User Fatigue and Eye Controlled Technology

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A major research project presented to OCAD University
in partial fulfillment of the requirements for the degree of
Master of Design in INCLUSIVE DESIGN

Toronto, Ontario, Canada, August, 2013

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Abstract

Computer Vision Syndrome (CVS), more commonly known as eye fatigue is a problem often associated with regular computer use. For some users of eye controlled technology, the eye fatigue is an even greater problem. The eyes are used not only to observe and process information on screen and the user's environment, but also to operate the computer instead of relying on a mouse, switch or keyboard. This can result in user fatigue, especially with new users of the technology. This research led to an analysis of several design elements through a series of surveys, interviews, and design prototype tests, coupled with literature reviews in both CVS and user interface design practices. This information was used to create a set of guidelines for user interface designers to refer to when developing applications for eye controlled technology.

Acknowledgements

I would like to thank my two advisors Geoffrey Shea and Dr. Mick Donegan, and professors Jutta Treviranus and Peter Coppin for their guidance in the development of my Major Research Project (MRP).

I thank Joschi Shea for making me aware of eye gaze technology and its opportunities for improvement. I also thank my colleagues in the Mobile Experience Lab at OCADU: Alex Haagaard and Tahireh Lal for their work on Cardinal, an eye gesture writing application that was designed as part of the Art & Ability project with Principal Investigator Geoffrey Shea.

Additionally, I would like to thank Lizna Husnani-Puchta at SNOW, Bert Shire at the Inclusive Design Research Centre, Lars Hildebrandt at Alea Technologies, Jon West and Nancy Cleveland at LC Technologies, Heidi Overhill at Sheridan College, and Tony Diamanti for their help and kindness while I was finishing my MRP. I greatly appreciate the support of Yehuda Fisher and my Inclusive Design classmates in both the 2013 and 2014 graduating year, including Spirit Synott and Sherly Thankappan throughout the planning, writing, and presentations that lead up to the completion of my MRP.

Finally, I would like to thank my family: Elizabeth Chitty, Robert Siddons Riley, Alison Chitty, Judy Miller, and the late Charles & Kathleen Chitty for their support and encouragement throughout my education. Without you, none of this work could have happened. Thank you.

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Introduction

1.1 Introduction

Design plays an important, but often an unacknowledged role in our daily lives. While design is usually intended to resonate with as many users or consumers as possible, it frequently overlooks the common disadvantages that many people face. When discussing accessibility outside of the inclusive design or disability community, some individuals feel that inclusive and accessible design stifles creativity, aesthetic appeal, and commercial success (Hassell 2012; Moss 2005; Norwegian Design Council 12-13). However, one can argue that we have yet to fully exploit the possible union between accessibility and these other important values.

Accessibility is a term that embraces many things, such as alternative and/or augmentative communication (AAC). AAC technology is used by individuals with disabilities who need alternative methods to convey their needs and ideas. One form of AAC is computers which can be controlled by the eye instead of using a mouse or keyboard as the main input device. Eye gaze technology is increasingly used by individuals with disabilities, such as those with cerebral palsy (CP) or amyotrophic lateral sclerosis (ALS), a disease that can cause immobilization and involuntary movement that can make it difficult or impossible to operate a computer by conventional, physical means.

1.2 Eye Controlled Technology & User Fatigue

Eye gaze technology was initially designed for the marketing industry to track where consumers were looking in a store, or an advertisement, or product. The technology was soon adopted by the AAC community to create the eye controlled AAC technology. Eye gaze technology is making its way into the mainstream consumer culture through software applications such as PolyGaze and Eye Tribe for use on off-the-shelf technology and with devices such as the Samsung Galaxy 4S smartphone which uses eye tracking to pause videos and scroll through content on screen ("Launch of new Samsung Galaxy S4 takes assistive technology a step forward," 2013). Eye control is a beneficial tool, however it is not without its shortcomings.

Computer Vision Syndrome (CVS), more commonly known as eye fatigue, is a problem often associated with regular computer use (Divjak & Bischof, 2009). CVS can affect more than just users of eye gaze technology. According to the National Institute of Occupational Safety and Health in the US, 90% of people who spend at least 3 hours a day at a computer suffer from CVS (Beck, 2010). Eye fatigue is an ancient yet persistent issue that has likely been affecting much of the world's population since we first began communicating with pictures, symbols, and written words. Inadequate lighting and paper glare were identified problems leading to eye fatigue in the past and now we have almost constant computer, tablet, e-reader, TV and mobile screen use to exacerbate the problem (Goldsberry, 1936; Rosenfield, 2010). For those of us who use eye gaze computers for human functions, the time spent in front of the screen can be even more strenuous.

As found through personal use and discussions with users of eye gaze technology, eye fatigue affects user experience for at least some people. This is especially true, as with any new form of control method, it requires practice from the user until it feels normal and comfortable. Many experienced users of eye controlled technology do not experience eye fatigue, even when using it for long periods of time (M. Donegan, personal communication, 2013; D. Hawes, personal communication, 2013). Some users experience fatigue for many reasons such as the particular visual user interface being viewed, the quality of calibration[1] , or the computer system itself (M. Donegan, personal communication, 2013). Other factors can include the cognitive load and dependency on the eye to dwell on triggers to operate the computer (J. Treviranus, personal communication, 2013). There are many

1. Calibration trains an eye controlled system in the characteristics of each user's eye ("MyTobii: How Does Calibration Work?" n.d.)

areas to consider when looking at improving user experience, and I chose to focus my major research project (MRP) on the visual elements of the user interface of eye controlled computers. The amplified CVS effect caused by using eye controlled technology makes it an ideal medium on which to study the effect design has on eye fatigue.

It is important for designers to look at ways to reduce the strain that computer use puts on the eyes when designing user interfaces for applications, websites, and mobile devices. CVS can be decreased or avoided by taking regular breaks and keeping an adequate distance from the screen, but computer users rarely heed this advice ("Prevent Eye Strain," 2010). The design and guidelines that come out of this thesis will be transferable to other mainstream and developing technologies where CVS is a problem. This furthers the importance of research in this area as our population becomes increasingly dependant on technology. As gaze aware systems enter the mainstream consumer market, more and more people can benefit from the guidelines proposed in Chapter 4 of this document.

1.3 Preliminary Work

I worked as a research assistant with OCAD University faculty member Geoffrey Shea from September 2011 to April 2013 on his Art & Ability project. The project focuses on artists with disabilities and it was during my research with Shea that I was first exposed to the problem of eye fatigue with the eye gaze technology. This occurred when we had the opportunity to work with a young user, who is a regular user of eye controlled technology.

The user identified eye fatigue as a nuisance when using his computer over extended periods of time. Other aspects of the technology that he identified in discussions with his father were speed, inaccuracy, and the desire to have a conversation with someone using eye gaze technology without an obtrusive screen in the way. As a result, our research team began work on Cardinal.

Figure 1. Face to face conversation.

Figure 2. A screen based AAC system obstructing a face to face conversation.

Cardinal combined an alphabet board and an eye tracking device. Eye gesture, instead of eye gaze, was used to communicate letters. The difference between the two is similar to that of a mouse click or keystroke versus a swipe motion on a tablet. With eye gaze, the user needs to fixate on a target, while with gesture, the user only needs to glance in the direction of the target. Eye gesture's freedom of motion can reduce fatigue and increase speed in comparison to eye gaze systems as it requires less accuracy (Treviranus, personal communication 2013).

The alphabet board would be in place for training, but once the user had memorized the board, it could be removed. This would allow for face to face conversation (see Figure 1 and 2) to take place as the system could be operated without a screen by using the eye tracking technology to read the eye gesture and output the desired verbal communication.[2]

The research I completed with Shea and my peers on the research team, Tahirah Lal and Alex Haagaard, provided me with a springboard for my own major research project. It allowed me a greater understanding of disability studies and the different types of eye tracking with a focus on the MyTobii P10[3] , an eye controlled computer produced by the Swedish eye tracking

2. The concept was first presented as a poster at the GRAND 2012 Conference, followed by a demo of the application in April 2013 at the Disrupting/Undoing exhibit at OCADU. Cardinal then went on to win the Best Poster Award at the Tobii Eye Tracking Conference on Human Behaviour.

3. Although the MyTobii has been replaced by more up-to-date technologies, I have been assured by my advisors, Dr. Mick Donegan and Geoffrey Shea that this system is more than adequate for the purposes and needs of my research.

company Tobii. Through my work on the project, I was able to gain first hand experience using a MyTobii, and the opportunity to work with a user of eye controlled technology. It provided me with a firm base to begin my own research separate from that taking place within the Mobile Experience Lab.

