
- Incineration of videos.

QUESTION 3.7

In the subsequent dissemination of your research findings – in the form of the finished thesis, oral presentations, publication etc. – how will anonymity/ confidentiality be protected?

The names of the participants will not be published anywhere.

QUESTION 3.8

Is this research supported by funding that is likely to inform or impact in any way on the design, outcome and dissemination of the research?

YES

NO

√

If yes, this needs to be explained and justified.

QUESTION 3.9

| | | |
|---|-----|---------|
| Has any organization/company participating in the research or funding the project, imposed any conditions to the research | YES | NO √ |
|---|-----|---------|

If yes, please indicate what the conditions are.

SECTION 4: FORMALISATION OF THE APPLICATION

APPLICANT

I, **Bongeka Mpofu** have familiarised myself with the UNISA Ethics policy, the form completed and undertake to comply with it. The information supplied above is correct to the best of my knowledge. I have read the policy for research ethics of UNISA and the contents of my application as presented to the CREC of CSET is a true and accurate reflection of the methodological and ethical implications of my proposed study. I shall carry out the study in strict accordance with the approved proposal and the ethics policy of Unisa. I shall maintain the confidentiality of all data collected from or about research participants, and maintain security procedures for the protection of privacy. I shall record the way in which the ethical guidelines as suggested in the proposal has been implemented in my research. I shall notify URERC in writing immediately if any change to the study is proposed or if any adverse event occurs or when injury or harm is experienced by the participants attributable to their participation in the study.

NB: PLEASE ENSURE THAT THE ATTACHED CHECK SHEET IS COMPLETED

SIGNATURE OF APPLICANT

DATE

SUPERVISOR / DIRECTOR OF SCHOOL

NB: PLEASE ENSURE THAT THE APPLICANT HAS COMPLETED THE ATTACHED CHECK SHEET AND

| | |
|---|--------------------|
| <p>THAT</p> <p style="text-align: center;">THE FORM IS FORWARDED TO YOUR COLLEGE RESEARCH COMMITTEE FOR FURTHER ATTENTION</p> | |
| <p>.....</p> <p>NAME OF SUPERVISOR/ PROJECT LEADER</p> <p>.....</p> <p>.....</p> | |
| <p>SIGNATURE</p> | <p>DATE</p> |

| RECOMMENDATION OF COLLEGE RESEARCH AND ETHICS COMMITTEE | |
|---|---|
| <p>The application is (please tick):</p> | |
| <input type="checkbox"/> | Approved |
| <input type="checkbox"/> | Recommended and noted |
| <input type="checkbox"/> | Not Approved, referred back for revision and resubmission |
| <p>.....</p> <p>NAME OF CHAIRPERSON:</p> <p>.....</p> <p>.....</p> | |
| <p>SIGNATURE</p> | <p>DATE</p> |

| RECOMMENDATION OF SENATE RESEARCH AND ETHICS COMMITTEE |
|--|
| <p>.....</p> |

NAME OF CHAIRPERSON:

.....

.....

SIGNATURE

DATE

ETHICAL CLEARANCE APPLICATION FORM

CHECK SHEET FOR APPLICATION

PLEASE TICK

| | |
|--|--|
| 1. Form has been fully completed and all questions have been answered | |
| 2. Questionnaire/interview protocol attached (where applicable) | |
| 3. Informed consent document attached (where applicable) | |
| 4. List of acronyms and abbreviations should be attached. | |
| 5. Approval from relevant authorities obtained (and attached) where research involves the utilization of space, data and/or facilities at other institutions/organisations | |
| 6. Signature of Supervisor / project leader | |
| 7. Application forwarded to College Research Committee for recommendation | |
| 8. A complete copy of the proposal should be available if so requested. | |

Appendix C: Letter of Approval

UNISA



Bongeka Mpofu (49131699)
School of Computing
UNISA
Pretoria

2013-02-06

Permission to conduct research project

Ref: 049/BM/2013

The request for ethical approval for your MSc in Computing research project entitled "Using Eye Tracking to Optimise the Usability of Content Rich E-Learning Material" refers.

The College of Science, Engineering and Technology's (CSET) Research and Ethics Committee (CREC) has considered the relevant parts of the studies relating to the abovementioned research project and research methodology and is pleased to inform you that ethical clearance is granted for your study as set out in your proposal and application for ethical clearance.

Therefore, involved parties may also consider ethics approval as granted. However, the permission granted must not be misconstrued as constituting an instruction from the CSET Executive or the CSET CREC that sampled interviewees (if applicable) are compelled to take part in the research project. All interviewees retain their individual right to decide whether to participate or not.

We trust that the research will be undertaken in a manner that is respectful of the rights and integrity of those who volunteer to participate, as stipulated in the UNISA Research Ethics policy. The policy can be found at the following URL:

http://cm.unisa.ac.za/contents/departments/res_policies/docs/ResearchEthicsPolicy_apprvCounc_21Sept07.pdf

Please note that if you subsequently do a follow-up study that requires the use of a different research instrument, you will have to submit an addendum to this application, explaining the purpose of the follow-up study and attach the new instrument along with a comprehensive information document and consent form.

Yours sincerely

Chair: School of Computing Ethics Sub-Committee



University of South Africa
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PO Box 392 UNISA, 0003 South Africa
Telephone + 27 12 429 6122 Facsimile + 27 12 429 6848
www.unisa.ac.za/cset

Appendix D: Consent form

INFORMED CONSENT

for the Master's study entitled:

Using eye tracking to optimize the usability of content rich e-learning material

Conducted by Bongeka Mpofu at UNISA

This study is conducted for the purposes of enhancing the readability and learnability of study material on computer screen and on mobile devices.