1.4 Questions to be Answered

- What visual design elements affect user fatigue through regular computer use?
- What visual design elements affect user fatigue on eye tracking technology?
- What are the unique needs of eye controlled technology users, related to user interface design?
- What work as been done previously in interface design for eye tracking technology?

1.5 Rationale

There is a substantial amount of research already done on the effect that the printed word, work environment, computer hardware, and computer positioning have on eye fatigue, but very little on the visual user interface itself (Yan et al., 2032; Bali, Navin, & Thanker 2007). Considering the amount of research on typography, paper, and colour by people such as Dr. Miles Tinker, Josef Albers, and Louise Goldsberry in the first half of the twentieth century, it is surprising that little has been done on interface design, especially when one considers the difference between print and digital material (Yan et al. 2008). The design considerations in books, newspapers, and other printed material do not always apply to the illuminated, pixilated screen of a computer.

We increasingly depend more on computer screens over paper for communication, leisure, and work. Yet, little research has been done on the relation between what the user sees on screen and CVS. The focus of recent research has been on the computer work environment, computer hardware and position, and the eye exercises computer users can perform to reduce the risk of eye fatigue. The visual representation of information was proven to reduce eye fatigue on paper before the introduction of the personal computer (PC) and the graphical user interface (GUI), yet little research is available on the visual layout of information on screen (Tractinsky, 128).

There is an evident lack of research done on the affects visual interface design has on eye fatigue. What information does exist is scattered, often included in papers on subjects that do not concentrate on CVS or user experience. The focus for eye gaze interface has primarily been on making it usable by persons with disabilities through skill acquisition and faster typing with a focus on eye-typing software (Donegan et al. 71). As an emerging technology, it is important for designers to focus on interface design issues at the outset to avoid costly redesigns later to be inclusive, and to increase adoption of the new technology by the public.

Chapter 2
Literature Review

2.1 Introduction

The literature covered will primarily discuss the work of experts and organizations in the field of eye gaze technology. As eye gaze technology is relatively new to the market, there is a lack of information directly related to its aesthetics and user experience. As most of the research on designing interfaces for eye controlled AAC systems has been on skill acquisition and speed, papers on these topics will be my focus as they represent the bulk of work done on interface design for eye controlled technology.

2.2 Group and Individual Research Studies

The MyTobii, the AAC device used in the Mobile Experience Lab, was the result of the work Dr. Mick Donegan at SMARTlab in the UK collaborating on with Tobii in Sweden. Tobii eye tracking technology was originally developed for the marketing industry, so that they could analyze and understand where consumers' eyes looked when in a store or viewing an advertisement. Donegan saw the potential of eye tracking through a demonstration of a Tobii product and began working with Kirk Ewing, a programmer at Tobii in 2003 to produce a computer system using the technology. Through SMARTlab and Tobii's research and development, the MyTobii computer was created which allowed persons with severe mobility and speech impairments to operate a computer and communicate ("Mick Donegan and the MYTOBII story," n.d).

Donegan is a Senior Research Fellow and Senior Principal Investigator at SMARTlab. He is an assistive technology specialist and has done extensive work in the field of gaze technology, speech recognition, remote support technology, and access to gaming technology for persons with disabilities ("Dr. Mick Donegan Brief Bio," 2009). He has been the driving force behind many ground-breaking projects such as SMARTlab's 'Duet for Eyes' in 2009 where two individuals performed a musical duet using eye gaze technology and the SHIVA project which enables users to create sculpture with eye gaze ("Dr Mick Donegan," n.d.).

Dissertations related to interface design for eye tracking have been written by Heiko Drewes, Manu Kumar, and Päivi Majaranta. Drewes' 2010 dissertation for the Ludwig-Maximilians-Universität in München argues against the popular use of Fitt's Law[4] for eye gaze interface design and promoted the use of eye gaze as an addition selection method in addition to regular graphical user interface (GUI) design (Drewes, 2010).

Kumar's 2007 dissertation for Stanford University looked at the possibility of using eye gaze to complement keyboard and a mouse pointer use with the goal of reducing repetitive strain injuries. He argues that eye tracking is a beneficial alternative to point and selecting, scrolling, document navigation, switching between applications, password entry, and zooming for both able-bodied and disabled users (Kumar, 2007).

Dr. Päivi Majaranta is a key figure in eye gesture technology research. Her PhD dissertation "Text Entry by Gaze" is one of the most comprehensive publications on eye gaze typing to date (Tall, 2009). It covers the history of eye tracking, methods of text entry, interface design, learning styles, and directions for future research. However, Chapter 7, which focuses on interface and layout design for text entry through eye gaze suggests solutions that are most efficient and usable, with no attention paid to aesthetics or a broader form of user experience (Majaranta, 2009).

Majaranta has worked with many experts in the field of eye gaze technology. In 2009, she came together with Dr. Richard Bates and Dr. Mick Donegan to write the chapter "Eye Tracking" for the Universal Access Handbook. Bates has published many papers on eye gaze technology for persons for disabilities. He has worked closely with the COGAIN Association network of

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4. Fitts' Law states that large or closer targets are easier to hit (Yoon, personal communication 2011; Zhao 2002).

excellent on eye gaze communication while a research fellow at the School of Computing Sciences at De Montfort University ("Dr Richard Ernest Arthur Bates," n.d.) ("COGAIN," n.d.).

Robert J. K. Jacob is a professor in Computer Science at Tufts University who has done extensive research in interaction and the user interface ("Rob Jacob" n.d.). His work in eye tracking technology has been referenced in many papers, particularly his concern regarding the Midas Touch[5] in using eye gaze as a selection method (Drewes, 2010; Hyrskykari, 2005; Kumar, 2009; Majaranta, 2009).

Jutta Treviranus is the Director of the Inclusive Design Research Centre and professor at OCAD University. In Treviranus' paper (1994) "Mastering Alternative Computer Access: The Role of Understanding, Trust, and Automaticity," Treviranus stresses the importance of creating environments for user skill acquisition and reduction of errors through the design of AAC systems. She also points out that when AAC is used for basic functions such as communication, the technology can become part of the user's identity. With this in mind, I interpret that not only personalization of the user interface is important, but the aesthetics of the interface as well.

No experts or specialists on CVS were isolated during the research process. Currently, health professionals, especially optometrists, appear to be most vocal about CVS but I found little academic research exists. This may be due to the amount of work that has already been done to isolate the causes and prevention of eye fatigue. However, there is an obvious void in relating this research to visual communication and interface design. Design choices, such as contrast and text size, are known to contribute to CVS. Research in accessible design is relevant to decreasing CVS in eye gaze technology ("Computer Vision Syndrome," n.d.) ("Prevent Eye Strain," 2010).

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5. The term 'Midas Touch' derives from the Greek myth of King Midas where everything he touched turned to gold. When talking about eye gaze technology, the Midas Touch refers to how users trigger targets unintentionally simply by looking at the screen of an eye controlled computer (Jacob 1991, 156).

Aesthetically pleasing design can increase usability and encourage use (Tractinsky 128). This is important when one takes into account the high abandon rates of AAC as attractive systems are more likely to be used (Scherer 115, 130). However, there is a lack of research related to aesthetics for human-computer interaction (HCI) (Tractinksy 128).

The disregard of aesthetics is especially true when designing for marginalized groups. For example, the Canadian National Institute for the Blind (CNIB) has established Clear Print, a set of guidelines for making documents, websites, and products accessible to the vision impaired without discussion of visual aesthetics (Russell-Minda, 2006). The Registered Graphic Designers of Ontario (RGD) have also been promoting their work on accessibility design, but with a focus on universal design and disability as a whole (RDG, 2010). The focus in both of publications by the CNIB and RGD have been to create design that can communicate clearly to the largest possible audience.

In the research of text communication, Dr. Miles Tinker was a pioneer in accessible design at the University of Minnesota for his work in typography studies. Dr. Aries Arditi at the Lighthouse Institute is a contemporary expert on typography for vision impairment and both these researchers have provided seminal work for accessible design.

Tinker and Arditi's research has been referenced in numerous studies on accessible design, including those done by notable organizations such as the Royal National Institute of Blind People Scientific Research Unit and the American Printing House for the Blind. Both these organizations have designed typefaces that focus on making a typeface more legible for those who are partially blind, rather than readable for long periods of time (Perera, 2008; APH, 2004). With hours spent on the computer for work and leisure, it is important for text to be both legible and readable.

Another contemporary of Arditi is Robert Bringhurst. He is a Canadian typographer who has said to written the "…*finest book ever written* *about typography*" according to many type specialists ("The Elements of Typographic Style," 2013; "Robert Bringhurst," 2013; Brown, 2011; Rutter, 2005) and other design specialists such as Grahame Lynch, associate professor at Ryerson University. This is a beneficial reference for guiding design involving type, especially when one is looking for readability and legibility of content leading to a positive user experience. Areas of relevance to user interface design include line length of text for optimal reading experience and best practices for use of typography and layout.

The research that has already been done in the field of eye gaze technology and accessible design provides my major research project with a strong base from which to build. By studying the work others have done and finding new ways of applying it with eye gaze technology, I can create alternative user interface designs for the eye controlled technologies and design guidelines to reduce eye fatigue on eye controlled devices. By lowering the barriers to communication with eye controlled technology, persons with disabilities and society as a whole will benefit.

2.3 Review of Eye Controlled Systems and Related Technology

Eye gaze technology was initially designed for the marketing industry. It was adopted by the AAC community to create the MyTobii, and is now available for use on off-the-shelf computers in addition to do-it-yourself projects like the EyeWriter, as well as mobile technology such as the Galaxy S4 cell phone. Eye gaze technology uses infrared, which is highly accurate, to determine the location of the pupil when recording eye gaze (Kunka & Kostek, n.d.). Infrared light is electromagnetic radiation that has a wavelength longer than that of visible light. When infrared light is directed at the eye, the pupil appears at a high contrast allowing the technology to determine the eye's location very accurately. This allows for reliable operation of eye gaze technology ("The Basics of Eye Tracking," n.d.).

There are three similar technologies to infrared eye gaze that use alternative methods to common touch based computing: electroculography, visible light, and electroencephalography. Electrooculography (EOG) records eye movements and the position of the eye by measuring the "...difference in electrical potential between two electrodes placed on either side of the eye." (Millodot, n.d.). It is very sensitive and less intrusive than other forms of eye based technology as the user does not need anything pointed towards the eye. However, the electrical charge gradient inside the eye can create signal inaccuracy that is an issue when using EOG to operate a computer (Ashwash & Hu, n.d.).

Visible light is the electromagnetic radiation, such as sunlight, that allows the human eye to see ("Visible spectrum," n.d.). Visible light is used to extract data for computer vision and determine the position of objects. Regular cameras can be used to record visible light for computer vision, making it very financially accessible. It does not rely on specific areas of the eye like infrared does, but it can be very obtrusive due to its need for brightness and insensitivity to details (Kunka & Kostek, n.d.).

Electroencephalography (EEG) records the electrical activity around the scalp. EEG headsets are worn to collect information from brave waves that are wirelessly sent to a computer ("Electroencephalography," n.d.). It is often set up using a gel or paste, although dry units are available (Hunt & Petry, n.d.). The signals are easily distracted by surrounding noise and can be time-consuming to set up which makes it a poor choice for computer operation at its current stage of development ("Electroencephalography," n.d.).

Infrared eye gaze technology is easy to set up, use, and has greater accuracy than other options on the market. Eye controlled technology is still new on the consumer market, and is far ahead in accuracy and mass-market appeal currently than the competing technologies discussed above. Thus, developers and interface designers need to be prepared for its use in their designs presently, and in the future.

2.3 Rationale for Designs

I have built a rationale for visual user interface design by studying previous research on design for conventional mouse and keyboard driven interfaces and eye controlled technology. By studying the work others have done, I have been able to find new ways of applying it to eye gaze technology. The following literature informed the development of designs for this Major Research Project:

2.3.1 CVS and User Interface Design

As previously stated, the focus of recent research has been on the computer work environment, the computer hardware and position, and eye exercises computer users can do to reduce user fatigue. However, contrast and glare, an area related to the user interface, has been isolated in CVS research.

One of the notable causes of CVS and one of the key differences between reading on screen or on paper is reflected glare (Yan et al., 2031-2032). Positive contrast (ex: black text on a white background) reduces reflections seen on the screen (Thomson, 113). However, high contrast on screen causes eye fatigue as well (Yan et al., 2022). Contrast can also play a role in matching the screen luminance to the lighting of the environment. The light of the computer screen and light within the work environment should have closely matched luminance to one another to reduce CVS (Thomson, 113). Applications such as f.lux have dealt with this problem by reducing screen brightness to match the time of day (afternoon: bright, evening: dim). Fine mesh fabric has also been placed over computer screens to reduce glare (Thomson, 113), which can also be related to Kumar's work on a dotted interface for eye gaze technology.

2.3.2 Eye Controlled Technology

Eye controlled technology requires a different approach than conventional mouse and keyboard driven user interface design. In order to design for a less fatiguing interface, it is important to understand the differences between eye gaze and mainstream user interface design. One main distinction is that targets must be larger to accommodate the lack of precision that eye gaze has in comparison to the mouse or the keyboard (Drewes, 140; Kumar, 23; Majaranta, 16, 2009). Existing GUI are smaller than those needed for accurate selection with eye gaze. However, one should not throw out all GUI conventions as they are familiar to users, and familiarity of an interface makes it easier to use and therefore, a better user experience for those with previous experience with computers (Drewes, 142).

In conventional mouse and keyboard driven interfaces, navigational elements are positioned around the edges of the screen with the content within. However, in eye gaze technology, the central region of the screen has the highest accuracy with the lowest on the left and right sides (Komogortsev, 1256-1257). This creates conflict with conventional GUI design.

As larger targets permit less content on the screen, Majaranta suggests organizing content hierarchically in menus and sub-menus to allow access to information and targets that the user needs in a single window (16). An alternative organizational method is to have small to medium sized page elements on a screen that are temporarily enlarged when the eye dwells on a target, as enlargement increases eye tracker accuracy (Kumar, 23). Methods currently used to achieve enlargement are zooming, a fisheye lens effect on screen, expansion of targets or areas of the screen (Drewes, 142-143). However, this can be confusing to users, especially the distortion caused by the fish-eye view (Kumar 20).

Eye gaze interfaces need to be flexible (Donegan et al., 70 2005; Komogortsev, 1259). Many users can only move their eyes up/down or left/right, thus applications need to be designed to allow limited and/or free eye movement (Donegan et al., 12 2006). Also, diagonal head movements are more difficult to perform than up/down/left/right movements, so avoiding situating targets using diagonal movements are suggestions (Treviranus, 34).

The varying needs of users who utilize eye controlled technology and the gaze data produced from the technology makes attentive interfaces appealing, especially as they are less intrusive and cognitively fatiguing (Kumar, 146). Attentive interfaces are context-aware interfaces which are programmed to display information optimized for the individual's gaze (Selker, 147; Vertegaal, 26). Similarly, programs such as iGaze offers 36 possible layout designs that adapt to the calibration of different users, keeping to an information hierarchy system with the targets requiring the most accuracy in the centre of the screen (Komogortsev, 1257).

Many people with disabilities who need to use gaze controlled technology have complex visual issues. Thus, it is important to have an adaptable interface to allow them to change the colour, shape, and size of calibration targets as well (Donegan et al., 12 2006). An interface with a background surface of dots can be beneficial as well. Dots do not improve accuracy, but do make pointing easier and improve the user experience (Kumar et al., 67-68).

The use of space on a visual user interface is often an issue with eye gaze technology as targets need to be large. Keyboards are an important aspect of interface design as they allow greater freedom of expression for literate users, and selection of symbols for non-literate users. Scrollable keyboards help solve this problem as they take up less screen space. However, they do slow down typing speed (Majaranta, 66). As for the placement of keys, QWERTY is suggested by Majaranta. Although QWERTY is not an ergonomic layout, it is good to use for people with past QWERTY experience as it is familiar and in widespread use. However it may not be the best choice for people who have not used a QWERTY keyboard in the past (Majaranta, 60). However, if using a grid system, COGAIN stresses the importance of resizable grid keyboards (Donegan et al., 70 2005).

Alternative keyboards designed for eye controlled systems include Dasher, which is a dynamic zoomable keyboard (Majaranta, 44). Dasher is a unique interface as it is not composed of buttons or menus as are traditional computer interfaces. Instead, it embeds word prediction into the writing process, making it easier and faster to type with when compared to other writing software for eye controlled systems (Majaranta, 45). Letters are positioned at the right of the screen. As a user looks at a letter, it enlarges and moves to the centre of the screen. Once it crosses the centre axis, the more probable characters appear. If a letter is triggered mistakenly, all the user has to do is look left (Tuiski et al., 19)

Feedback is an important part of the user interface to confirm the computer recognizes what the eye is looking at. Conventional computer interfaces show an on-screen pointer. However, dragging a pointer with your eyes on a gaze controlled system increases eye strain (Mohn, 2009). Preference on the use of a mouse pointer is varied though, as many users feel frustrated when they do not see its presence on screen (M. Donegan, personal communication 2013).