I am voluntarily taking part in this eye tracking study.

I understand that:

- my eye gaze patterns will be recorded on the computer
- data and information I share today will be handled confidentially and anonymously
- I can withdraw from this study at any time and have the information provided in my questionnaires removed in entirety from this study
- my personal data will be protected to the extent provided by law and all references to information about my data will be kept anonymous to the extent provided by law.

Signature: _____

Name: _____ Contact details (*cell no*) _____

(*Please print*)

Date: _____

Appendix E: Questionnaires

1. Pre-test Questionnaire

PRE-EXPERIMENT QUESTIONNAIRE

for the Master's study entitled:

Using eye tracking to optimize the usability of content rich e-learning material

Conducted by Bongeka Mpofu at UNISA

Mark the appropriate answer by placing an X next to it or write down your answer where applicable.

| | | | | | | |
|---|----------|-------|-------|--------|-------|----------|
| 1. Gender | | Male | | Female | | |
| | | | | | | |
| 2. Age | Below 20 | 21-25 | 26-30 | 30-40 | 40-50 | Above 50 |
| | | | | | | |
| 3. Is English your home language? | | | | | | |
| | | | | | | |
| 4. Describe your level of computer skills (choose one). | | | | | | |
| Very Low - I have never used a computer | | | | | | |
| Low - I perform only simple, repetitive tasks | | | | | | |
| Average – I cope with general computer tasks | | | | | | |
| Very High - I do complex computer programming or other specialized tasks and solve my own computer problems | | | | | | |
| High – I perform specialized tasks and learn new skills by myself | | | | | | |
| 5. For which of the following do you use a computer? (You can choose more than one) | | | | | | |
| To receive or send emails, read news and notes | | | | | | |
| To browse www and use online applications (e.g. online spreadsheets and presentation tools) | | | | | | |
| To download music. | | | | | | |
| Games, Facebook, twitter | | | | | | |

| | | |
|---|--|--|
| For myUnisa (or other study related Internet access) | | |
| 6. For which of the following do you use a cell phone? (You can choose more than one) | | |
| To receive or send emails. | | |
| To browse www and use online applications (e.g. online spreadsheets and presentation tools). | | |
| To download music | | |
| Games, Facebook twitter | | |
| For myUnisa (or other study related Internet access) | | |
| 7. Which of the following best describes your attitude towards the Internet on your phone? (Choose one) | | |
| I find the Internet and the applications very useful | | |
| My phone has the capabilities but I rarely use them | | |
| I cannot afford to use the Internet on my phone, but if I could I would. | | |
| I am not interested to use the Internet on my phone. | | |
| 8. Which of the following best describes how you read your study material | | |
| I study from printed material provided by the University. | | |
| I download the study material and then print it out to read it. | | |
| I download the study material and then read it on a computer. | | |
| I download the study material and then read it on a mobile phone. | | |

POST-EXPERIMENT QUESTIONNAIRE

for the Master's study entitled:

Using eye tracking to optimize the usability of content rich e-learning material

Conducted by Bongeka Mpofu at UNISA

Write down your answer in the spaces provided.

1. What does GUI stand for?

2. What was the most interesting information you read?

3. List 3 other things you remember reading.

4. What strengths of GUI were mentioned?

5. List examples of commonly used icons in interactive systems.

Appendix F: Post-test questionnaire with responses

POST-EXPERIMENT QUESTIONNAIRE

for the Master's study entitled:
Using eye tracking to optimise the usability of content rich e-learning material
Conducted by Bongeka Mpofu at Unisa

Write down your answer in the spaces provided.

| |
|--|
| 1. What does GUI stand for? |
| Graphical User Interface |
| 2. What was the most interesting information you read? |
| Cross-culture interpretation- Basically unlike text, graphics are more universally understood at first view. |
| 3. List 3 other things you remember reading. |
| Weaknesses of GUIs - Clutter - Ambiguity - Some text cannot be replaced by graphics |
| 4. What strengths of GUI were mentioned? |
| - Cross-culture interpretation - Vibrant colours makes GUIs more appealing |
| 5. List examples of commonly used icons in interactive systems. |
| keyboards, mouses, touch inputs. |

Appendix G: Gaze Replay Observation

Using eye tracking to optimize the usability of content rich e-learning material

OBSERVATION FORM

DATE: 18 March, 2013

TIME: 10:03am

The gaze replay was repeatedly watched and the following was noted per participant;

- thorough reading, coverage of at least half of each sentence
- type of eye movement, i.e. horizontal or vertical
- type of regressions, i.e. word, sentence, paragraph or entire page

The notes below are based on the observations of the participants' eye movements in the gaze replay. These give insights of how students read text on the different platforms.

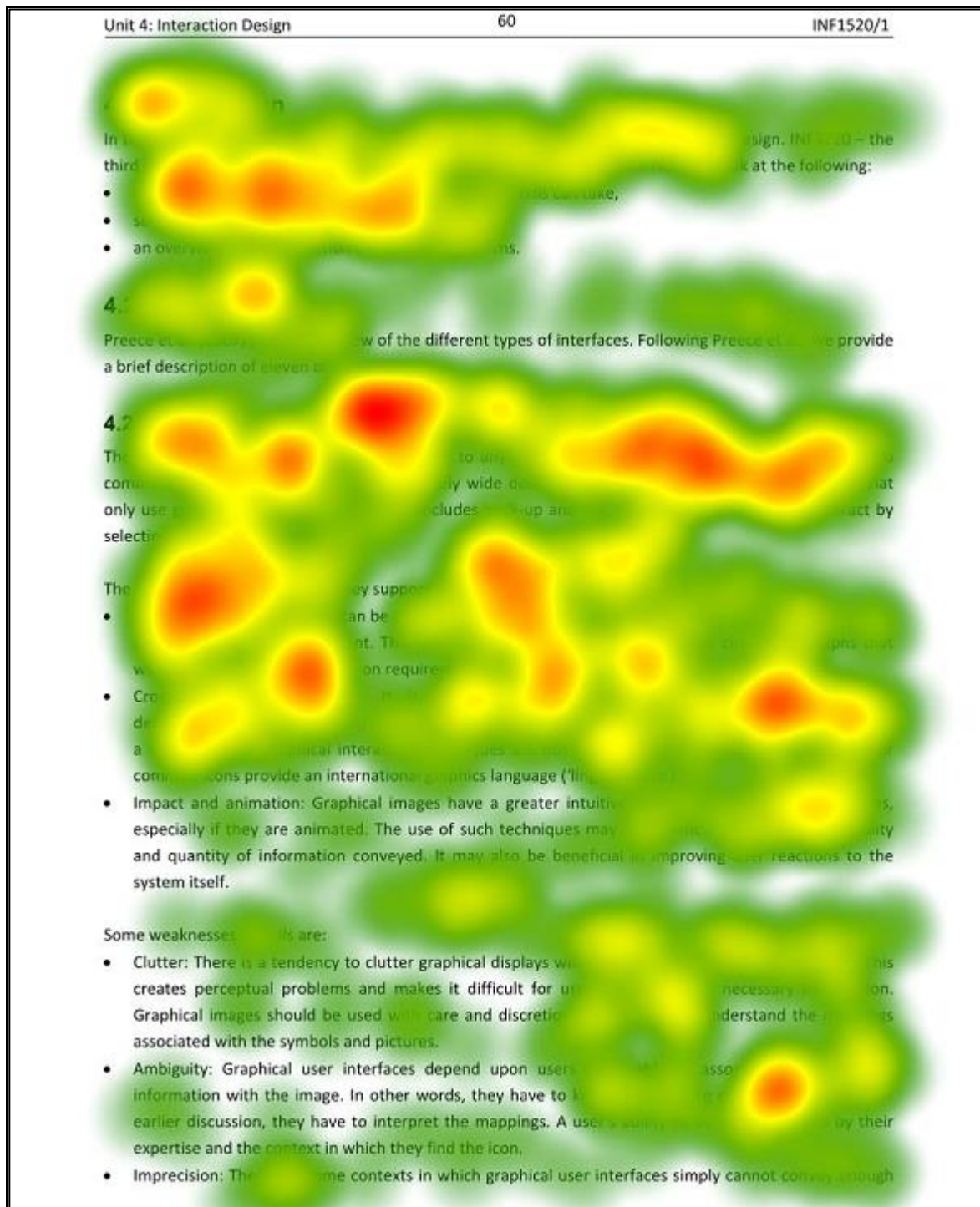
| <i>Participant</i> | <i>Reading Pattern</i> | <i>Regressions</i> | <i>Time spent reading the text</i> |
|--------------------|---|---|------------------------------------|
| M1 | There were mainly horizontal eye movements. The participant read more than half of all the sentences. | The participant read the whole document twice | 05:04 |
| M2 | The eye gaze showed multiple horizontal and few vertical eye movements. | There were few sentence and paragraph regressions. The participant scrolled to the beginning of the document to re-read the whole page. | 03:33 |
| M3 | The participant had many horizontal eye movements and few vertical ones. | The participant had multiple sentence and paragraph regressions, two whole page regressions. These increased the duration time. | 04:50 |
| M4 | The participant had multiple horizontal eye movements, few vertical eye movements. | There many sentence regressions. | 05:03 |

| | | | |
|------------|--|--|-------|
| M5 | The gaze replay revealed horizontal eye movements and vertical eye movements for moving to the next line to be read. | There were only sentence regressions. No paragraph nor whole page regressions were observed. | 02:31 |
| M6 | There were many horizontal eye movements that reached the end of most sentences. Few vertical eye movements were observed. | The participant had few regressions. | 03:56 |
| M7 | Sentences that were read were not well covered. The horizontal eye movements were short and some did not reach the end of the sentences. | The gaze replay shows that the participant skipped many sentences. | 03:26 |
| M8 | There were many horizontal and vertical eye movements. | The participant read the whole document twice. | 04:24 |
| M9 | There was a wide coverage of sentences. Many fixations per line were observed. | There were many sentence regressions. | 03:53 |
| M10 | Multiple horizontal eye movements which covered more than half of the sentences were observed. | The participant re-read most of the sentences in the document. | 03:34 |
| P1 | There were short horizontal eye movements. A few vertical eye movements were observed. | The participant read the text in a short time. Very few regressions were observed. | 02:02 |
| P2 | The participant had many horizontal eye movements and less vertical ones. | Participant had few sentence regressions and no whole page regressions. | 02:27 |
| P3 | Many sentences were not read in entirety | There were few sentence and paragraph regressions. The participant had no page regressions. | 03:41 |
| P4 | The dot and the trailing line in the gaze replay covered many sentences. | The participant took most of his time reading the text in the document. Many parts of the document were re-read. | 05:51 |