Highlighting the cell that the user is looking at proves less distracting and less user fatiguing than an on-screen pointer (Donegan et al., 14 2006). Audio feedback also is strongly recommended. It can be used to confirm that a selection has been made and inform the user which target was selected. It is especially helpful when blink selection is used over selection by dwelling on a target, as it can signify to the user that they can move onto the next letter. The feedback helps create a supportive, informative, and comfortable user interface and experience (M. Donegan, personal communication, 2013).

Kumar recommends audio or haptic feedback, such as motions or vibrations, for eye gaze technology (144). Majaranta advises combining audio with visual feedback. She suggests short audio feedback, but warns against using sounds that replicate speech (91). For those using long dwell times, Majaranta recommends that animations playing over the target be used to support focus on the button (92).

One of the main concerns of eye gaze technology is the Midas Touch (Drewes, 2010; Hyrskykari, 2005; Kumar, 2009; Majaranta, 2009). A frequently implemented solution is a pause button. This allows the user to view the screen without the problem of the Midas Touch (Donegan et al., 2006). Designating a section of the screen for resting the eyes is also suggested, such as used in the design of eye controlled applications being developed in the Mobile Experience Lab at OCAD University. Another example of this is the dynamic pie menu, designed by Majaranta and her team, for editing text. The menu features an opening in the centre so that the user can view the text as they are editing. This allows the user to access the editing tools around it (131).

Chapter 3
Participant Research Methodology

3.1 Research Methods

This project combined a variety of research methods and approaches. Initially, research was largely literature based, supplemented with casual discussions with industry experts and users of eye controlled technology to gather information. This was followed by an online survey to gather an international user perspective and user feedback on designs shown through a series of tests on an eye controlled system. The methods and information derived from these methods are included below.

3.2.1 Interviews

Interviews were used to gain first hand knowledge of industry professionals and users of eye controlled systems. Literature is often out of date by the time it is published, especially in the technology field, thus it was important to gain a current understanding from experts and users. Additionally, both provide knowledge not shared or apparent in literature, and can back up theories in the literature review. A casual interview style was used to encourage a near-natural flow of discussion online and in person.

3.2.2 Expert Interviews

I had the pleasure of conversation with various professionals working in the eye controlled AAC technology field over Skype and through email. Included in the questions I asked experts were what areas in user interface they felt needed improvement; how they would go about solving problems; and what related work in the eye tracking and eye fatigue may be of benefit to my project.

I encountered differing opinions on the sustenance of user fatigue and eye gaze controlled technology. In conversation, it was felt that eye fatigue was a greater problem for new users over those who use eye gaze technology as part of their daily lives (M. Donegan, personal communication, 2013; D. Hawes, personal communication, 2013; J. West, personal communication 2013) (B. Barclay, personal communication 2013). I also learnt that white text on a black background was successfully being used by LC Technologies to reduce user fatigue that informed the designs for my MRP. Not only is it more comfortable for the user, but it also prevents the eyes from drifting which can create inaccuracies in the eye tracker reading the pupil (M. Donegan, personal communication, 2013; N. Cleveland, personal communication 2013)(Drewes 36).

3.2.3 User Interviews

Finding users to interview was a challenge, especially as there are so few eye controlled system users in Canada (M. Donegan, personal communication, 2013; G. Shea, personal communication, 2013; N. Rothschild, personal communication, 2013). However, I did enjoy conversation with a user of AAC eye-based communication who used a MyTobii to communicate, listen to music, write email, and use social media such as Facebook. He usually used the MyTobii for 15 minutes at a time and did feel fatigue from use. He felt that larger text and different icons would benefit his experience. He advised steering away from strong colours and from grey in interface design.

3.3.1 Online Survey

The online survey was born from the user and expert interviews. An online survey was employed to obtain an international and diverse perspective on eye gaze technology, to reach a wider audience beyond that available locally as the user pool within Canada is limited (M. Donegan, personal communication 2013; G. Shea, personal communication 2013). The survey was aimed towards individuals who use gaze controlled technology as an assistive technology on a regular basis. The purpose of the survey was to identify areas of strength and improvement in the user interface design applications designed for AAC gaze controlled technology.

The anonymous survey included 9 questions: 6 multiple-choice questions and 3 written responses. To ensure inclusively, all questions were optional to answer. Participation was voluntary and participants were welcome to skip any question that they may have felt uncomfortable answering. Participants were also free to end the session or withdraw from participation at any time during the survey.

The survey was circulated on my personal social media accounts, through email to target organizations, institutions, and businesses by both myself and my advisers, was posted on the LC Technologies Facebook page, and on the You & Your Assistive Technology message board. It is through Alea Technologies' promotion of the survey that the bulk of responses were produced.

3.3.2 Results of Survey

The results of the survey confirmed that user fatigue is a concern only to a few users, even when used for ten hours or more at a time. Text based activities, with the possible exception of gaming, made up the bulk of eye gaze system use. The preferred brands of users were Alea Technologies using Grid software.

Only the multiple-choice questions were answered by the participants of the online survey. Of those, 57% used Alea Technologies IntelliGaze, and 14% of respondents, used each of Tobii/MyTobii, LC Technologies, and Seeing Machines/FaceLAB5 systems. 60% of respondents used Grid/Grid 2 while Communicator and SonoKey each made up 20% of responses. 80% of users reported using eye controlled technology every day, while 20% only reported using it 3 to 5 days a week. During that time, 40% used it for more than 10 hours at a time, while others used it for under an hour, 5-7 hours, or 8-10 hours at 20% each. Writing, speaking, email, reading, internet, and playing games each made up 13% of responses, while listening to music and watching movies each made 10% of responses, with users creating art using eye gaze 2% of the time. Through use, 80% of respondents said they never suffered from user fatigue, while 20% answered that they sometimes felt fatigued from using eye controlled devices.

3.4.1 User Testing

When the first stage of interviews and surveying was completed, user testing was put into place to gain first hand insight on participant knowledge and the literature review. The goal of this project was to increase usability and the user experience, thus it was important to see how users reacted to various positioning and styles on screen to better understand the affect the user interface has on eye controlled system users.

In-situ and on-campus user testing was conducted. In-situ testing was meant to be done by persons with disabilities while on-campus testing was designed for non-disabled users with no prior experience using eye gaze or AAC before. In-situ testing was ideal as it provided a realistic context of use and encourages participation as the researcher would need to come to the user so that the user would not need to come into a lab that is not convenient or familiar to them (J. Yoon, personal communication, 2011). Users with a background using eye controlled systems were preferred, but a benefit of conducting research with individuals with no previous experience was that they were more susceptible to user fatigue and eye strain through using eye tracking for the first time when completing the tests.

The interface elements built for user testing were completed in Adobe Flash to gain insight on the design guidelines obtained from the literature and interviews with users and experts. Participants were asked to select various targets with their eyes, verbalizing their thoughts and feelings using the 'think aloud technique' with the opportunity to reflect after each test was completed before moving onto the next one. Each user testing session was composed of 6 short exercises to test hypotheses of what encouraged a positive user experience and what affected user fatigue on screen.

3.4.2 Test 1

Test 1 was designed to test Fitt's Law that larger targets are easier to hit, and that centred objects are easier to trigger than targets located on other areas on the screen. The screen was stark white with a single white square with a thin black border in each stage of the test. The purpose of this was to start off the test with a simple and non-threatening appearance to allow users to get comfortable with using the MyTobii P10. In Test 1, 67% of respondents said that small targets were harder to hit while 33% said that size made no difference.

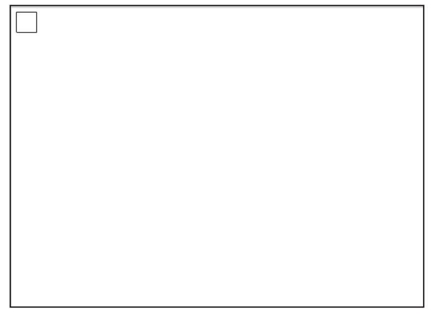


Figure 3. Screen capture of Test 1.

3.4.3 Test 2

Test 3 was a replica of Test 2, but instead showed a black screen with black boxes with a white border and white lettering on each rectangle. 71% of respondents vocalized that that extreme left, right, top, and bottom of the screen is challenging to hit. 43% felt that white on black was better for their eyes. 14% said that colour made no difference.

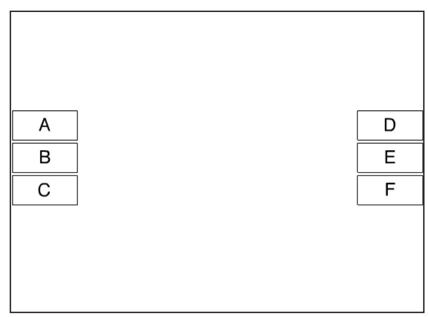


Figure 4. Screen capture of Test 2.