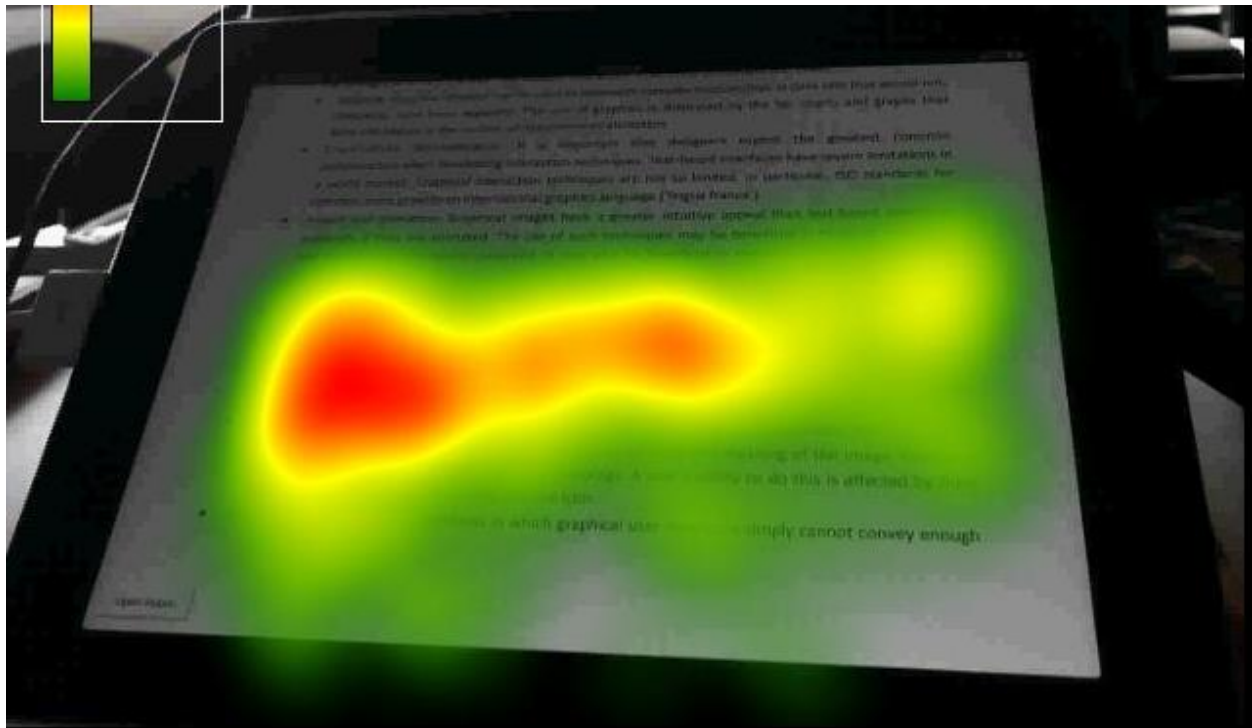
| | | | |
|------------|--|--|-------|
| P5 | There were multiple horizontal eye movements. Some were shorter than half the line of the sentences. | There were many forward passes and few regressions. | 03:15 |
| P6 | The participant took her time to read the whole document. | She read the whole document twice covering most of the sentences. | 03:21 |
| P7 | Many horizontal eye movements were observed but they were short. | The participant had very few backward passes. | 02:35 |
| P8 | The horizontal eye movements were long and most of them reached the end of the sentences. | The participant read the whole document, and then read the first two paragraphs again. | 03:12 |
| P9 | Almost all sentences were read but the horizontal eye movements were short. | There were only sentence regressions, no paragraph nor whole page regressions | 02:41 |
| P10 | Most words in the document were read. | The participant re-read the sentences and paragraph but did not read the whole page again. | 03:56 |
| S1 | The document was read thoroughly. There were many horizontal and vertical eye movements. | The entire document was read three times. | 04:30 |
| S2 | The horizontal eye movements reached the end of the sentences. | The participant made backward passes to previously read words. | 03:03 |
| S3 | The horizontal eye movements covered almost all words in the document. | All paragraphs in the document were read twice. | 07:14 |
| S4 | There were horizontal eye movements; more than a half of the sentences were read. | There were multiple sentence and paragraph regressions. | 05:11 |
| S5 | The horizontal eye movements reached the end of sentences. | The participant had many sentence and paragraph regressions. | 04:25 |
| S6 | Multiple horizontal eye movements and few vertical lines were observed. | Some paragraphs were read more than once. | 03:56 |

| | | | |
|------------|--|--|-------|
| S7 | Wider horizontal eye movements were recorded. | Participant re-read the second and third paragraphs after reading the entire page. | 04:47 |
| S8 | The horizontal eye movements covered most of the words in sentences. | There were backward passes to previously read words and paragraphs. | 03:27 |
| S9 | The page was read thoroughly. There were many horizontal eye movements. There were few vertical eye movements to the next line or paragraph. | The participant only had word and sentence regressions. | 03:11 |
| S10 | There were multiple horizontal and vertical eye movements. | The participant covered most of the sentences. Very few words were skipped. | 03:16 |


Appendix H: Heat maps and Gaze Replay



Heat map on computer screen



Heat map on mobile device



4.1 Introduction

In this unit we discuss a small selection of topics that are associated with interaction design. INF3720 – the third level module on HCI – covers the topic of interaction design in detail. Here we look at the following:

- the different forms that interfaces of interactive systems can take,
- some specific interaction design techniques
- an overview of the evaluation of interactive systems.

4.2 Interface Types

Preece et al. (2007) give an overview of the different types of interfaces. Following Preece et al., we provide a brief description of eleven of these.

4.2.1 Advanced Graphical Interfaces

The term graphical user interface (GUI) refers to any interactive system that uses pictures or images to communicate information. This is an extremely wide definition. It includes keyboard-based systems that only use graphics to present data. It also includes walk-up and use systems where users only interact by selecting portions of a graphical image.

The strength of GUIs is the way they support interaction in terms of (Shneiderman, 1998):

- Visibility:** Graphical displays can be used to represent complex relationships in data sets that would not, otherwise, have been apparent. This use of graphics is illustrated by the bar charts and graphs that were introduced in the section on requirements elicitation.
- Cross-cultural communication:** It is important that designers exploit the greatest common denominators when developing interaction techniques. Text-based interfaces have severe limitations in a world market. Graphical interaction techniques are not so limited. In particular, ISO standards for common icons provide an international graphics language ('lingua franca').
- Impact and animation:** Graphical images have a greater intuitive appeal than text-based interfaces, especially if they are animated. The use of such techniques may be beneficial in terms of the quality and quantity of information conveyed. It may also be beneficial in improving user reactions to the system itself.

Some weaknesses of GUIs are:

- Clutter:** There is a tendency to clutter graphical displays with a vast array of symbols and colours. This creates perceptual problems and makes it difficult for users to extract the necessary information. Graphical images should be used with care and discretion if people are to understand the meanings associated with the symbols and pictures.
- Ambiguity:** Graphical user interfaces depend upon users being able to associate some semantic information with the image. In other words, they have to know the meaning of the image. From our earlier discussion, they have to interpret the mappings. A user's ability to do this is affected by their expertise and the context in which they find the icon.
- Imprecision:** There are some contexts in which graphical user interfaces simply cannot convey enough

(Picture included with permission of the participant)

Appendix I: Reading Speed/ Number of Words Read Per Minute

| Reading Speed on Mobile Device | | | | | | | | | | |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|----------------|
| P1 | | | | | | | | | | |
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total Avg Word |
| <i>Duration (min:sec)</i> | 00:43 | 00:24 | 00:36 | 00:25 | 00:24 | 01:01 | 00:31 | 00:49 | 00:11 | 05:04 |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| <i>Reading Speed - (words per minute)</i> | 85 | 65 | 97 | 132 | 118 | 48 | 114 | 72 | 76 | 85 |
| <i>No of Words per minute</i> | 85 | | | | | | | | | |
| P2 | | | | | | | | | | |
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total Avg Word |
| <i>Duration (min:sec)</i> | 00:27 | 00:11 | 00:28 | 00:25 | 00:24 | 00:21 | 00:31 | 00:27 | 00:19 | 03:33 |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| <i>Reading Speed - (words per minute)</i> | 136 | 142 | 124 | 132 | 118 | 140 | 114 | 131 | 44 | 121 |
| <i>No of Words per minute</i> | 121 | | | | | | | | | |
| P3 | | | | | | | | | | |
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total Avg Word |
| <i>Duration (min:sec)</i> | 00:40 | 00:26 | 00:34 | 01:03 | 00:31 | 00:25 | 00:25 | 00:31 | 00:15 | 04:50 |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| <i>Reading Speed - (words per minute)</i> | 92 | 60 | 102 | 53 | 91 | 118 | 142 | 114 | 56 | 89 |
| <i>No of Words per minute</i> | 89 | | | | | | | | | |

P4

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words | |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|--|
| <i>Duration (min:sec)</i> | 00:37 | 00:23 | 00:31 | 00:45 | 00:39 | 00:35 | 00:27 | 00:41 | 00:25 | 05:03 | |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 | |
| <i>Reading Speed - (words per minute)</i> | 99 | 68 | 112 | 75 | 72 | 84 | 131 | 86 | 34 | 85 | |
| <i>No of Words per minute</i> | 85 | | | | | | | | | | |

P5

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words | |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|--|
| <i>Duration (min:sec)</i> | 00:15 | 00:18 | 00:25 | 00:22 | 00:11 | 00:17 | 00:17 | 00:15 | 00:11 | 02:31 | |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 | |
| <i>Reading Speed - (words per minute)</i> | 244 | 87 | 139 | 153 | 256 | 173 | 208 | 236 | 76 | 170 | |
| <i>No of Words per minute</i> | 170 | | | | | | | | | | |

P6

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words | |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|--|
| <i>Duration (min:sec)</i> | 00:23 | 00:33 | 00:34 | 00:51 | 00:24 | 00:19 | 00:21 | 00:18 | 00:13 | 03:56 | |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 | |
| <i>Reading Speed - (words per minute)</i> | 159 | 47 | 102 | 66 | 118 | 155 | 169 | 197 | 65 | 109 | |
| <i>No of Words per minute</i> | 109 | | | | | | | | | | |

P7

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words | |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|--|
| <i>Duration (min:sec)</i> | 00:34 | 00:11 | 00:31 | 00:28 | 00:23 | 00:12 | 00:19 | 00:38 | 00:10 | 03:26 | |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 | |
| <i>Reading Speed - (words per minute)</i> | 108 | 142 | 112 | 120 | 123 | 245 | 186 | 93 | 84 | 125 | |
| <i>No of Words per minute</i> | 125 | | | | | | | | | | |