3.4.4 Test 3

Test 3 was a replica of Test 2, but instead a black screen with black boxes with a white border and white lettering on each rectangle. Participants provided more feedback with Test 3 than Test 2. The far left, right, and bottom targets were hardest to hit. For the most part, they felt that the colour scheme made it easier to select targets and was relaxing, although one participant felt that black on white or white on black made no difference at all. Subtle movements were vocalized as being a challenge.

3.4.5 Test 4

Test 4 was designed to gain user feedback on techniques used to amplify what the user was looking at. This included target enlargement, fish-eye lens, and target highlighting to trigger a drop-down menu. 25% of the respondents to Test 4 liked the fisheye visual the best. Similarly, 25% preferred the dropdown menu, with 13% being drawn towards the enlargement option. 25% also said that they preferred a minimal approach to the visual elements on screen that was less cluttered.

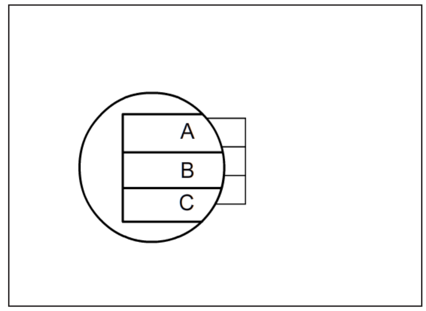


Figure 5. Screen capture of Test 4 showing an enlarged target.

3.4.6 Test 5

Test 5 provided users with more complete interface than in previous sections. It included a body of text with a menu button, with black text on a white background. Once the menu button was triggered, a selection of buttons would appear, circling the body of text. There were two variations of this each varying in size. 50% of respondents had a positive reaction to the concept displayed in Test 5. 25% liked having a large space to view content within the menu and having all the options easily accessible as they interacted with the content. 25% said downward motions were easier to perform with 25% said that triggering element on the bottom of the menu was difficult.

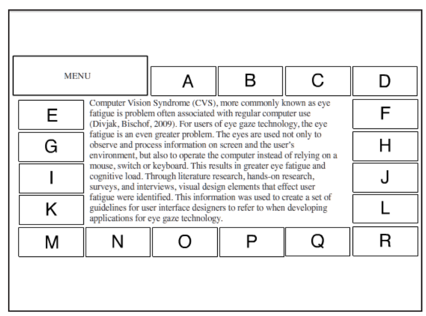


Figure 6. Screen capture of Test 5.

3.4.7 Test 6

Test 6 allowed each participant to view 5 colour schemes: black on white, white on black, grayscale, pastel, and primary colours. 67% of respondents had a negative reaction to grayscale designs while 50% felt that white text on a black background was more comfortable to view. When colour was shown, 33% appreciated colour for its aesthetic qualities, and 33% said it helped to guide their eye around the screen.

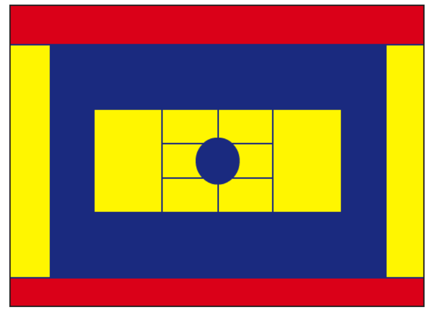


Figure 7. Screen capture of Test 6.

3.4.8 Summary of Results of Participant Research

From user testing, it was found that extreme left, right, top, and bottom of the screen are challenging to hit, particularly elements on the bottom. Subtle movements were vocalized as being a challenge. White text on a black background was felt to be soothing while black text on a white background was considered intense and tiring, confirming expert feedback that white on black colour schemes reduce eye fatigue. During user testing, colour was seen as a benefit to create hierarchy, guide the eye around the screen, and create an aesthetically pleasing experience. However, white text on black was still preferred, with some participants enjoying the pastel colour scheme.

Chapter 4
Guidelines for User Interface Design

4.1 Design Guidelines for User Interface Design

Through literature and participant research, design guidelines were created for the user interface design of eye controlled technology. The purpose of these guidelines was to improve user experience through the reduction of user fatigue with an emphasis on eye fatigue. The following areas of the size of visual target, layout of interface elements; computer feedback; colour scheme; typography; and customizability were explored. Examples of the guidelines applied to user interfaces of eye controlled applications can be seen in Appendix B.

4.2.1 Size

Proposed Guideline: Targets need to be larger than those commonly used in mouse, keyboard, touch, and switch interface design.

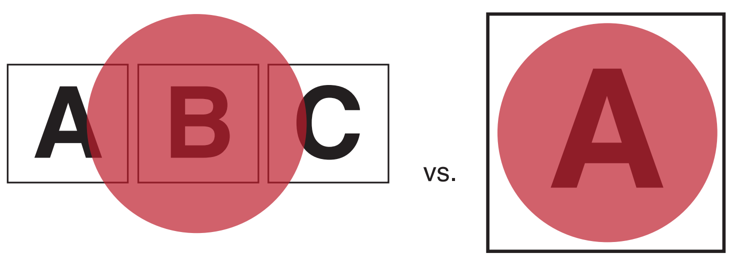


Figure 8. Size

Targets need to be large in size to accommodate the precision of current eye tracking technology (Kumar, 23). Larger targets are easier to hit (Majaranta, 16; Jacob 1991, 156). This was supported by feedback during user testing.

Enlargement of targets and a fish eye lens are possible alternatives to large targets on a screen where many targets and/or content is needed. However, this can confuse the user, as found through user testing and Kumar's study (20-23). Sub-menus or scroll are also an option, although this may also cause confusion and require the user to learn and memorize where each menu leads. No alternative is ideal according to literature or participant research. The designer may choose one at their discretion or create a new solution themselves.

4.2.2 Layout

Proposed Guideline: Position targets within the central region of the screen, with the most frequently accessed target(s) at the centre, with less accessed material positioned outward.

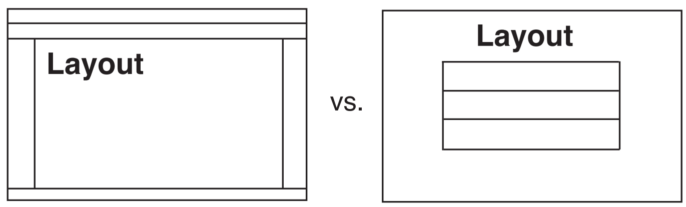


Figure 9. Layout

Target elements should be spaced adequately apart and in the centre and upper levels of the screen. If the far right or left of the screen needs to be utilized for controls, the targets should be positioned in the middle or at the top of the screen. These areas have the highest accuracy, as found through user testing and Komogortsev's study (1256-1257). This makes it easier for users to select the intended object on screen, thus making a more positive user experience. However, interface designers need to be aware that many eye gaze system users can only move their eyes up/down or left/right. Thus, applications need to be designed to permit both limited and/or free eye movement (Donegan et al., 2006, 12).

During user testing, subtle movements such as moving from one target to another that was situated very close to it, were more challenging than wide movements. Additionally, going left to right, vice versa, and diagonally were more challenging than top to bottom. Designers should be conscious of the hierarchy of targets on a screen, positioning targets that are more likely to be triggered in sequence on areas of the screen that reflect this feedback.

An easily accessible pause button should be integrated into the interface of eye controlled systems. This will allow users to rest their eyes and survey the screen without the issue of the Midas Touch, which plagues eye gaze users (Drewes, 2010; Hyrskykari, 2005; Kumar, 2009; Majaranta, 2009).

4.2.3 Feedback

Proposed Guideline: Use visual and auditory feedback to signify that a target has been selected and triggered successfully.

Figure 10. Feedback

If eye tracking technology and calibration could recognize without error what the user is looking at, feedback may not be necessary. However, current eye controlled technology lacks perfect precision (Drewes, 140; Kumar, 23; Majaranta, 16, 2009). The eye is never still, with eye jitter and fixations affecting the coordinates of the eye tracker (MacKenzie, 2012; "An Introduction to Eye Tracking and Tobii Eye Trackers," 2010). The sight of a pointer/cursor to show where the computer was registering the eyes' gaze was felt to be distracting and fatiguing (Mohn, 2009; Jacob, 1995). During the user testing for this project, participants found the pointer's constant movement frustrating and strenuous when their gaze was focused on a target. However, many users of eye controlled technology also feel frustrated when they do not see a mouse (M. Donegan, personal communication 2013).

Observations in the Mobile Experience Lab showed that users like to have computer feedback to confirm that the computer has registered their eye movements. Combining visual and auditory feedback improves user performance and reduces the necessary physical and mental workload necessary to operate an eye controlled computer (Majaranta, 70). Thus, highlighting triggered targets or an animation to signify dwell time would provide visual feedback without constantly telling the user where they are looking with a short non-verbal sound (Majaranta, 91-92).

4.2.4 Colour Scheme

Proposed Guideline: Interfaces that are viewed for an extended period of time should be in negative contrast, composed of a dark background with light foreground elements. Difference in colour should be used to create hierarchy and appeal to the user's individual aesthetic preferences.

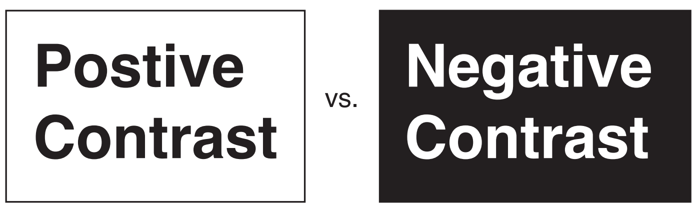


Figure 11. Contrast for text.

A white or light coloured text and/or contours on a black background should be used when a user is looking at the screen for an extended period of time. During user testing, participants felt this to be the least straining of the colour schemes presented to them. When colour was used, it was appreciated for its aesthetic qualities, which varied with each participant (e.g., pastels vs. primary colours) and colours create hierarchy within an interface design, such as red, signifying a priority target. As colour choice varies with each user, designers should provide the option to change colours to suit aesthetic preference and needs, while keeping in mind the affects colour has on hierarchy and eye strain.

4.2.5 Typography

Proposed Guideline: Interfaces should use large type sizes, a typeface that is familiar to the user, and line lengths that are 20-30x the type size.

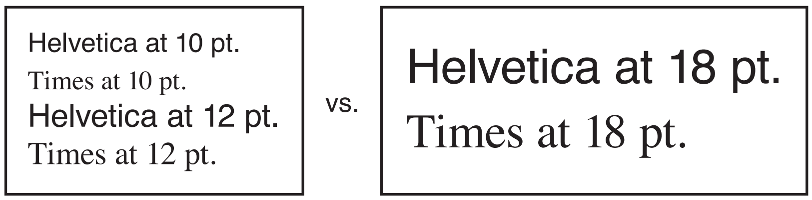


Figure 12. Typography

Large type should be used in interface design. Typefaces at 10pt or 12pt were difficult to read by the users interviewed and those who took part in user testing due to vision impairments. This is common of users of eye control systems, as many have poor vision (Donegan et al., 2006, 12). In general, size affects legibility and 16 to 18 point type is ideal for readers with low vision (Tinker, 36)(Russell-Minda et al., 410)

No preference for serif, sans serif, or font style was isolated during the study. The debate over the legibility and readability of sans serif and serif typefaces is still on-going and designers have strong opinions on the matter (Russell-Minda et al., 410, 413). If you ask any handful of designers who work with type, you will hear a variety of reasons for and against different typefaces. For the most part, familiar typefaces tend to have higher levels of readability and legibility (Unger, 84; Russell-Minda et al., 413; R. Hunt, personal communication 2011). Arial, Helvetica, Verdana, a nd Adsans are arguably more readable for persons with low vision (Russell-Minda et al., 410). However, during my own readability study in 2009 for my major research project on typography for the visually impaired, Times New Roman was found to be preferred for large blocks of text (Chitty 9). Designers and users should have the freedom to choose what font they feel works best for them.

For bodies of text, the line length should be between 45 and 75 characters long, with 66 being the ideal. If going beyond that character count, it is often found that the length of a line should be 20-40 times the font size, with 30x being the ideal. Generally, the longer the line length, the greater the space between lines of text should be and vice versa with short lines having shorter line lengths. (Bringhurst, 26-27). Leading should be multiplied 1.3 to 1.8, with 1.618 being considered the golden mean based on colour, line-length, x-height and individual font characteristics. This will allow the eye to comfortably read text over an extended period of time (McDonagh, n.d.).

4.2.6 Customizability

Proposed Guideline: Everyone has different needs and wants. Thus, interface design elements need to be customizable to meet the expectations of its user.

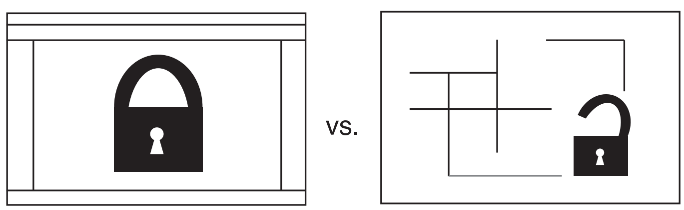


Figure 13. Customizability

There is no one-size-fits-all for technology, and the flexibility the digital world offers the designer and user allows for a perfect environment for the inclusiveness of different needs and subjectivity of aesthetic preferences. An adaptive technology is a user-friendly technology, and the easier it is to operate, the more it will be used (Scherer, 130-131). Everyone has different design preferences, from colours to type choice.

The varying needs of users who utilize eye controlled technology and the gaze data produced from the technology makes attentive interfaces appealing. This is because they are less intrusive and cognitively fatiguing than regular interfaces (Kumar, 146). Attentive interfaces are context-aware interfaces that are programmed to display information optimized for the individual's gaze (Selker, 147; Vertegaal, 26). Similarly, interfaces can be laid out to adapt to the calibration of different users, for optimal positioning to targets within a hierarchy system (Komogortsev, 1257). As many eye gaze system users can only move their eyes up/down or left/right, a flexible interface is ideal for eye controlled computers. Applications need to be designed to permit both limited and/or free eye movement in addition to design preferences of the use. (Donegan et al., 12 2006).

Chapter 5
Looking Back and Looking Forward

5.1 Future Research

Research on user fatigue and eye controlled technologies is a relatively new field (M. Donegan, personal communication 2013). There are many opportunities for further inquiry by myself and readers of this MRP. Areas include the causes and prevention of abandonment of AAC systems by users who are new to the technology, the differences in text and icons used in interface design and how they may affect user fatigue, and the optimal user interface for specific tasks, such as text entry versus photo browsing on eye controlled systems.

There is a high abandonment of new AAC technologies by users (Allemang, A6; Scherer 115). It would be beneficial to seek out users who have tried eye controlled systems and returned to their previous method of communication to research why they abandoned the technology. This would allow designers and organizations to build eye controlled systems that take into account the reasons why AAC users revert to older communication tools. This research would help create products that better reflect users' needs, are more natural for users to adapt to, and are a more successful product on the marketplace.

Studies have been done on how text affects CVS, but how images can or cannot contribute to user fatigue has been relatively unexplored. Text and images are very different visual elements on a screen. Research on how imagery can affect user fatigue would be beneficial, especially as most user interfaces today are mainly image-based. Many AAC systems are more graphic than regular computer applications as users may not have a high level of literacy (Donegan et al., 71). A study on images would improve the user interface design for both mainstream computer consumers and the AAC community.

Different tasks require different tools. This carries forth to computer applications, which is an area that has been largely ignored by CVS research (Yan et al., 2036). Applications are designed to carry out specific tasks and their interface reflects this. By studying specific tasks and user interface design, researchers and designers can isolate the specific needs and the optimal use of visual elements to make applications more intuitive and less fatiguing to users.

The causes and prevention of abandonment of AAC systems by users who are new to AAC technology, the differences in text and icons used in interface design and how they may affect user fatigue, and the optimal user interface for specific tasks are some of areas related to user fatigue and eye controlled systems that require further inquiry. Technology is constantly evolving, providing researchers, designers, and consumers a continual world of inquiry.

5.2 Conclusion

While no set of standards can be proclaimed as a prescriptive method for design, the guidelines in this MRP are those a designer can use in conjunction with their own research, instinct, and that of the users of their product or service. User fatigue inhibits communication and computer activity. By addressing the problems encountered on the eye controlled technology where fatigue is amplified for some users, particularly new users of technology, those who utilize eye controlled AAC technology will directly benefit. By reducing the elements of interface design that contribute to user fatigue, new users will be more likely to continue using eye controlled technology as they will have a more positive user experience. Additionally, the research can be applied to markets outside of assistive technology as user fatigue is a universal problem for users of screen-based technology.

CVS can be reduced through changes in the visual design of the user interface through the choice of contrast settings, typography, colours, and layout. Ways the designer can reduce user fatigue on eye controlled technology are addressed through the guidelines produced from this study (see Chapter 4) which will allow new approaches to evolve when designing the user interface of eye gaze technology. Changes will encourage a greater voice for persons who depend on eye communication devices to communicate. The positive impact of this research will not only be felt within the disability community, but by society as a whole.

Works Cited

Works Cited

Allemang, J. (2013, June 15). Giving a Voice to the Speechless. The Globe and Mail, p. A6.