P8

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words | |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|--|
| <i>Duration (min:sec)</i> | 00:42 | 00:20 | 00:27 | 00:37 | 00:34 | 00:17 | 00:21 | 00:51 | 00:15 | 04:24 | |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 | |
| <i>Reading Speed - (words per minute)</i> | 87 | 78 | 129 | 91 | 83 | 173 | 169 | 69 | 56 | 98 | |
| <i>No of Words per minute</i> | 98 | | | | | | | | | | |

P9

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words | |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|--|
| <i>Duration (min:sec)</i> | 00:31 | 00:16 | 00:41 | 00:29 | 00:21 | 00:22 | 00:23 | 00:35 | 00:15 | 03:53 | |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 | |
| <i>Reading Speed - (words per minute)</i> | 118 | 98 | 85 | 116 | 134 | 134 | 154 | 101 | 56 | 110 | |
| <i>No of Words per minute</i> | 110 | | | | | | | | | | |

P10

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
|---|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|------------------------------|
| Duration (min:sec) | 00:28 | 00:24 | 00:39 | 00:20 | 00:21 | 00:19 | 00:18 | 00:35 | 00:10 | 03:34 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 131 | 65 | 89 | 168 | 134 | 155 | 197 | 101 | 84 | 120 |
| No of Words per minute | 120 | | | | | | | | | |

Reading Speed on Screen

P1

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
|---|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| Duration (min:sec) | 00:37 | 00:31 | 00:36 | 00:58 | 00:24 | 00:35 | 00:25 | 00:23 | 00:01 | 04:30 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 99 | 50 | 97 | 58 | 118 | 84 | 142 | 154 | 840 | 95 |
| No of Words per minute | 95 | | | | | | | | | |

P2

| | | | | | | | | | | |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
| Duration (min:sec) | 00:13 | 00:07 | 00:15 | 00:13 | 00:35 | 00:21 | 00:31 | 00:27 | 00:21 | 03:03 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 282 | 223 | 232 | 258 | 81 | 140 | 114 | 131 | 40 | 141 |
| No of Words per minute | 141 | | | | | | | | | |

P3

| | | | | | | | | | | |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
| Duration (min:sec) | 01:07 | 00:45 | 00:34 | 01:15 | 00:40 | 00:36 | 00:42 | 00:55 | 00:38 | 07:12 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 55 | 35 | 102 | 45 | 71 | 82 | 84 | 64 | 22 | 60 |
| No of Words per minute | 60 | | | | | | | | | |

P4

| | | | | | | | | | | |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
| Duration (min:sec) | 00:37 | 00:23 | 00:31 | 01:04 | 00:39 | 00:19 | 00:26 | 00:41 | 00:31 | 05:11 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 99 | 68 | 112 | 53 | 72 | 155 | 136 | 86 | 27 | 83 |
| No of Words per minute | 83 | | | | | | | | | |

P5

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| Duration (min:sec) | 00:16 | 00:24 | 00:41 | 00:30 | 00:30 | 00:25 | 00:49 | 00:15 | 00:35 | 04:25 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 229 | 65 | 85 | 112 | 94 | 118 | 72 | 236 | 24 | 97 |
| No of Words per minute | 97 | | | | | | | | | |

P6

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| Duration (min:sec) | 00:23 | 00:33 | 00:34 | 00:51 | 00:24 | 00:19 | 00:21 | 00:20 | 00:13 | 03:58 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 159 | 47 | 102 | 66 | 118 | 155 | 169 | 177 | 65 | 108 |
| No of Words per minute | 108 | | | | | | | | | |

P7

| | | | | | | | | | | |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
| Duration (min:sec) | 00:21 | 00:40 | 00:20 | 00:47 | 00:55 | 00:09 | 00:19 | 00:42 | 00:34 | 04:47 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 174 | 39 | 174 | 71 | 51 | 327 | 186 | 84 | 25 | 90 |
| No of Words per minute | 90 | | | | | | | | | |

P8

| | | | | | | | | | | |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
| Duration (min:sec) | 00:25 | 00:13 | 00:34 | 00:18 | 00:29 | 00:19 | 00:13 | 00:31 | 00:25 | 03:27 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 146 | 120 | 102 | 187 | 97 | 155 | 272 | 114 | 34 | 124 |
| No of Words per minute | 124 | | | | | | | | | |

P9

| | | | | | | | | | | |
|---|--------------|--------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
| Duration (min:sec) | 00:23 | 00:30 | 00:26 | 00:18 | 00:17 | 00:15 | 00:18 | 00:42 | 00:02 | 03:11 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 159 | 52 | 134 | 187 | 166 | 196 | 197 | 84 | 420 | 135 |
| No of Words per minute | 135 | | | | | | | | | |

P10

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Word |
|---|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|-----------------------------|
| Duration (min:sec) | 00:14 | 00:12 | 00:25 | 00:29 | 00:18 | 00:20 | 00:14 | 00:41 | 00:23 | 03:16 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 261 | 130 | 139 | 116 | 157 | 147 | 253 | 86 | 37 | 131 |
| No of Words per minute | 131 | | | | | | | | | |

Reading Speed on Paper

P1

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
|---|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|------------------------------|
| Duration (min:sec) | 00:11 | 00:09 | 00:10 | 00:14 | 00:12 | 00:31 | 00:21 | 00:11 | 00:03 | 02:02 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 333 | 173 | 348 | 240 | 235 | 95 | 169 | 322 | 280 | 211 |
| No of Words per minute | 211 | | | | | | | | | |

P2

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & |
|----------------|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|--------------------|
|----------------|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|--------------------|

| | | | | | | | | | | |
|---|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|------------------------------|
| | | | | | | | | | | Avg Words |
| Duration (min:sec) | 00:16 | 00:09 | 00:05 | 00:08 | 00:17 | 00:15 | 00:29 | 00:25 | 00:23 | 02:27 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 229 | 173 | 696 | 420 | 166 | 196 | 122 | 142 | 37 | 175 |
| No of Words per minute | 175 | | | | | | | | | |
| P3 | | | | | | | | | | |
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
| Duration (min:sec) | 00:31 | 00:21 | 00:22 | 00:20 | 00:31 | 00:20 | 00:28 | 00:23 | 00:25 | 03:41 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 118 | 74 | 158 | 168 | 91 | 147 | 126 | 154 | 34 | 116 |
| No of Words per minute | 116 | | | | | | | | | |
| P4 | | | | | | | | | | |
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
| Duration (min:sec) | 00:20 | 00:33 | 00:51 | 00:34 | 00:55 | 00:40 | 00:24 | 01:03 | 00:31 | 05:51 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 183 | 47 | 68 | 99 | 51 | 74 | 148 | 56 | 27 | 73 |
| No of Words per minute | 73 | | | | | | | | | |

P5

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|
| <i>Duration (min:sec)</i> | 00:15 | 00:18 | 00:25 | 00:22 | 00:11 | 00:30 | 00:20 | 00:28 | 00:26 | 03:15 |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| <i>Reading Speed - (words per minute)</i> | 244 | 87 | 139 | 153 | 256 | 98 | 177 | 126 | 32 | 132 |
| <i>No of Words per minute</i> | 132 | | | | | | | | | |

P6

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|
| <i>Duration (min:sec)</i> | 00:30 | 00:17 | 00:16 | 00:42 | 00:17 | 00:23 | 00:15 | 00:20 | 00:21 | 03:21 |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| <i>Reading Speed - (words per minute)</i> | 122 | 92 | 218 | 80 | 166 | 128 | 236 | 177 | 40 | 128 |
| <i>No of Words per minute</i> | 128 | | | | | | | | | |

P7

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
|---|-------|-------|---------|---------|---------|---------|---------|---------|---------|-------------------|
| <i>Duration (min:sec)</i> | 00:10 | 00:25 | 00:14 | 00:19 | 00:21 | 00:16 | 00:20 | 00:18 | 00:12 | 02:35 |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| <i>Reading Speed - (words per minute)</i> | 366 | 62 | 249 | 177 | 134 | 184 | 177 | 197 | 70 | 166 |
| <i>No of Words per minute</i> | 166 | | | | | | | | | |

P8

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
|---|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|------------------------------|
| Duration (min:sec) | 00:21 | 00:15 | 00:09 | 00:22 | 00:14 | 00:12 | 00:11 | 01:07 | 00:21 | 03:12 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 174 | 104 | 387 | 153 | 201 | 245 | 322 | 53 | 40 | 134 |
| No of Words per minute | 134 | | | | | | | | | |

P9

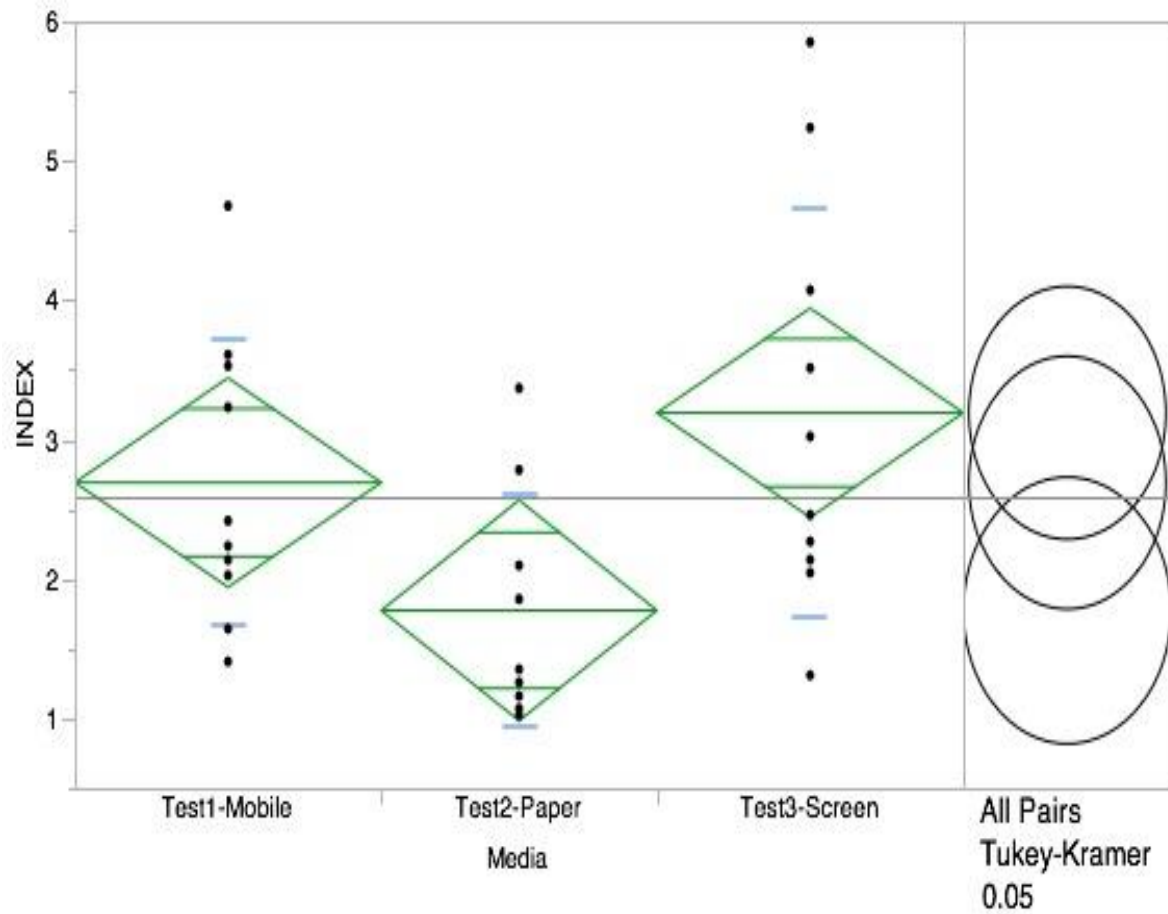
| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words |
|---|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|------------------------------|
| Duration (min:sec) | 00:13 | 00:21 | 00:22 | 00:19 | 00:18 | 00:13 | 00:11 | 00:32 | 00:12 | 02:41 |
| No of words | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 |
| Reading Speed - (words per minute) | 282 | 74 | 158 | 177 | 157 | 226 | 322 | 111 | 70 | 160 |
| No of Words per minute | 160 | | | | | | | | | |