"An Introduction to Eye Tracking and Tobii Eye Trackers" (2010). Tobii Technology. Web. May 6 2013.

"APH Products: Visual Efficiency and Low Vision". 2004 *American Printing House for the Blind Inc*. Web. 30 October 2008.

Ashwash, I. & Willie Hu. (n.d.). "Eye Gestures Recognition." *Google Scholar*. Web. 6 April 2012.

Bali J, Navin N, Thakur BR (2007). "Computer vision syndrome: A study of the knowledge, attitudes and practices in Indian Ophthalmologists". *Indian Journal of Ophthalmol*. Web. 19 June 2013.

Beck, M. (2010). "Becoming a Squinter Nation." *Wall Street Journal*. Web. 22 June 2012.

Brown, T. (2011) "More Meaningful Typography." *A List Apart*. Web. 10 June 2013.

Chitty, N. (2009). *ImpTimes: Typography for the Visually Impaired.* (unpublished final term paper). Ryerson University: Toronto.

Chun, A., & Nementh, J. (n.d.) *Design and Colour for Fashion Communication*. Ryerson School of Fashion: Toronto.

CNIB. (n.d.). Clear Print: Accessibility Guidelines. [brochure]

"COGAIN." (n.d.). *COGAIN*. Web. 22 June 2012.

"Computer Vision Syndrome." (n.d.). *American Optometric Association*. Web. 15 July 2012.

Divjak, M., & Bischof, H. (2009). “Eye blink based fatigue detection for prevention of Computer Vision Syndrome”. *IAPR Conference on Machine Vision Applications Proceedings*, 350–353. Web. 6 July 2012.

Donegan et al. (2005). “D3.1 User requirements report with observations of difficulties users are experiencing.” *Communication by Gaze Interaction (COGAIN)*. Web. 12 September 2012.

Donegan et al. (2006a). “D3.2 Report on features of the different systems and development needs.” Communication by Gaze Interaction *(COGAIN)*. Web. 12 September 2012.

Donegan et al. (2006b). “D3.3 Report of user trials and usability studies.” *Communication by Gaze Interaction (COGAIN)*. Web. 12 September 2012.

“Dr Mick Donegan.” (n.d.). *SMARTlab*. Web. 13 July 2012.

“Dr. Mick Donegan Breif Bio.” (2009). *ITU Telecom World*. Web. 22 June 2012.

“Dr Richard Ernest Arthur Bates.” (n.d.). *De Montfort University*. Web. 22 June 2012.

“ETRA.” (n.d.). *ACM Digital Library*. Web. 20 June 2012.

“Electroencephalography,” (n.d.). *Wikipedia*. Web. 6 April 2012.

Hassell, J. (2012). “Web Accessibility Myths 2011 part 2.” *Hassell Inclusion*. Web. 29 April 2013.

Hunt, W., & Petry D., (n.d.). “Electroencephalography (EEG) Headset Brain-Computer Interfaces (BCI).” *Google Scholar*. Web. 13 Sept. 2012.

Hyrskykari, A., Majaranta, P. and Räihä, K.-J. (2005). “From Gaze Control to Attentive Interfaces.” *University of Tampere*. Web. 7 July 2012.

Jacob R. “Advanced Interface Design and Virtual Environments.” (1995). *Department of Computer Science and Informatics at the University of the Free State*. Web. 10 June 2013.

Jacob R. "The Use of Eye Movements in Human-Computer Interaction Techniques: What You Look At is What You Get." (1991). *ACM Transactions on Information Systems*. 9(3), 154-169. Web. 23 January 2013.

Komogortsev, O., Holland, C., & Camou, J. (2011). "Adaptive eye-gaze-guided interfaces: design & performance evaluation." *CHI '11 Extended Abstracts on Human Factors in Computing Systems, CHI EA*. 1255–1260. New York, NY, USA: ACM. Web. 12 January 2013.

Kumar, M. (2007). *Gaze-enhanced User Interface Design*. (Doctoral dissertation). Stanford University: Stanford.

Kunka, B. & Bozena Kostek. (n.d.)."Non-intrusive infrared-free eye tracking method." *Google Scholar*. Web. 13 September 2012.

MacKenzie, I. S. (2012). "Evaluating eye tracking systems for computer input." *York University*. Web. 10 June 2013.

Majaranta, P. (2009). *Text Entry by Eye Gaze*. (Doctoral dissertation). University of Tampere: Tempere. Web.

McDonagh, M. "Best Practices." (n.d.). *Typography on the Web*. Web. 10 June 2013.

"Mick Donegan and the MYTOBII story." (n.d.). *Tobii*. Web. 20 June 2012.

Millodot, M. (2009). "Electrooculogram." *The Free Dictionary*. Web. 16 April 2012.

Moss, T. (2005). "Web accessibility myths." *Webcredible*. Web. 21 June 2013.

Norwegian Design Council. *Innovating with People: The Business of Inclusive Design*. Oslo: Norwegian Design Council. 2010.

Perera, S. (2008). "LPFONT: An Introduction into the Legibility of Large Print Typefaces." *RNIB Scientific Research Unit*. Web. 15 October 2008.

"Prevent Eye Strain." (2010). *WIRED Wiki*. Web. 15 July 2012.

Registered Graphic Designers of Ontario. (2010). AccessAbility Handbook. [brochure]

"Rob Jacob". (n.d.). *Tufts University*. Web. 23 January 2013.

"Robert Bringhurst." (2013). *Wikipedia*. Web. 2 May 2013.

Russell-Minda, E. (2006). "Clear Print: Executive Summary." *CNIB*. Web. 15 October 2008.

Russell-Minda, E., Jeffrey W. Jutai, Graham J. Strong, et al. (2007). "The Legibility of Typefaces for Readers with Low Vision: A Research Review." *Journal of Visual Impairment & Blindness*, 101 (7). 402-415. Web. 10 June 2013.

Rutter, R. (2005). Introduction. *The Elements of Typographic Style Applied to the Web*. Web. 10 June 2013.

Scherer, M. (1996). *Living in the State of Stuck*. Cambridge, MA: Brookline Books.

Selker, T. (2004). "Visual attentive interfaces." *BT Technology Journal*. Web. 18 April 2013.

Tall, M. (2009). "Päivi Majaranta PhD Thesis on Text Entry by Eye Gaze." *Martin Tall On Gaze Interaction*. Web. 8 July 2012.

"The Elements of Typographic Style." (2013). *Wikipedia*. Web. 2 May 2013.

"Launch of new Samsung Galaxy S4 takes assistive technology a step forward." (2013). *The Royal Hospital for Neuro-disability*. Web. 16 June 2013.

Thomson, W. D. (1998). "Eye problems and visual display terminals—the facts and the Fallacies". *Ophthalmic and Physiological Optics*, 18(2), 111–119.

Tinker, M. *Legibility of Print*. Ames: Iowa State University press. 1969.

Tuisku, O., Majaranta, P., Isokoski, P., & Räihä, K.-J. (2008). "Now Dasher! Dash away! Longitudinal study of fast text entry by Eye Gaze." *ETRA*. Web. 20 June 2012.

Tractinsky, N., Katz A., Ikar D. (2000) "What is Beautiful is Usable." *Interacting with Computers*. 13 (2), 127-145.

Treviranus, J. (1994). “Mastering Alternative Computer Access: The role of understanding, trust and automaticity.” *Inclusive Design Research Centre*. Web. 13 July 2012.

Unger, G. (2007). *While You’re Reading*. New York: Mark Batty Publisher.

Vertegaal, R. (2008). “Attentive user interfaces.” *Social Science Information*, 47(3), 275–298. Web. 15 April 2013.

Yan, Z., Hu, L., Chen, H., & Lu, F. (2008). Computer Vision Syndrome: A widely spreading but largely unknown epidemic among computer users. *Comput. Hum. Behav.,* 24(5), 2026–2042. Web. 13 July 2012.

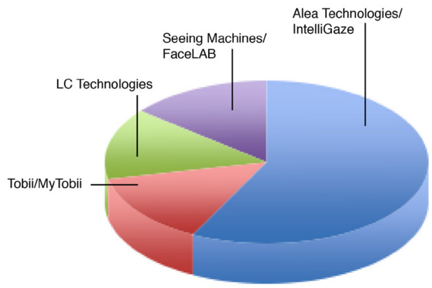
Zhao H. (2002). “Fitts’ Law: Modeling Movement Time in HCI.” *University of Maryland: Theories in Computer Human Interaction.* Web. 10 June 2013.

Appendices

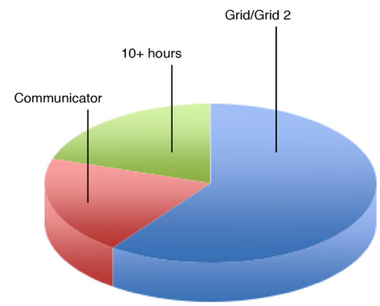
Appendix A

Visuals of the results from the online survey.

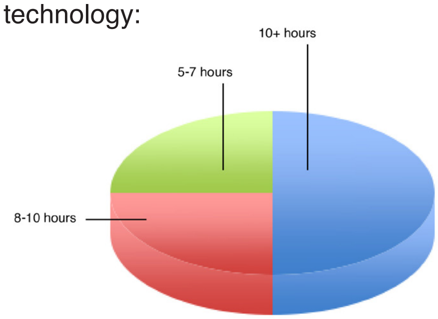
Form(s) of gaze controlled technology used:



Software used on gaze controlled technology:

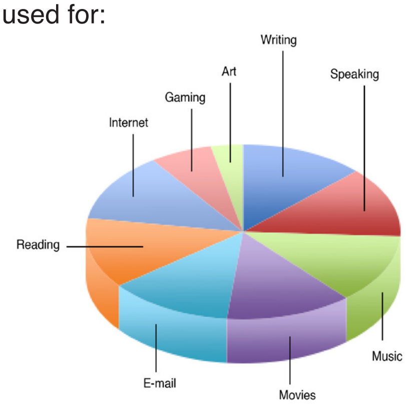


Average time spent on eye controlled system on a day when using the technology:

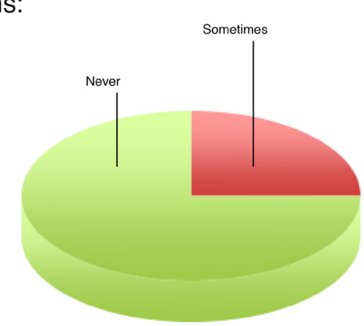


The average number of days in a week an eye controlled system is used:

What eye gaze technology is used for:

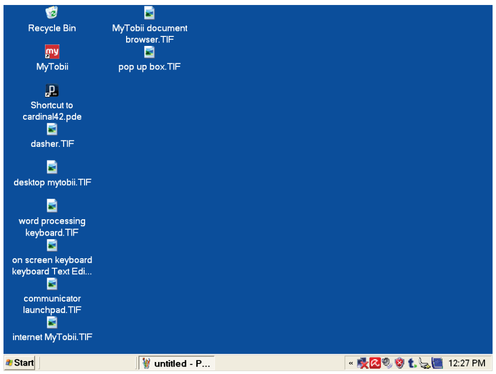


The need for breaks from feeling fatigued from using eye controlled systems:

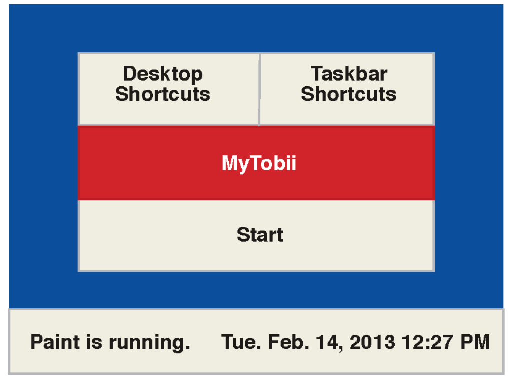


Appendix B

Excersises in applying the guidelines in Chapter 4 to user interface design for eye controlled systems:

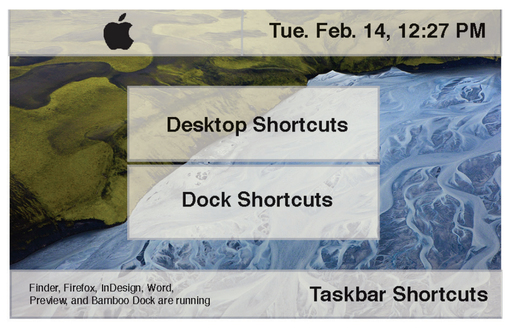


Screen capture of Windows running on a MyTobii P10.

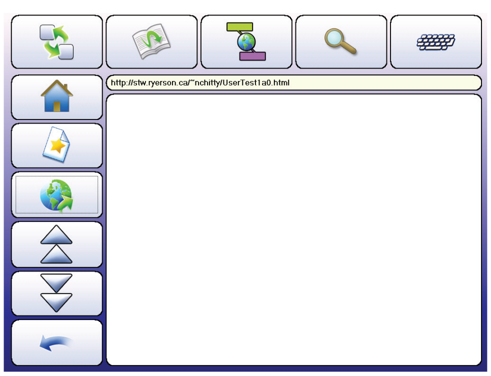


A re-imagination of Windows optimized for use on an eye controlled system.

Screen capture of OS X running on a MacBook Pro.

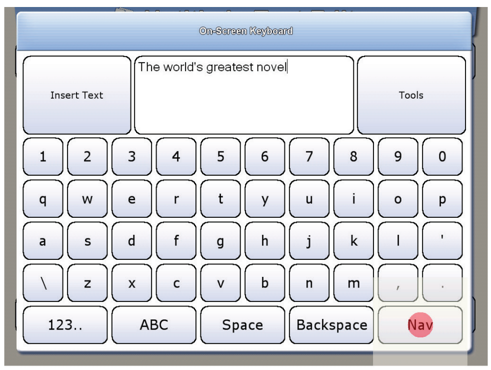


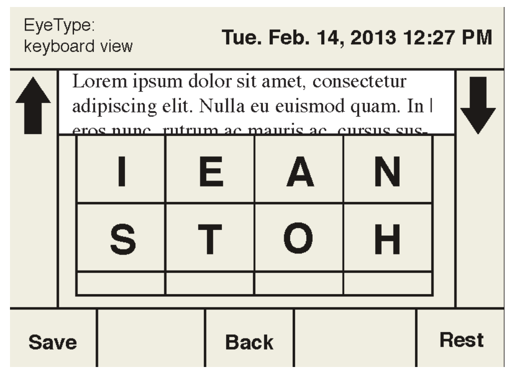
A re-imagination of OS X for use on an eye controlled system.



Screen capture of the MyTobii web browser running on a MyTobii P10.

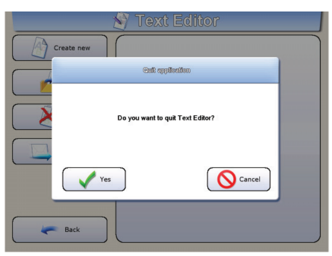
A concept for a web browser for use on an eye controlled computer.

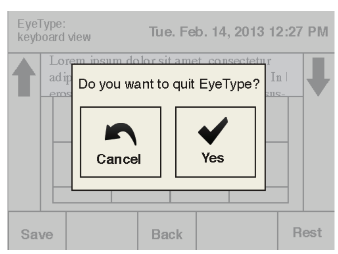


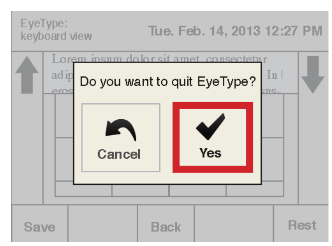


Screen capture of the on-screen keyboard within a MyTobii text editing application.

A concept for an on-screen keyboard.

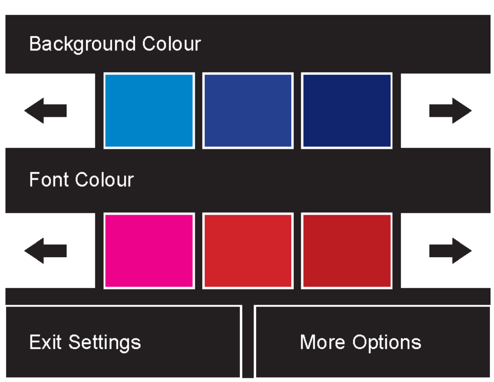


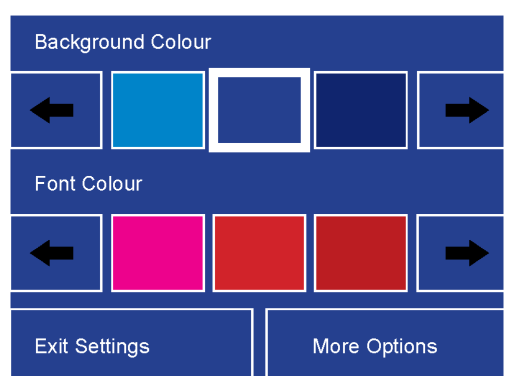




Screen capture of a pop-up on within the MyTobii Text Editor application.

A concept for a pop-up to confirm action with audio.





A concept for customization features that a user of eye controlled technology can change themselves.

A concept for the preview of a selected colour when customizing an eye controlled computer.