P10

| SECTION | 4.1 | 4.2 | 4.2.1.1 | 4.2.1.2 | 4.2.1.3 | 4.2.1.4 | 4.2.1.5 | 4.2.1.6 | 4.2.1.7 | Total & Avg Words | |
|--|------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|------------------------------|--|
| <i>Duration (min:sec)</i> | 00:31 | 00:30 | 00:25 | 00:45 | 00:17 | 00:20 | 00:21 | 00:38 | 00:09 | 03:56 | |
| <i>No of words</i> | 61 | 26 | 58 | 56 | 47 | 49 | 59 | 59 | 14 | 429 | |
| <i>Reading Speed - (words per minute)</i> | 118 | 52 | 139 | 75 | 166 | 147 | 169 | 93 | 93 | 109 | |
| <i>No of Words per minute</i> | 109 | | | | | | | | | | |
| | | | | | | | | | | | |

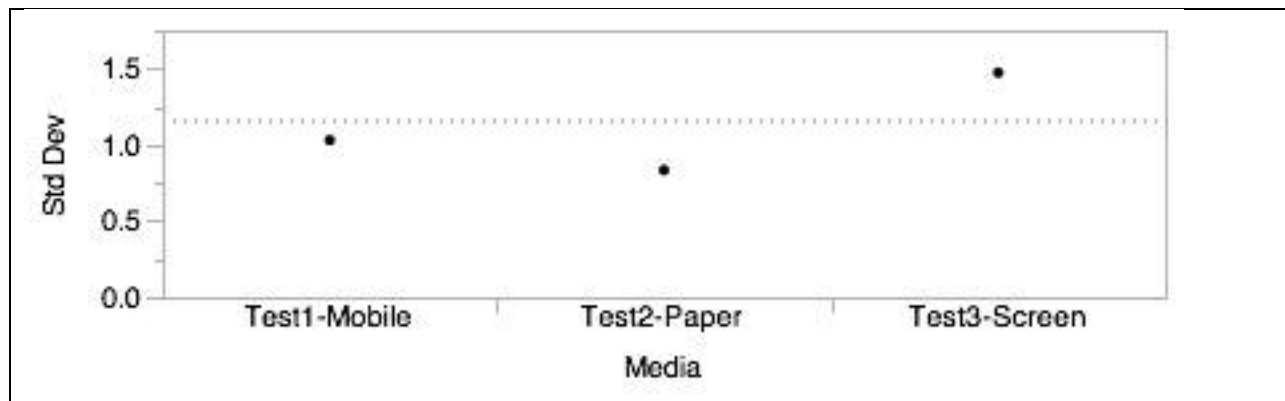
Appendix J: Linearity of Saccades

Appendix J.1: One Way Analysis Index by Media



| One Way Anova Summary of Fit | |
|------------------------------|----------|
| | |
| Rsquare | 0.030484 |
| Adj Rsquare | -0.04133 |
| Root Mean Square Error | 6.19123 |
| Mean of Response | 3.663738 |
| Observations (or Sum Wgts) | 30 |

Appendix J.2: Tests that the Variances are Equal



| Level | Count | Std Dev | MeanAbsDif to Mean | MeanAbsDif to Median |
|--------------|-------|---------|--------------------|----------------------|
| Test1-Mobile | 10 | 1.03023 | 0.855981 | 0.8012 |
| Test2-Paper | 9 | 0.83315 | 0.668364 | 0.631822 |
| Test3-Screen | 10 | 1.4727 | 1.181404 | 1.147524 |

| Test | F Ratio | DFNum | DFDen | Prob > F |
|----------------|---------|-------|-------|----------|
| O'Brien[.5] | 1.6711 | 2 | 26 | 0.2076 |
| Brown-Forsythe | 1.0515 | 2 | 26 | 0.3638 |
| Levene | 1.8011 | 2 | 26 | 0.1851 |
| Bartlett | 1.3625 | 2 | . | 0.256 |

Appendix J.3: Compare Densities

